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International Rice Research Institute

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TRAINING AND TECHNOLOGY TRANSFER

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Edwin C. Lozada, *BS, training assistant*[4,6]
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WATER MANAGEMENT

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Rolando O. Samaniego, *research assistant*[6]

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[1]Left during the year.
[2]On study leave/training.
[3]Joined and left during the year.
[4]Joined during the year.
[5]Cooperative research staff.
[6]On project appointment.
[7]Transferred from Computer Center to Entomology.
[8]Transferred from Training and Technology Transfer to Visitors Office.
[9]Died during the year.
[10]Transferred from Indonesia to Bangladesh.

About this report

After more than 25 years of research on rice, is there still something left to do that goes beyond national concerns?

After more than 25 years of building up national research systems and training thousands of scientists, is there still a role for an institution like IRRI?

There is, and this 26th *Annual report* is only one proof of the need for an international center that focuses on research, training, and institution-building issues linked to the staple crop of almost half of the world's population. The price of rice has become very consumer friendly, leading to lower investments in rice production schemes. Some scientists, planners, and policymakers question the rationale for such short-term decisions. But there can be no doubt when it comes to rice research. We must search for a new rice yield plateau, especially for the irrigated and favorable rainfed lowland production systems. Those areas fill the rice bowls of the growing number of poor consumers, especially the urban poor. At the same time, we have to contribute to the common goal of improving the living conditions of the underprivileged in the less favorable rice environments.

IRRI is increasingly concerned with research issues related to the future of both the rural and the urban poor. They are IRRI's primary target group. We can, however, be effective only in a very close partnership with our fellow scientists, administrators, and policymakers in the rice-growing countries themselves. IRRI will not hesitate to maintain, strengthen, and enhance this relationship, keeping in mind the mandate given to us more than a quarter century ago.

This *Annual report* reviews research conducted by IRRI staff during 1987. Some experiments are summarized completely. Others are ongoing, and interim results are reported. In all cases, further information can be obtained from the departments concerned. IRRI scientists also report their results in *IRRI highlights*, the *International rice research newsletter* (IRRN), the *IRRI research paper series* (IRPS), conference proceedings, monographs, and technical journals.

Each year, the Institute intensifies its cooperative work with national and international agencies, based on priorities expressed at work plan meetings. Although almost every section of this report mentions these activities, they are featured in the International Collaboration section. Three programs that are based on international cooperation—the International Rice Testing Program (IRTP), the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER), and the Asian Rice Farming Systems Network (ARFSN)—are discussed there. Other sections that include a particularly strong international focus are Machinery Development and Testing, and Training Programs.

The abbreviations and acronyms used in this report are listed on the following pages. In addition, we have spelled out all names and terms on first use in each subsection and have used abbreviations thereafter.

The report refers to four fundamental types of rice culture. Upland culture means rice grown in rainfed, naturally well-drained soils with bunded or unbunded fields without surface water accumulation. Rainfed lowland culture means rice grown in fields that are usually bunded and in which the crop is not irrigated, but the soil is flooded for a portion of the crop cycle to a depth of 1-50 cm. Irrigated culture means rice grown with irrigation in bunded fields. Deepwater culture means rice grown in unbunded fields that become submerged under 50 cm or more of water. The adjectives upland and lowland describe rice and rice-growing soils.

The report uses the International System of Units (SI) with a few exceptions. Monetary units are usually in U.S. dollars ($); if not, exchange rates are provided. Control or check normally means an untreated control. Grain yield is calculated as rough rice, and protein content as a percentage of brown rice, at 14% moisture content. Yield refers to grain yield unless otherwise noted. Fertilizer amounts are given in terms of the elements (N, P, K, Zn, etc.) and not in the older conventional oxide formulations (P_2O_5, K_2O, etc.).

Pedigrees are indicated by a slant bar (/) rather than by a multiplication sign (×). For example, PTB33 × IR30 is written PTB33/IR30. The sequence of crosses is illustrated by the number of slant bars: (PTB33 × IR30) × IR36 is written PTB33/IR30//IR36. Fourth and further crosses are designated /4/, /5/, and so on. Backrosses are designated by an asterisk (*) and a number indicating the dosage of the recurrent parent. The asterisk and the number are placed adjacent to the crossing symbol, which divides the recurrent and donor parents.

Unless otherwise noted, scoring of morphological characters and of damage attributed to rice pests and physiochemical stresses is based on scales in *Standard evaluation system for rice* (SES), 2d, 1980. Copies are available from the International Rice Testing Program, IRRI.

A single asterisk (*) means difference at the 5% level of significance, and a double asterisk (**) means a significant difference at the 1% level; ns means not significant. Unless otherwise stated, separation of means in table columns is by Duncan's multiple range test at the 5% level.

This report normally uses generic names for chemicals. Use of a commercial or brand name does not constitute endorsement.

A thumb index on the back cover provides access to each section. To use it, bend the book slightly and follow the margin index to the page with the black edge marker.

Abbreviations and acronyms

AARD = Agency for Agricultural Research and Development, Indonesia
AAS = atomic absorption spectrophotometer
ABA = abscisic acid
AC = amylose content
AF = after fallow, alluvial fan
ai = active ingredient
AIRAT = African Irrigated Rice Advanced Trial
AIRON = African Irrigated Rice Observational Nursery
AIRPSS = African Irrigated Rice Preliminary Screening Set
AR = after rice
ARA = acetylene-reducing activity
ARIS = Agno River Irrigation System, Philippines
ARSFN = Asian Rice Farming Systems Network
ASL = Analytical Service Laboratories
AT = alluvial terrace
ATR = apparent translocation rate
AURAT = African Upland Rice Advanced Trial
AURON = African Upland Rice Observational Nursery
AURPSS = African Upland Rice Preliminary Screening Set
AVRDC = Asian Vegetable Research and Development Center

B&I = broadcast and incorporated
Bak = bakanae
BB = bacterial blight
BB&I = basal broadcast and incorporated
BC = backcross
BGA = blue-green algae
BIFS = Burma-IRRI Farming Systems Project
Bl = blast
BLS = bacterial leaf streak
BPH = brown planthopper
BPI = Bureau of Plant Industry, Philippines
BRP = brown rice protein
BRRI = Bangladesh Rice Research Institute
BS = best split
BSR = broadcast seeded rice
BVP = basic vegetative phase

CAAS = Chinese Academy of Agricultural Sciences
CABI = Commonwealtn Agricultural Bureaux International
CAI = cellulolysis adequacy index
CAO = custard-apple oil
CARD = Center for Agricultural Research and Development, Bhutan
CEC = cation exchange capacity
CEDIA = Centro de Investigaciones Arroceros, Dominican Republic
CFU = colony-forming unit
CGIAR = Consultative Group on International Agricultural Research
CGR = crop growth rate
CIAT = Centro Internacional de Agricultura Tropical
CIDA = Canadian International Development Agency
CIMMYT = Centro Internacional de Mejoramiento de Maiz y Trigo
CIPR = Christmas Island phosphate rock
CM = chicken manure
CMS = cytoplasmic male sterile
CNRRI = China National Rice Research Institute
CP = cowpea
CPD = Communication and Publications Department
CPU = central processing unit
CRIFC = Central Research Institute for Food Crops, Indonesia
CRIN = Caribbean Rice Improvement Network
CV = common variance, coefficient of variation
CY = crop year

DA = Department of Agriculture, Philippines
DAD = days after draining
DAF = days after flooding
DAI = days after inoculation, days after infestation
DAS = days after seeding, days after sowing
DBH = days before harvest
DBMS = database management system
DBPI = days before panicle initiation
DBT = days before transplanting
DE = days after emergence
DM = dry matter
DMRT = Duncan's multiple range test
DP = deep placed, deep placement
DS = dry season
DSR = direct seeded rice
DT = days after transplanting
DW = dry weight
DWR = deepwater rice

EC = electrical conductivity
ELISA = enzyme-linked immunosorbent assay
ET = evapotranspiration

FAS = fluorescent-antibody staining
fb = followed by
FFY = fresh fodder yield
FIA = farmer irrigators association
FMP = fused magnesium phosphate
FOFIFA = National Center for Applied Research on Rural Development, Madagascar
FR = farm reservoir
FSRI = Farming Systems Research Institute, Thailand
FTM = fertilizer testing model

GA_3 = gibberellic acid
GB = germplasm bank
GC = gel consistency
GCA = general combining ability
GEU = Genetic Evaluation and Utilization
GF = grain filling
GLH = green leafhopper
GM = green manure
GT = gelatinization temperature
GV = granulosis virus

H = hybrid
HB = hoja blanca
HD = high density
HI = harvest index
HPLC = high performance liquid chromatography
HYP = high yield potential

I = indica
IARC = international agricultural research center
IAS = Institute of Animal Science, UPLB
IBPGR = International Board for Plant Genetic Resources
ICAP = inductively coupled argon plasma spectrometer
ICAR = Indian Council of Agricultural Research
ICRISAT = International Crops Research Institute for the Semi-Arid Tropics
IDP = intensive data plot
IDRC = International Development Research Centre, Canada
IF = interfluve
IFDC = International Fertilizer Development Center
IFRON = International Floating Rice Observational Nursery
IGFD = individual grain filling duration
IGGR = individual grain growth rate
IGW = individual grain weight
IHB = International Hybridization Block
IIMI = International Irrigation Management Institute
IITA = International Institute of Tropical Agriculture
IJ = indica-japonica
INSFFER = International Network on Soil Fertility and Fertilizer Evaluation for Rice
INSFRF = International Network on Soil Fertility and Sustainable Rice Farming
IP = interhill miniplain
IPB = Institute of Plant Breeding, UPLB
IPM = integrated pest management
IRAT = Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres, France
IRBBN = International Rice Bacterial Blight Nursery
IRBN = International Rice Blast Nursery
IRBPHN = International Rice Brown Planthopper Nursery
IRCTN = International Rice Cold Tolerance Nursery
IRDWON = International Rice Deepwater Observational Nursery
IRGC = International Rice Germplasm Center
IRGQSS = International Rice Grain Quality Screening Set
IRIS = Inarihan River Irrigation System, Philippines
IRON = International Rice Observational Nursery
IRRI = International Rice Research Institute
IRRSWON = International Rice Rainfed Shallow Water Observational Nursery
IRRSWYN-E = International Rice Rainfed Shallow Water Yield Nursery-Early
IRRSWYN-M = International Rice Rainfed Shallow Water Yield Nursery-Medium
IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery
IRSGON = International Rice Slender Grain Observational Nursery
IRSBN = International Rice Stem Borer Nursery
IRSTYN = International Rice Salinity Tolerance Yield Nursery
IRTN = International Rice Tungro Nursery
IRTP = International Rice Testing Program
IRUSS = International Rice Ufra Screening Set
IRWBPHN = International Rice Whitebacked Planthopper Nursery
IRYN-E = International Rice Yield Nursery-Early
IRYN-M = International Rice Yield Nursery-Medium
IRYN-VE = International Rice Yield Nursery-Very Early
ITPRON = International Tide-Prone Rice Observational Nursery
IURON = International Upland Rice Observational Nursery
IURYN-E = International Upland Rice Yield Nursery-Early
IURYN-M = International Upland Rice Yield Nursery-Medium
IVTDMD = in vitro true dry matter digestibility

J = japonica

KLT = kerosene light trap

LA = leaf area
LAI = leaf area index
LATRIS = Lower Agno-Totonoguen River Irrigation System, Philippines
LD = low density
LD_{50} = lethal dose required to kill 50%
LER = land equivalent ratio
LF = leaffolder
LS = linear shrinkage
LSc = leaf scald
LSD = least significant difference
LSS = line source sprinkler
LTR = light transmission ratio
LWR = length-to-width ratio

M = maize
MARDI = Malaysian Agricultural Research and Development Institute
MB = mungbean
MBCR = marginal benefit-cost ratio
MCD = Multiple Cropping Department
MPN = most probable number
MR = moderately resistant
MRM = multifertilizer response model
MRRTC = Maligaya Rice Research and Training Center, Philippines
MS = moderately sensitive
MT = maximum tillering
MV = modern variety

NBPGR = National Bureau of Plant Genetic Resources, India
NC = neem cake
NHI = nitrogen harvest index
NIA = National Irrigation Administration, Philippines
NO = neem oil
NPV = nuclear polyhedrosis virus
NSB = neem seed bitters
NSK = neem seed kernel
NSKE = neem seed kernel extract

ON = observational nursery
OC = organic carbon
OYT = observational yield trial

P = peanut
PAB = photosynthetic aquatic biomass
PAPR = partially acidulated phosphate rock
PAR = photosynthetically active irradiance
PB = Plant Breeding Department
PCU = polymer-coated urea
PD = planting density
PhilRice = Philippine National Rice Research Institute
PI = panicle initiation
PL = plastic limit
PMC = pollen mother cell
PPH = plants per hectare
PRL = Pesticide Residue Laboratory

PSS = preliminary screening test
PU = prilled urea
PVC = polyvinyl chloride

RADPC = relative area under disease progress curve
RAVC = return above variable costs
RC = runoff coefficient
RCBD = randomized complete block design
RDA = Rural Development Administration, Korea
RFH = rice forage hay
RFS = rice forage silage
RH = relative humidity
RI = relative resistance index
RIARS = Regional Integrated Agricultural Research Systems, Philippines
RLD = root length density
RLH = relative lesion height
RRI = Rice Research Institute, Dokri, Pakistan
RRL = relative root length
RRTC = Rice Research and Training Center, Egypt
RS = researcher's split
RSHT = routine seed health test
RSR = row seeded rice
RSV = ragged stunt virus
RT = river terrace
RTBV = rice tungro bacilliform virus
RTSV = rice tungro spherical virus
RTV = rice tungro virus, tungro
RYT = replicated yield trial

S&P = seepage and percolation
SAR = sodium adsorption ratio
SB = soybean, stem borer
SCSFA = short-chain saturated fatty acids
SCU = sulfur-coated urea
SD = standard deviation
SDW = seedling dry weight
SEA = Secretary of State of Agriculture, Dominican Republic
SES = *Standard evaluation system for rice*
SFP = sink formation profile
ShB = sheath blight
ShR = sheath rot
SHU = Seed Health Unit
SLA = specific leaf area
SMT = soil moisture tension
SSB = striped stem borer
SSST = standard seedbox screening test
SWRI = surface water retention index

TARC = Tropical Agriculture Research Center, Japan
TDMY = total dry matter yield
TPR = transplanted rice
TSP = triple superphosphate
TV = traditional variety

UCL = Université Catholique de Louvain
UPLB = University of the Philippines at Los Baños
UR = upland rice
URYT = Upland Rice Yield Trial
USAID = United States Agency for International Developme
USDA = United States Department of Agriculture
USG = urea supergranules

VAM = vesicular-arbuscular mycorrhizal fungi
vol = volume

WA = wild aborted
WAI = weeks after inoculation
WARDA = West Africa Rice Development Association
WB = water balance
WBPH = whitebacked planthopper
WCV = wide compatibility variety
WDI = water deficit index
WS = wet season
WSR = wet seeded rice
WT = weeks after transplanting
WTD = water-table depth

Xco = bacterial blight caused by *Xanthomonas campestris* p *oryzae*

YSB = yellow stem borer

Genetic evaluation and utilization (GEU) program

Genetic resources

International Rice Germplasm Center and Statistics Department

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FIELD COLLECTION

International Rice Germplasm Center

Over the last 5 yr, the number of requests for samples of populations of wild species has significantly increased (Table 1). Recent developments in tissue and embryo culture in particular and biotechnology in general have been a major reason for the increased interest in the material. The accessions (representing different populations) of wild species in the world collection conserved by the International Rice Germplasm Center (IRGC) total 2,375 from 23 species, with 4 species belonging to 3 genera related to *Oryza*. Wild *Oryza* species have been used successfully in breeding programs both at IRRI and in national agricultural research systems. However, the genebank accessions of these species available to rice scientists do not adequately cover their range of variability.

With that in mind, collaborative plans were drawn up in September with India and Thailand for collecting wild relatives of rice in both countries, which are still rich in variation for these species. The first phase of collection was implemented in November and December.

In November, an IRRI staff member joined with the staff of the National Bureau of Plant Genetic Resources (NBPGR) (India) to collect wild species in Kerala State in southwestern India. The trip netted 65 samples of 7 species (Table 2). This collection covered habitats high in the western Ghat Mountains, where *Oryza granulata* can be found on the forest floor and *O. officinalis* near rapids. In addition, the close wild relatives of rice *O. rufipogon* (perennial), *O. nivara* (annual), and *O. sativa* f. *spontanea* (weedy) were collected from saline tracts near the coast and from laterite soils in the north of the State.

In December, an IRRI staff member joined with the staff of the Thai Rice Germplasm Bank at the Pathum Thani Rice Research Center to collect wild rices from central and northern Thailand. This resulted in the first collections of *Oryza granulata* from Thailand in 30 yr and the first collection of wild rices from the Nan Valley in the extreme north of Thailand. The species collected during the trip are listed in Table 2.

These collections of wild rice from India and Thailand are now being grown for seed increase both in the home country and at IRRI. At the time of gathering the seeds, data on 45 characteristics—including location, species name, local names, and ecological, morphological, and taxonomic data—were recorded for the samples.

SEED DEPOSITS AND INVENTORY

International Rice Germplasm Center

Major donors of seed to the IRGC were

- the International Board for Plant Genetic Resources (IBPGR) 696 samples collected from Burkina Faso and 4 samples collected from Zimbabwe
- Thailand: Pathum Thani Rice Research Center 664 samples
- Nepal: Agricultural Botany Division, Khumaltar 241 samples
- Pakistan: National Agricultural Research Center, Islamabad 203 samples
- Japan: Institute of Tropical Agriculture,

Table 1. Progress in International Rice Germplasm Center distribution of seed of *Oryza* cultigens and wild species, 1982-87.[a]

Year	*O. sativa* samples distributed (no.)		*O. glaberrima*, genetic testers, and wild rices distributed (no.)	
	Within IRRI	To national programs	Within IRRI	To national programs
1982	33,975 (279)	11,075 (154)	378 (26)	438 (20)
1983	28,443 (287)	3,756 (150)	342 (20)	972 (38)
1984	28,170 (277)	6,619 (146)	83 (17)	448 (29)
1985	30,709 (306)	4,736 (172)	1,138 (24)	1,174 (36)
1986	39,135 (327)	9,897 (187)	2,253 (13)	595 (28)
1987	35,212 (297)	8,714 (214)	1,758 (53)	618 (47)

[a]Figures in parentheses are number of requests.

Table 2. Species of *Oryza*, their habitats, and population samples collected in India and Thailand in 1987.

Species	Habitat	Population samples (no.)	
		India	Thailand
O. sativa	Farmer's field	3	0
Weed race (*O. sativa* f. *spontanea*)	Farmer's field and field margin	34	34
O. nivara	Seasonally dry ditches	10	8
O. rufipogon	Deep water	8	34
O. officinalis	Partial shade, often beside streams	3	4
"*O. malampuzhaensis*"	Forest floor	2	0
O. granulata	Forest floor	5	7
O. ridleyi	In shade of trees, beside water	0	1

Kyushu University, Fukuoka—202 samples

- India: NBPGR, New Delhi—190 samples
- Kampuchea: Prey Phdan Agricultural Station—176 samples
- Sierra Leone: Rice Research Station, Rokupr—29 samples

Rice workers in national agencies and the International Rice Testing Program donated many other batches in smaller quantities totaling 2,687 samples.

At the end of 1987, the IRGC's total holdings of 82,518 accessions consisted of 74,498 registered *O. sativa* accessions, 2,983 *O. glaberrima* strains, 2,375 populations of wild species, 695 mutants and genetic stocks, 1,748 newly planted samples, and 219 unplanted samples.

SEED INCREASE AND DISTRIBUTION

International Rice Germplasm Center

Field planting for seed increase, characterization, and rejuvenation was divided between the IRRI farm and a rented field in Dayap, Calauan, Laguna. Seed production was again hampered by Zn deficiency and virus diseases. The unusually cloudy weather and two typhoons during the wet season (WS) also contributed to lower-than-usual seed yields.

Seed distribution to IRRI researchers and to rice scientists abroad remained at a high level of about 46,000 samples, but the number of requests (611) was the highest on record (Table 1). A marked increase in demand came from cellular and molecular biologists. The screened nursery area was expanded to produce difficult-to-grow germplasm.

Rigorous quality control of seed being distributed was continued. Every seed sample for rejuvenation, distribution, and preservation was checked against seed stored in the seed file, and the morphoagronomic data were consulted when necessary.

CHARACTERIZATION AND SEED PRESERVATION

International Rice Germplasm Center

The varying quality of seed produced in 1986 WS and 1987 dry season (DS) slowed the process of channeling fresh seed into the preservation phase and necessitated rigorous selection of seed before storage. During 1987, 4,356 accessions of *O. sativa* were selected, dried, and canned for preservation. The canned accessions totaled 32,336 at year's end, a little over one-fourth of the IRGC rice cultivar holdings.

A total of 5,248 seed samples were sent to the National Seed Storage Laboratory in Ft. Collins, Colorado, USA, for duplicate storage.

For initial seed increase, 2,279 plots were planted; for field characterization, 4,779. Field and laboratory characterizations were completed for about 3,000 *O. sativa* accessions, resulting in 63,047 accessions completely characterized for 45 morphoagronomic traits. For the process of preservation—rejuvenation and canning—13,094 plots of aged seed were planted.

BIOMETRICAL PROCEDURE FOR DETECTING PROBABLE DUPLICATES

Statistics Department and International Rice Germplasm Center

Cultivars in the IRGC collection contain a considerable number of duplicates because seed samples of the same country were deposited by national and state agencies in batches over a period of time, or because the same variety carried a slightly different name, or because the variety has been disseminated to other countries and redeposited by

another donor. When a batch of seed is being registered, the variety name, country of origin, and grain characteristics are useful criteria in comparing and sorting out obvious duplicates, which are either discarded or bulked. However, this simple procedure has limited application. A statistical procedure that makes use of the 45 morphoagronomic traits in the GB-BASIC file and their limits of variation would provide a more powerful tool to detect probable duplicates. Moreover, the 45 traits may be reduced to a smaller, more practical number of useful ones.

A 2-yr study was designed to test the feasibility of such an approach. By using 15 qualitative (discrete) and 9 coded quantitative (continuous) traits, we identified 279 pairs of probable duplicates from 39,180 accessions having complete data: 260 pairs (93%) have the same country of origin, 276 pairs (99%) are of the same variety group, and 258 pairs (92%) have both the same origin and variety group. Of this group, 213 pairs were planted in 1986 WS and 1987 WS for side-by-side comparison and for measuring the extent of variation in a given trait. Eventually 134 pairs (63%) were found to be morphologically similar; examples are shown in Table 3.

The ratio of the variance among accessions to environmental variance was used as a measure of stability for continuous traits. Among 12 continuous traits, only grain length, grain width, and maturity showed high levels of stability and would be useful as criteria for identifying probable duplicates.

Kappa statistics (K), a measure of agreement, was used to measure the stability of qualitative and coded quantitative traits. Of the 15 qualitative traits, 10 gave K values ranging from 0.68 to 0.90 and are considered to have high degrees of agreement. These traits are related to the pigmentation of some plant parts, pubescence, and endosperm type. On the other hand, apiculus color, blade color, collar color, internode color, and awning had low K values (-0.28 to 0.38). All the 9 coded quantitative traits had low degrees of agreement, with K values ranging from -0.13 to 0.21. Coding schemes for these traits need to be reexamined.

Based on the 1986-87 data, several potential matching procedures for detecting probable duplicates have been designed and will be subsequently evaluated.

COMPUTERIZATION OF IRGC OPERATIONS

International Rice Germplasm Center and Statistics Department

The IRGC expanded its microcomputer facility and associated staff during the year. The following computer-related tasks, previously performed by Statistics Department staff, are now routinely undertaken by IRGC staff: encoding of morphoagronomic data, management of the seed inventory system, generation of data sheets on which GEU scientists requesting seed are to record screening results, and information retrieval from the Germplasm Databank (through the GEU-SQL DS Database Management System).

In addition, many IRGC operations were computerized during the year: the printing of field planting books, field characterization sheets, and re-identification sheets. An inventory system for seed lots in the short-term storeroom was also

Table 3. Examples of morphologically similar pairs found after field verification, IRGC and Statistics Department, 1987.

Pair no.	Accession number	Variety name	Variety group	Country of origin	Seed source
1	15292	Sinnanayam	Indica	Sri Lanka	Sri Lanka
	15310	Sinnakayan	Indica	Sri Lanka	Sri Lanka
2	30070	Khaophei	Indica	Laos	Laos
	30146	"Unnamed"	Indica	Laos	Laos
3	29996	Baroka	Indica	Indonesia	Indonesia
	30080	Tjempo Brondol	Indica	Indonesia	Indonesia
4	40253	Fukuyuki	Japonica	Japan	Philippines
	36150	Fynzan	Japonica	China	USSR

developed to facilitate inventory, seed distribution, processing of seed for medium- and long-term storage, and discarding of old stocks.

IRGC staff began to catch up with backlog chores such as the entry of data from past field collection missions. A portion of the encoded data was furnished to IBPGR for consolidation and testing.

The IRGC and the Statistics Department collaborated on developing IRRIGEN, a program package to computerize and streamline germplasm bank operations. IRRIGEN is expected to be completed in time for use as the training material for a 10-wk course on Database Management for Genetic Resources scheduled in the second quarter of 1988.

RETURN OF TRADITIONAL RICES TO THE PHILIPPINES

International Rice Germplasm Center

A large-scale seed increase of Philippine traditional lowland and upland varieties was made during DS to produce fresh seed for return to Philippine Government agencies. The newly established Philippine National Rice Research Institute (PhilRice) received 639 lowland varieties and 647 upland varieties for its research base. Seventy-two varieties previously recommended by the Philippine Seed Board were also increased for PhilRice. Another set of 576 lowland varieties in larger quantities was turned over to the Philippine Department of Food and Agriculture, which in turn allocated the seeds to 4 regional experiment stations for further seed increase so that interested Philippine farmers may have access to the difficult-to-find varieties of the past. Another group of 39 upland rice varieties of known reputation was planted near year's end in response to the request of a number of Filipinos for certain traditional varieties that were well-known for their eating quality.

TECHNICAL ASSISTANCE TO NATIONAL CENTERS

International Rice Germplasm Center

The head of IRGC continued to advise and assist several genebanks in the areas of design, refrigeration machinery, laboratory equipment, and staff management. Such assistance was extended to the Institute of Crop Germplasm Resources of the Chinese Academy of Agricultural Sciences, China National Rice Research Institute, and NBPGR in India.

INTERCENTER COLLABORATION

International Rice Germplasm Center

In recent years, the plant genetic resources programs of the various international agricultural research centers under the Consultative Group on International Agricultural Research (CGIAR) system have been receiving greater attention from sectors both inside and outside the system. Focus has increased on availability of and access to the germplasm conserved by the centers. To improve the overall effectiveness of the conservation and management programs of the centers by sharing experiences and reviewing activities, the heads of genetic resources of the centers met twice during 1987. The first meeting was convened in Rome by the Technical Advisory Committee of the CGIAR. The second meeting was attended by 10 centers. The participants developed guidelines to form an intercenter plant genetic resources working group that will meet periodically to sustain collaboration.

Genetic evaluation and utilization (GEU) program

Agronomic and physiological characteristics

Agronomy, Plant Physiology, and Plant Breeding Departments

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MAXIMUM YIELD EXPERIMENT

Agronomy Department

IRRI. Yield potentials of 10 early- and medium-maturing rices were evaluated at 3 N rates at 2 IRRI sites. Urea supergranules were deep-placed 4 d after transplanting at 29, 58, and 87 kg N/ha followed by prilled urea topdressed during desired growth stages. Planting dates were staggered for uniform ripening.

In the dry season (DS), medium-maturing IR21820-154-3-2-2-3 yielded the highest (8.0 t/ha) at the old site (Fig. 1). At the new site, early-maturing IR35366-90-3-2-1-2 and medium-maturing IR29723-143-3-2-1 yielded highest at 7.2 and 7.9 t/ha, respectively.

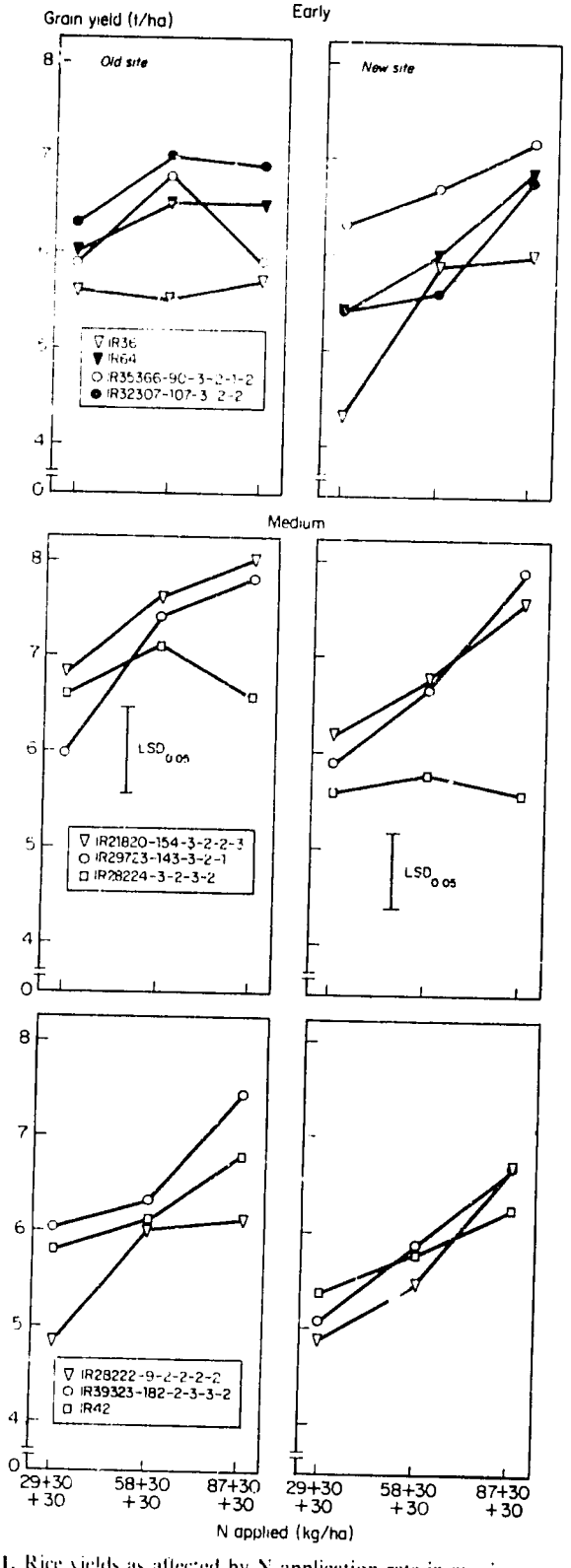
Early-maturing rices responded positively to increasing N application at the new site. Medium-maturing rices, except IR28224-3-2-3-2, responded positively to increasing N rates at both sites. Lodging, particularly at high N levels, lowered yields of IR21820-154-3-2-2-3 at both sites.

In the wet season (WS), yields were unstable because of pests and diseases. Early-maturing IR35366-90-3-2-1-2 gave highest yield (5.8 t/ha) at the new site (Fig. 2). Yields of all rices hardly exceeded 5.0 t/ha at both sites. Generally, medium-maturing rices responded negatively to higher N rates.

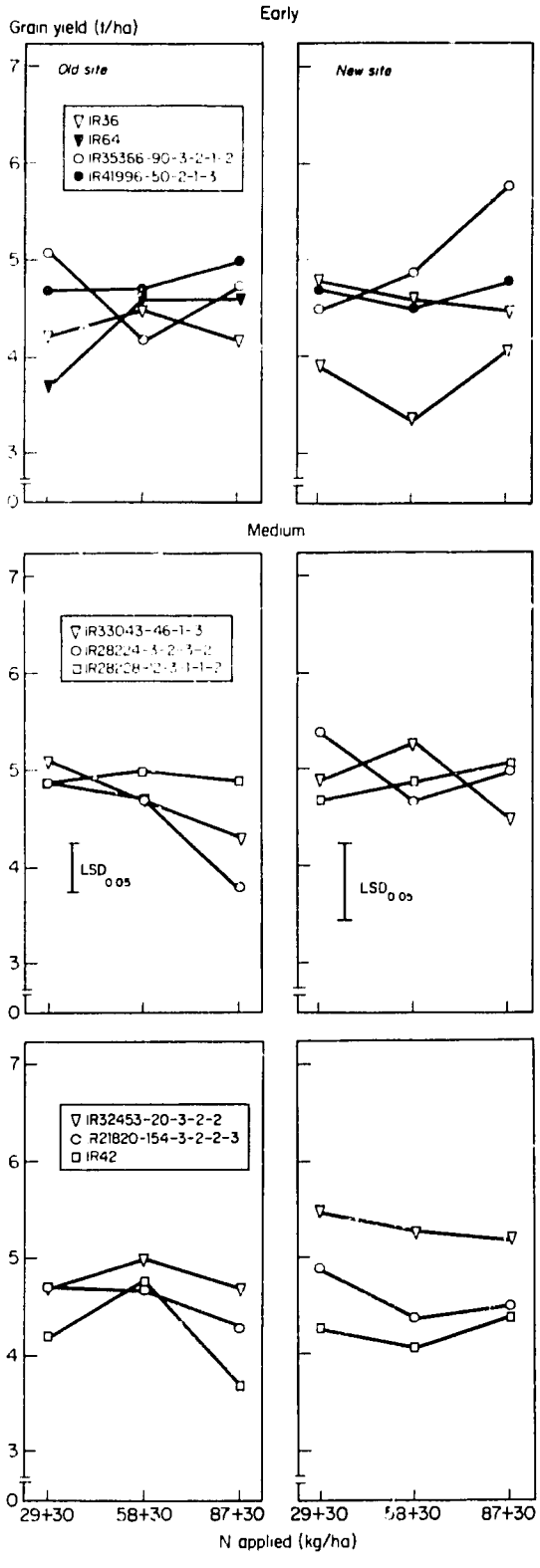
Low yields in DS were due to sheath blight (ShB) and sheath rot (ShR) infections, particularly at high N rates. In WS, tungro (RTV) infestation, ShB, stem borer (SB), and lodging were primarily responsible for low yields.

Farmer's field. Maximum yield in DS was 7.5 t/ha for medium-maturing test cultivars and 6.3 t/ha for early-maturing rices (Fig. 3). Medium-maturing IR9723-143-3-2-1 gave the highest yield, as it has consistently done at this site in most cropping seasons. The early-maturing rices generally achieved maximum yields with addition of 118 kg N/ha. Yields of medium-maturing rices IR28222-9-2-2-2-2 and IR42 responded positively to increasing N application while that of IR39323-182-2-3-3-2 declined. Low yields of most rices were attributed to SB damage.

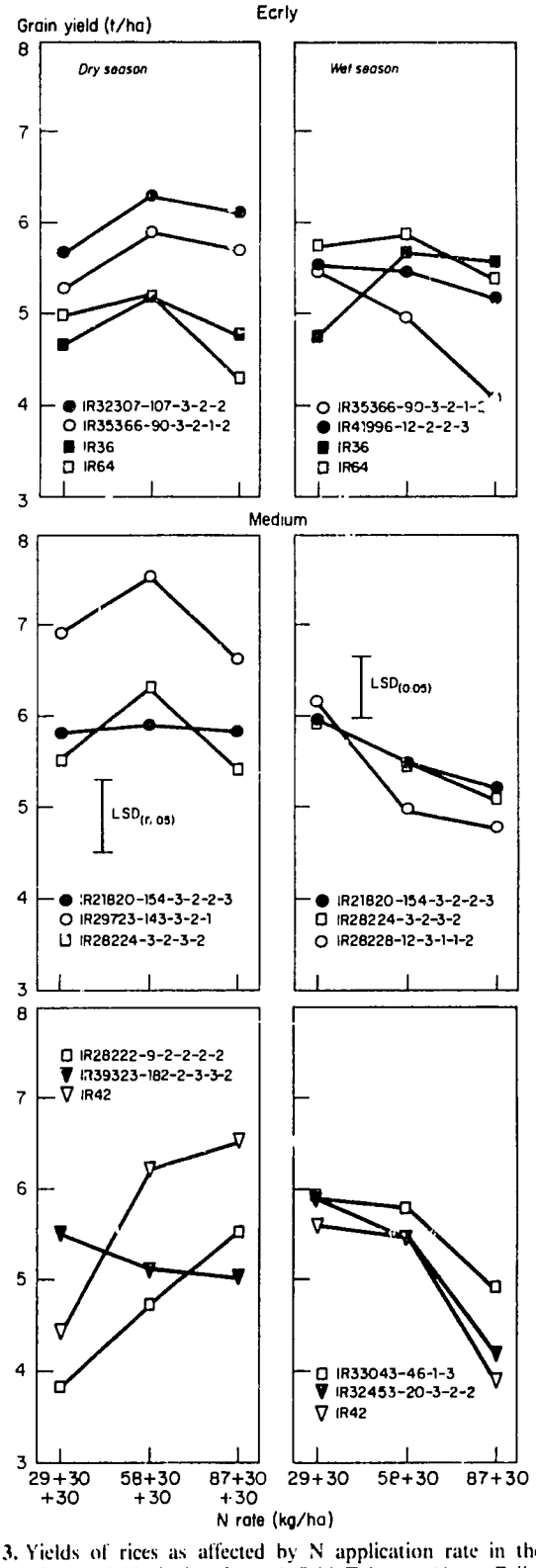
In WS, the maximum yield was 6.2 t/ha from IR28228-12-3-1-1-2. Two other rices yielded 6.0 t/ha. Except for IR36, yields declined with



1. Rice yields as affected by N application rate in maximum yield trial at 2 sites, IRRI, 1987 DS.



2 Rice yields as affected by N application rate in maximum yield trial at 2 sites, IRRI, 1987 WS.



3. Yields of rices as affected by N application rate in the maximum yield trial in a farmer's field. Talavera, Nueva Ecija, Philippines, 1987.

Table 1. Grain yield of hybrid rices, their high-yielding parents, and IR64 at 5 N levels. IRRI, 1987 DS.

Cultivar	Duration (d)	Grain yield[a] (t/ha)				
		0 N	60 N	90 N	120 N	150 N
IR54752A/IR29723-143-3-2-1R	133	4.3 bc	5.2 c	5.8 ab	5.8 c	6.2 a
IR29723-143-3-2-1R	133	5.4 a	6.2 a	6.1 a	6.5 ab	6.1 a
IR54752A/IR54R	128	4.9 ab	5.5 bc	5.7 ab	5.9 bc	6.2 a
IR54R	125	4.1 c	5.8 abc	5.2 b	4.8 d	5.0 bc
IR54752A/IR46R	128	4.3 bc	5.5 bc	5.6 ab	6.8 a	5.6 ab
IR46R	125	4.3 bc	6.0 ab	5.3 b	6.0 bc	4.7 c
IR54752B	128	4.3 bc	5.3 c	5.5 ab	5.6 c	5.2 bc
IR64[b] (check)	118	2.7 d	4.0 d	4.3 c	4.4 d	3.9 d

[a]CV = 11%, LSD (0.05) = 0.6 t/ha. [b]Partly affected by rice tungro virus.

increase in applied N. Lodging was common in all rices.

YIELD PERFORMANCE OF HYBRID RICE

Agronomy Department

IRRI. In 1987 DS, three hybrid rices were compared with their parents and with check variety IR64 at varying N levels. IR64 was slightly affected by RTV. Without N, yield of IR29723-143-3-2-1R was significantly higher than that of its hybrid IR54752A/IR29723-143-3-2-1R (Table 1). At intermediate N rate (60-90 kg N/ha), yields of hybrids and parents were similar, indicating need to improve the present F_1 stock. Among hybrids, IR54752A/IR46R had the most sterile plants (9%).

In WS, yields of two early-maturing and five medium-maturing hybrids at five N rates were compared with those of their high-yielding parents and checks. Since all hybrids, except for IR46830A/IR9761-19-1R, and their parents were affected by virus diseases such as RTV and ShR, yields are not presented.

Yields of early-maturing hybrids were similar to those of checks IR66 and IR35366-90-3-2-1-2. Medium-maturing hybrid yields equaled those of checks IR32453-20-3-2-2 and IR28150-84-3-3-2. Increasing N rate did not increase yield returns. Sterility of the hybrids ranged from 3 to 17% across all N levels.

Maligaya. In DS, yields of eight IRRI-developed hybrids were compared with those of four IRRI-developed rices in Nueva Ecija. NPK was applied at 150-26-50 kg/ha. Among the hybrids, IR54752A/ARC113-5-3 yielded highest at 6.6 t/ha (Table 2). This was significantly lower than the yield of the highest-yielding (7.9 t/ha) check IR32307-107-3-2-2, named IR66 by the Philippine Seed Board. Yields of hybrids were below those of check rices partly because hybrids had sterility ranging from 9 to 85%.

In WS, only three hybrids earlier tested were retained. Eight new hybrids were included to compare with four check varieties and nine breeding lines developed by IRRI and the Philippine Bureau of Plant Industry (BPI) (Table 3). N was reduced to 90 kg/ha while P and K remained

Table 2. Yields of hybrid rices and check cultivars. Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines, 1987 DS.

Cultivar	Grain yield[a] (t/ha)	Sterile hills/5 m²	
		no.	%
IR54752A/IR46R	5.1	41	33
IR54752A/ARC113-5-3	6.6	12	9
IR54752A/IR29723-143-3-2-1	5.2	31	25
IR54752A/IR27315-145-1	3.8	54	43
IR54752A/IR54R	5.4	40	32
IR54752A/IR2797-105-2	2.6	75	60
IR54752A/IR13419-113-1	3.5	64	51
IR54752A/IR32841-46-1	0.5	106	85
IR64	7.4	–	–
IR54	7.2	–	–
IR32307-107-3-2-2 (IR66)	7.9	–	–
IR28150-84-3-3-2	7.1	–	–
LSD (0.05)	1.4	18	
CV (%)	15	30	

[a]Av of 3 replications. For each cultivar, N was 150 kg/ha, 2/3 basal broadcast and incorporated (B&I) + 1/3 top-dressed at 5-7 d before panicle initiation (DBPI). P and K application rates were 26 and 50 kg/ha.

Table 3. Yields of hybrid rices and check cultivars. Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines, 1987 WS.

Cultivar	Grain yield[a] (t/ha)	Sterile hills/ 5 m²	
		no.	%
IR46830A/IR9761-19-1	4.9	0	–
IR54752A/IR64R	3.2	45	36
IR54752A/IR46R	5.0	18	14
IR54752A/IR29723-143-3-2-1R	4.0	10	8
IR54752A/IR54R	5.0	6	5
IR46830A/IR50R	4.6	0	–
IR54752A/IR28178-70-2-3	4.6	15	12
IR54752A/IR21916-128-2-2R	3.7	20	16
IR54752A/IR25912-63-2-2	2.1	77	62
IR54752A/IR29512-81-2-1R	3.0	49	39
IR54752A/IR19392-211-1R	4.3	27	22
IR64 (check)	5.2	0	–
IR66 (check)	5.0	0	–
IR54 (check)	4.6	0	–
IR28150-84-3-3-2 (check)	4.2	0	–
IR29723-143-3-2-1	4.4	0	–
IR28228-12-3-1-1-2	4.8	0	–
IR32453-20-3-2-2	4.3	0	–
IR35366-90-3-2-1-2	5.2	0	–
IR41993-131-2-3-1	4.7	0	–
MRC19011-446	4.0	0	–
MRC20391-1631	3.9	0	–
MRC12379-927-1	5.2	0	–
MRC7849-584	4.9	0	–
LSD (0.05)	1.6	14	
CV (%)	16	57	

[a]Av of 3 replications. For each cultivar, N was 90 kg/ha, 2/3 basal B&I + 1/3 topdressed at 5-7 DBPI. P and K application rates were at 26 and 50 kg/ha.

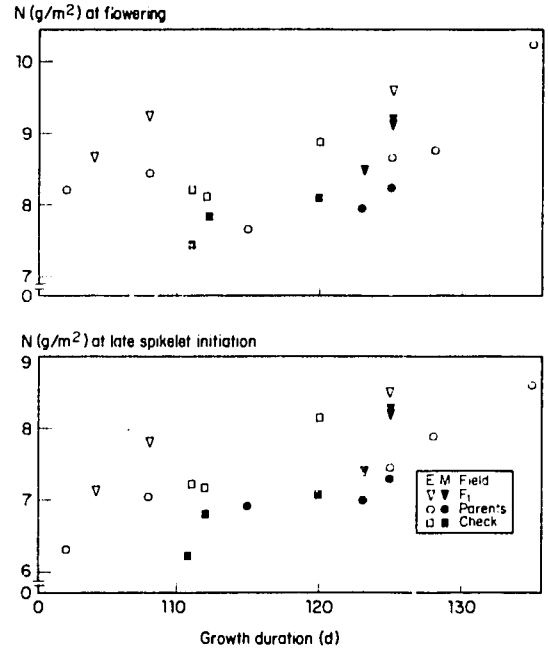
at 26-50. IR64, IR35366-90-3-2-1-2, and MRC12379-927-1 yielded highest at 5.2 t/ha. Several hybrids yielded comparably with the highest-yielding check cultivars. Significantly, 2 hybrids were completely fertile, while sterility of others ranged from 5 to 62%.

RESPONSE OF HYBRID RICE TO NITROGEN

Plant Physiology Department

A 1986 WS experiment at IRRI using 6 combinations of F_1 hybrids with parents and 2 check varieties evaluated response to 60 and 90 kg N/ha with and without topdressing.

Nitrogen absorption pattern. During growth, F_1 hybrids absorbed more N than did their parents (Fig. 4). Differences in N absorption were greater



4. Relationship between growth duration and amount of N in the plant. IRRI, 1987.

at 3 wk after transplanting (WT) than at 5 WT (Table 4). After 5 WT, N absorption was limited by the mineralization of soil organic N. Likewise, no differences in N absorption were noted from topdressed N at the panicle primordia initiation stage. Hence, F_1 hybrids have better N absorption ability at tillering than do parents of the same growth duration.

Yield and yield components. Yield and yield components reflect N absorption. For entries with the same growth duration, F_1 hybrids gave higher grain yield than did their parents (Table 5). Although there was no definite pattern of differences on percentage of ripened grains between F_1 hybrids and their parents, sink size was greater in F_1 hybrids (Table 5). This is attributed to higher N absorbed before the late stage of spikelet initiation (Fig. 4).

Potential sink size of F_1 hybrids was higher than that of their parents, despite the high spikelet degeneration (sink degeneration) (Table 5). This can be explained by their low absorbed N_1:N_2 ratio compared with their parents, where N_1 and N_2 are amounts of N absorbed before and after late stage of spikelet initiation.

Table 4. Nitrogen absorption by F_1 hybrids and parents.[a] IRRI, 1987.

Entry	Growth duration (d)	N absorbed[b] (g/m²) 3 WT[c]	5 WT	Late spikelet initiation	Flowering	Maturity	Nitrogen harvest index
			Field E				
IR46830A/IR9761-19-1R	104	2.05	6.82	7.11	8.69	9.77	64.8
IR46830B	102	1.52	6.21	6.31	8.22	9.43	60.7
IR9761-19-1R	108	1.67	6.40	7.06	8.38	9.41	63.9
IR46830A/IR13292-5-3	108	2.34	7.08	7.86	9.25	10.30	67.0
IR46830B	102	1.52	6.21	6.31	8.22	9.43	60.7
IR13292-5-3	135	1.51	6.21	8.57	9.30	10.37	58.2
IR54752A/IR29512-81-2-1	125	2.26	6.84	8.96	10.17	11.10	65.4
IR54752B	125	1.55	5.69	7.43	8.27	9.38	64.6
IR29512-5-3	128	1.69	5.76	7.86	8.74	9.79	64.6
IR64 (check)	112	1.72	6.10	7.20	8.19	9.21	65.3
IR28150-84-3-3-2 (check)	120	1.59	6.10	8.19	8.90	9.88	64.0
			Field M				
IR46828A/IR13524-21-2-3-3-2-2	123	–	6.38	7.38	7.95	9.26	67.4
IR13524-21-2-3-3-2-2	115	–	5.61	6.96	7.64	8.84	64.8
IR54752A/IR54R	125	–	6.49	8.28	9.15	9.57	63.9
IR54752B	125	–	5.49	7.43	8.27	9.38	65.6
IR54R	123	–	5.10	7.04	7.94	8.66	62.5
IR54752A/IR19392-211-1	125	–	6.20	8.20	9.10	10.63	67.3
IR19392-211-1	125	–	5.34	7.31	8.21	9.21	67.4
IR64 (check)	112	–	5.60	6.82	7.80	8.80	63.2
IR28150-84-3-3-2 (check)	120	–	4.81	7.13	8.09	9.03	62.6

[a]N applied to each field was at 60 kg/ha. [b]WT = weeks after transplanting. [c]The dash (–) indicates no data were taken.

Table 5. Yield and yield components of F_1 hybrids and parents.[a] IRRI, 1987.

Entry	Growth duration (d)	Sink (g/m²)	Potential sink (g/m²)	Percent degeneration (%)	Ripened grains (%)	Yield (g/m²)	Lodging[b] (%)
			Field E				
IR46830A/IR9761-19-1R	104	743	1010	26.4	77	571	0
IR46830B	102	670	877	23.6	75	503	0
IR9761-19-1R	108	694	987	32.1	82	567	0
IR46830A/IR13292-5-3	108	850	1087	21.8	75	638	0
IR46830B	102	670	877	23.6	75	503	0
IR13292-5-3	135	883	1290	31.7	64	565	27
IR54752A/IR29512-81-2-1	125	779	1250	37.7	81	632	90
IR54752B	125	689	1033	33.3	86	591	87
IR29512-5-3	128	810	1217	33.5	75	605	80
IR64 (check)	112	760	982	22.6	87	659	80
IR28150-84-3-3-2 (check)	120	788	1022	22.9	74	584	67
			Field M				
IR46828A/IR13524-21-2-3-3-2-2	123	642	929	30.6	87	556	0
IR3524-21-2-3-3-2-2	115	601	790	23.9	93	560	0
IR54752A/IR54R	125	695	1110	37.5	71	495	57
IR54752B	125	543	790	31.3	81	440	0
IR54R	123	629	877	28.3	69	435	53
IR54752A/IR19392-211-1	125	920	1369	32.8	67	619	30
IR19392-211-1	125	638	952	28.2	76	519	0
IR64 (check)	112	551	730	24.5	90	495	0
IR28150-84-3-3-2 (check)	120	541	886	21.2	85	460	0

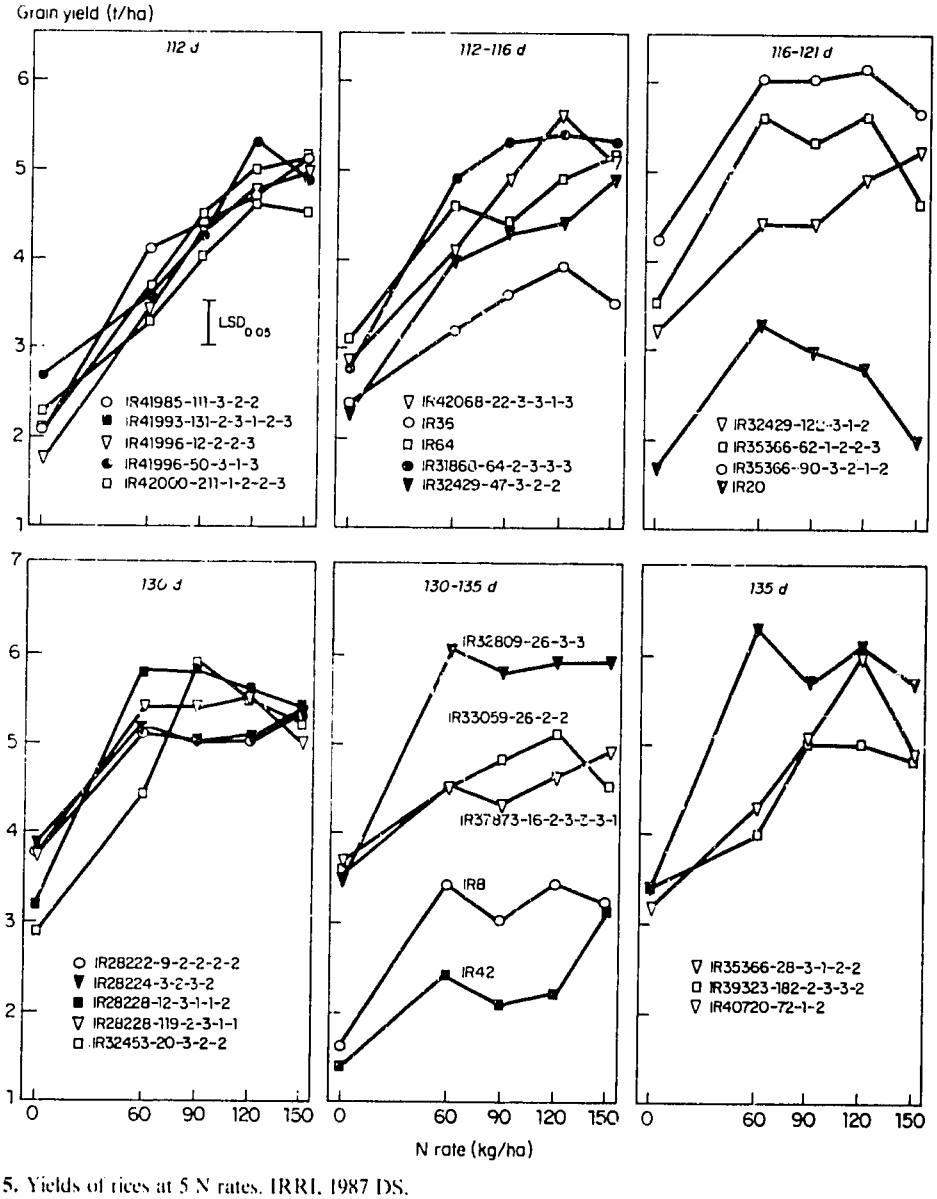
[a]N applied to each field was at 60 kg/ha. [b]Occurred at maturity.

Nitrogen harvest index was higher in F_1 hybrids (Table 4) because of their higher N absorption ability at early growth stages.

EFFECT OF PLANT DENSITY AND NITROGEN LEVEL ON YIELDS OF F_1 HYBRIDS AND ELITE INBRED CULTIVARS

Plant Breeding Department

Three F_1 rice hybrids developed collaboratively by IRRI and Korean scientists were evaluated with 3 elite inbred cultivars under 3 plant densities (30 × 15, 25 × 15, and 20 × 15 cm) and 5 N levels (0, 80, 150, 230, and 300 kg/ha) in a replicated field trial using the split-split plot design. Observations were recorded on yield (100 plants/plot converted into t/ha), total dry matter, grain dry matter, harvest index, panicle number per hill (6 hills/plot), spikelet number per hill (3 hills/plot), ripening ratio (percentage of grains showing specific gravity above 1.0 out of total grain harvested from 3 hills/plot), and 1,000-grain weight. Results are given in the section on Cooperative Country Projects.



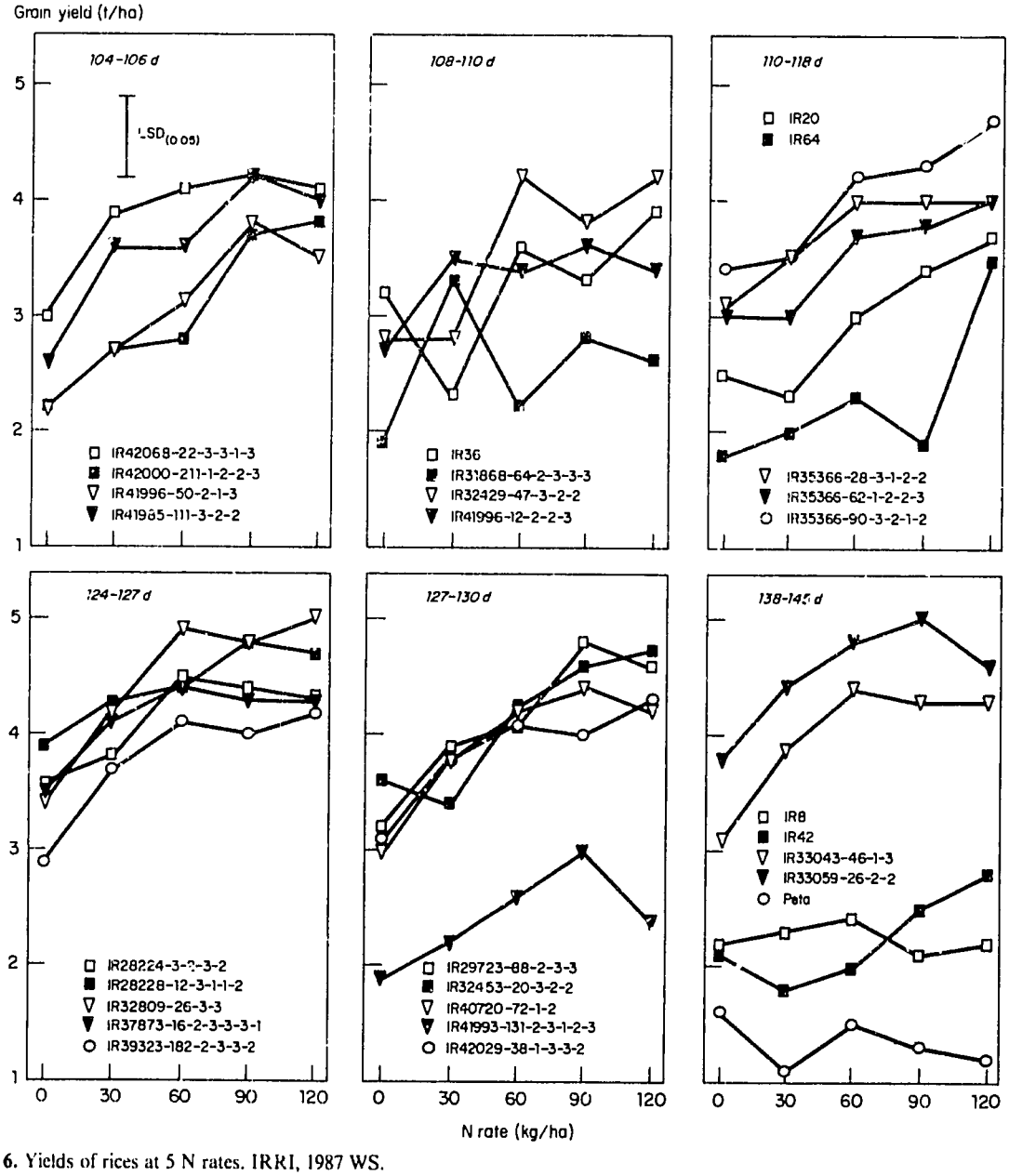
5. Yields of rices at 5 N rates, IRRI, 1987 DS.

YIELD PERFORMANCE AND NITROGEN RESPONSE OF VARIETIES AND BREEDING LINES

Agronomy Department

Irrigated rice. Yields of promising lines were compared with those of check varieties at different N rates at IRRI; at BPI research stations in Nueva Ecija, Bicol, and Iloilo; and in a farmer's field. N rates were higher in DS than WS.

IRRI. Without N fertilizer in DS, promising line IR28224-3-2-3-2 and experimental lines IR28228-119-2-3-1-1 and IR28222-9-2-2-2-2 yielded about 4.0 t/ha while IR35366-90-3-2-1-2 yielded highest with 4.2 t/ha (Fig. 5). The same line together with IR28228-12-3-1-1-2, IR 32809-26-3-3, and IR40720-72-1-2 responded best to 60 kg N/ha application. Increasing N rate for these rices, however, did not further improve yield.



6. Yields of rices at 5 N rates. IRRI, 1987 WS.

Of 27 test rices, yields of only nine entries (IR37873-16-2-3-3-3-1, IR32429-122-3-1-2, IR32429-47-3-2-2, IR42000-211-1-2-2-3, IR41985-111-3-2-2, IR41996-12-2-2-3, IR28222-9-2-2-2-2, IR28224-3-2-3-2, and IR64) increased at the highest N level. Yields of other test rices declined or leveled off with highest N. RTV caused low yields in IR8, IR20, and IR42. RTV and ShR severely damaged Peta.

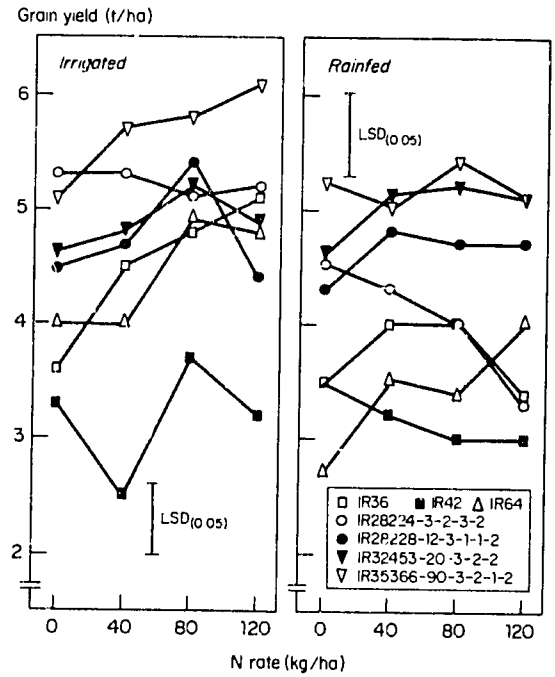
In WS, rices maturing in 104-120 d on plots without applied N yielded 3.0 t/ha or lower, except IR36, IR35366-90-3-2-1-2, and IR35366-28-3-1-2-2 (Fig. 6). On the other hand, yields of rices maturing in 124-145 d were between 3.0 and 4.0 t/ha, except for IR39323-182-2-3-3-2 and RTV-damaged IR41993-131-2-3-1-2-3, IR8, IR42, and Peta. At 30 kg N/ha, highest yield (4.2 t/ha) was recorded with IR33059-26-2-2. The same line yielded 5.0 t/ha at 90 N. Another line, IR32809-26-3-3, also yielded 5.0 t/ha but at 120 N. Three varieties and eight breeding lines did not obtain their maximum yields even at the highest N rate. Yield of other test rices declined or leveled off at 120 N. RTV damaged IR8, IR42, IR64, IR31868-64-2-3-3-3, IR41993-131-2-3-1-2-3, and Peta, and appeared in some IR32429-47-3-2-2 plots.

Farmer's field. Without N application in DS, IR28224-3-2-3-2 yielded 5.3 t/ha while early-maturing IR35366-90-3-2-1-2 gave 5.0 t/ha (Table 6). The same lines yielded highest at 100 kg N/ha with 6.6 and 6.7 t/ha. Medium-maturing IR42 and IR32453-20-3-2-2 suffered from later water stress. RTV caused low yield in IR42.

Table 6. Yields of IR varieties and promising breeding lines at 4 N levels (0-150 kg N/ha) in an irrigated farmer's field. Cabuyao, Laguna, Philippines, 1986 DS.

Variety or line	Duration (d)	Grain yield[a] (t/ha)			
		No N	50	100	150
IR36	111	3.1	4.0	4.4	5.3
IR42[b]	134	2.5	3.2	3.3	3.8
IR64	111	4.0	5.0	5.4	5.5
IR28224-3-2-3-2	123	5.3	5.8	6.6	6.3
IR32453-20-3-2-2	134	4.1	3.4	4.4	4.0
IR35366-90-3-2-1-2	111	5.0	6.2	6.7	6.6
IR41993-131-2-3-1	108	2.8	3.7	4.4	4.2

[a]Av of 3 replications. CV = 8%. LSD (0.05) = 0.6 t/ha.
[b]Affected by tungro.



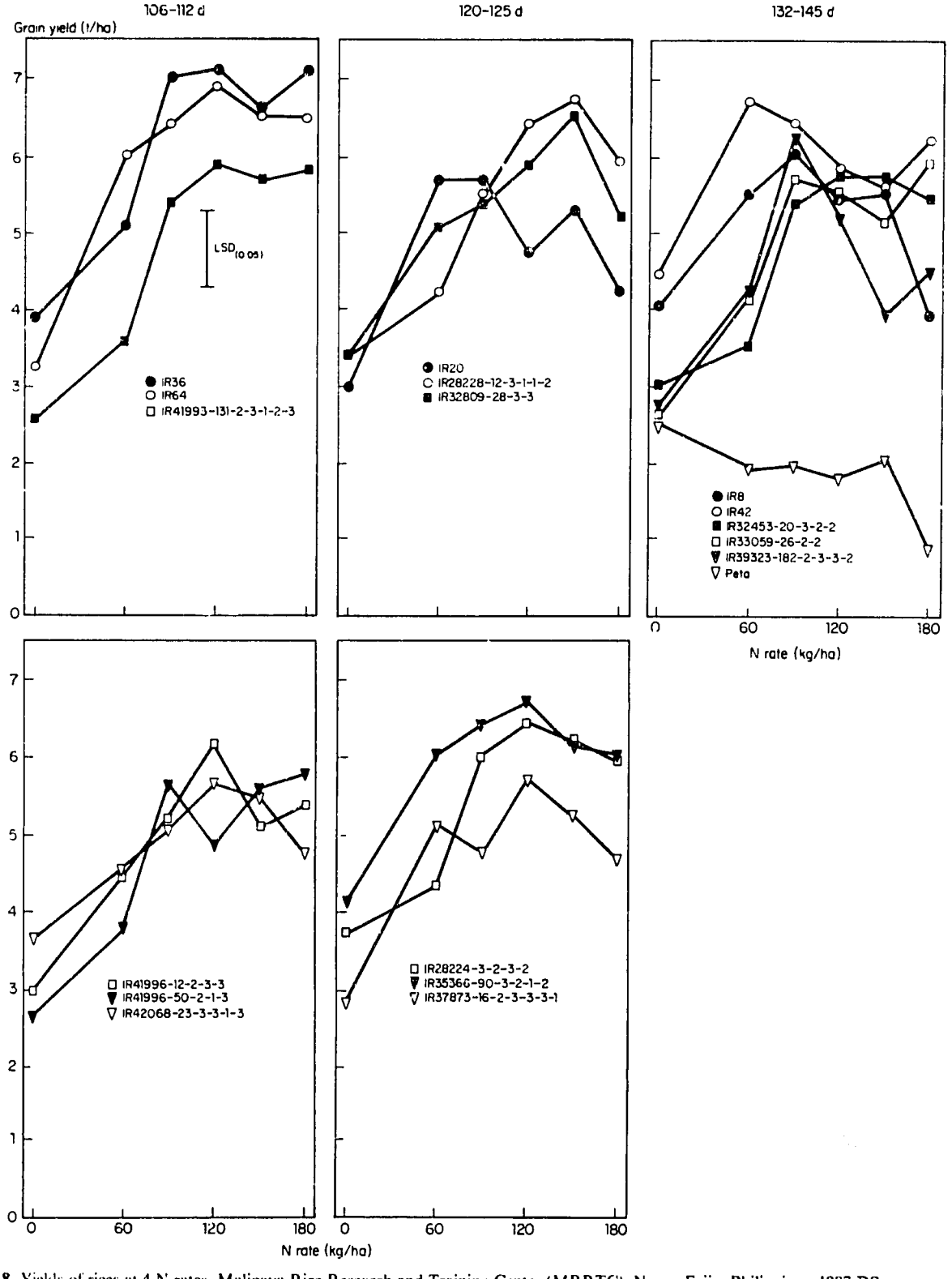
7. Yield of rices at 4 N rates in irrigated and rainfed farmers' fields. Cabuyao, Laguna, Philippines, 1987 WS.

In WS, promising line IR35366-90-3-2-1-2 yielded highest (Fig. 7). Without applied N, it yielded 5.1 t/ha, IR28224-3-2-3-2 yielded 5.3 t/ha, and two lines yielded 4.5 t/ha. RTV caused low yields of IR42 and IR64. RTV and ShR severely affected IR8.

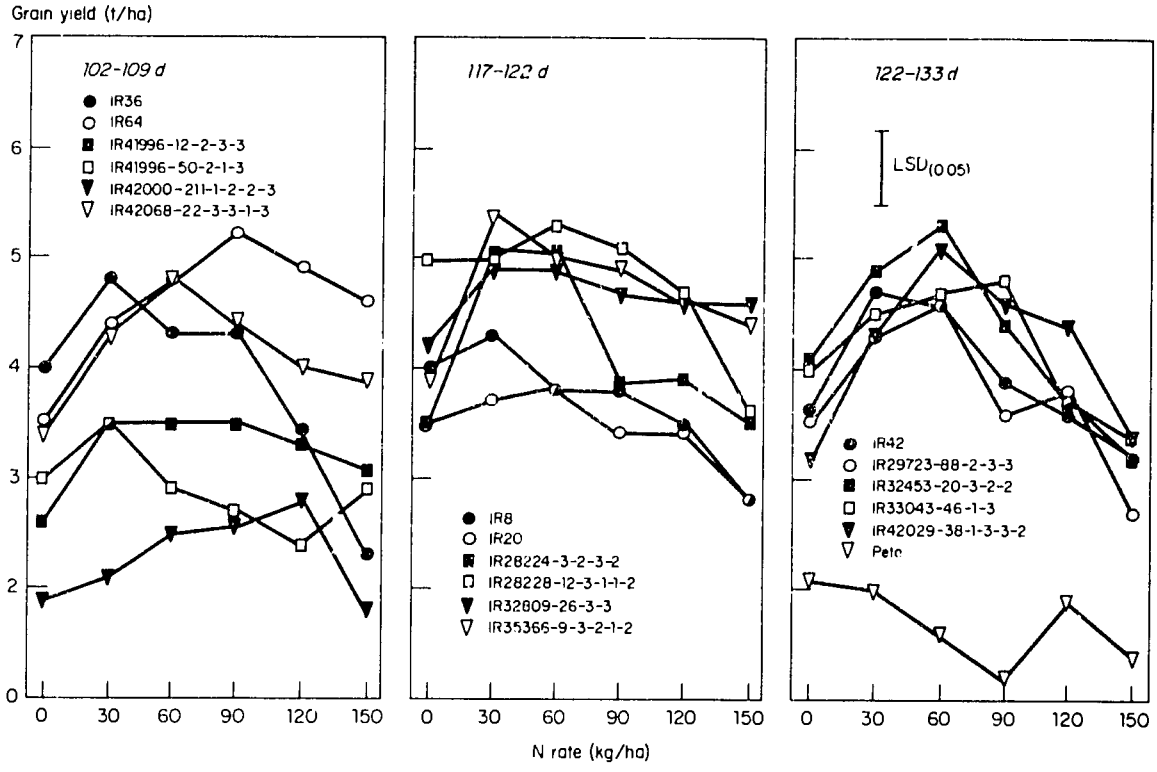
BPI stations. At the Maligaya Rice Research and Training Center (MRRTC) in Nueva Ecija in DS, IR36 yielded highest at 7.1 t/ha (Fig. 8). Optimum N application for rices maturing in 106-112 d and in 132-145 d was between 90 and 120 kg N/ha. Rices maturing in 120-125 d appeared to need a N rate of 150 kg/ha. Without applied N, IR8, IR42, and IR35366-90-3-2-1-2 yielded at least 4.0 t/ha. The traditional variety Peta responded negatively to N and produced lowest yields. SB damaged rices, hence the erratic N response.

In WS, highest yields among test rices were less than 6.0 t/ha (Fig. 9). Without N, many cultivars produced at least 4.0 t/ha and IR28228-12-3-1-1-2 yielded 5.0 t/ha. As in DS, Peta yielded lowest when N was applied. Severe lodging and bacterial blight infection lowered yields.

In Bicol during DS, RTV lowered yields of IR8, IR42, and IR64. Water shortage for 2 wk in March



8. Yields of rices at 4 N rates. Maligaya Rice Research and Training Center (MRRTC), Nueva Ecija, Philippines, 1987 DS.



9. Yields of rices at 6 N rates, MRRTC, Nueva Ecija, Philippines, 1987 WS.

affected yields of most early-maturing rices (Fig. 10). Five rices yielded 6.0 t/ha or more. IR32809-26-3-3 gave the highest yield of 7.2 t/ha at 150 kg N/ha. Test rices performed well at zero N, with IR28224-3-2-3-2 and IR28228-12-3-1-1-2 yielding 4.5 t/ha or more. As at MRRTC, Peta was outyielded by modern rices at all N levels.

In WS, IR32453-20-3-2-2 and IR32809-26-3-3, the same cultivars that produced the highest yields in DS, yielded more than 6.0 t/ha at 60 kg N/ha (Fig. 11). IR29723-88-2-3-3 outyielded the rest at zero fertilizer N. N application decreased Peta yields.

In Iloilo in DS, yields of early-maturing rices (105-110 d) were generally higher than those of rices harvested later (Fig. 12). Lack of irrigation water reduced yields as in the previous DS. Late-maturing rices greatly suffered during the reproductive phase. IR41996-50-2-1-3 yielded 6.0 t/ha.

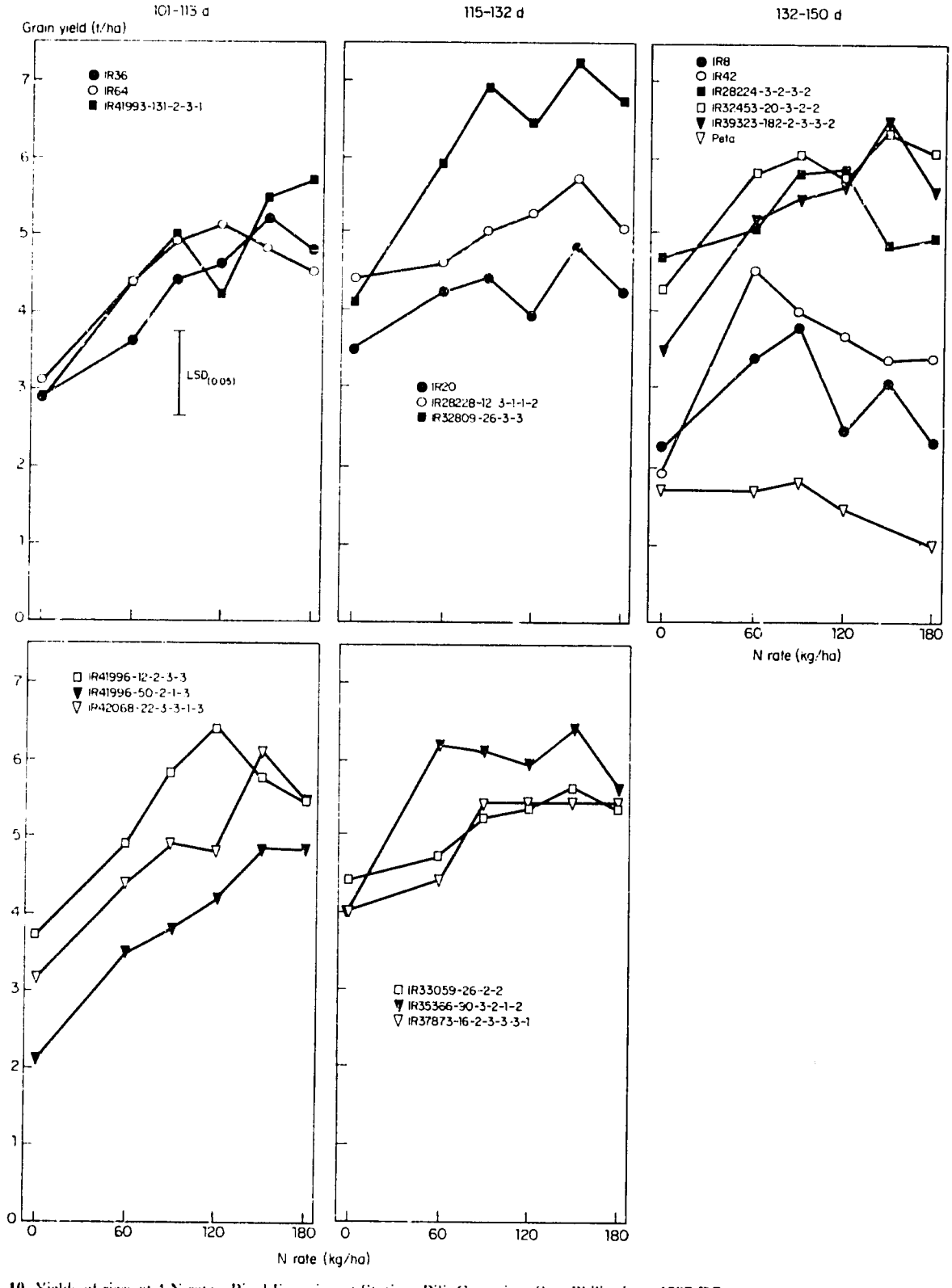
During WS, the Visayas climate favored rice growth. Yields were higher than at Maligaya and in Bicol (Fig. 13). Ten rices produced 5.0 t/ha or more even without N application. IR32809-26-3-3 was outstanding with or without N, yielding 5.8 t/ha at zero N and 7.4 t/ha at 60 kg N/ha. Optimum N rate for most rices was between 60 and 90 kg N/ha. Beyond 90 kg N/ha, yields declined. As observed at other stations, Peta, susceptible to lodging when supplied with N, was outyielded by modern rices at all N levels.

Rainfed rice. July-September drought delayed planting at IRRI. In the rainfed farmer's field, IR35366-90-3-2-1-2 yielded highest (Fig. 7) as it had in the irrigated. It produced 5.2 t/ha without N fertilizer. Three other lines yielded more than 4.0 t/ha at zero N. As in the irrigated field, IR42, IR64, and IR46 were affected by RTV, and yielded poorly.

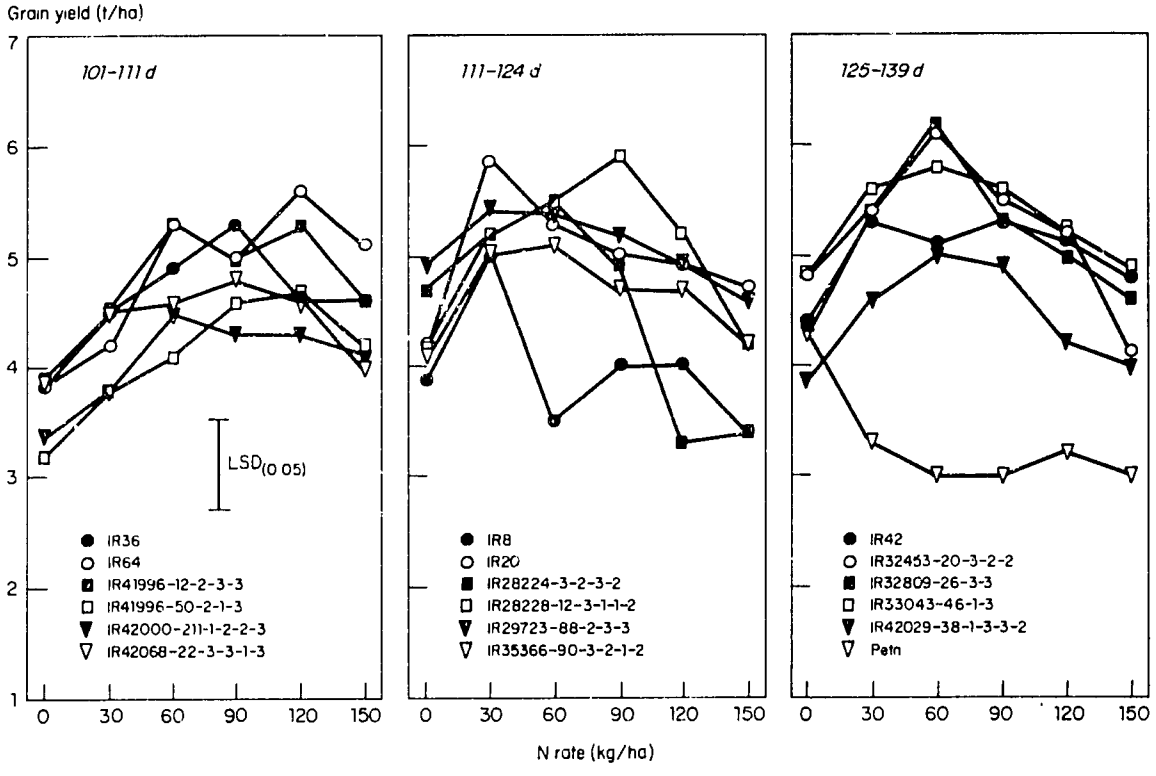
EVALUATION OF ELITE LINES FOR HIGH YIELD POTENTIAL

Plant Physiology Department

In 1987 DS, we began evaluation of elite lines provided by the Plant Breeding Department. The



10. Yields of rices at 4 N rates, Bicol Experiment Station, Pili, Camarines Sur, Philippines, 1987 DS.



11. Yields of rices at 6 N rates. Bicol Experiment Station, Pili, Camarines Sur, Philippines, 1987 WS.

objective is to identify and record traits associated with high yield potential (HYP).

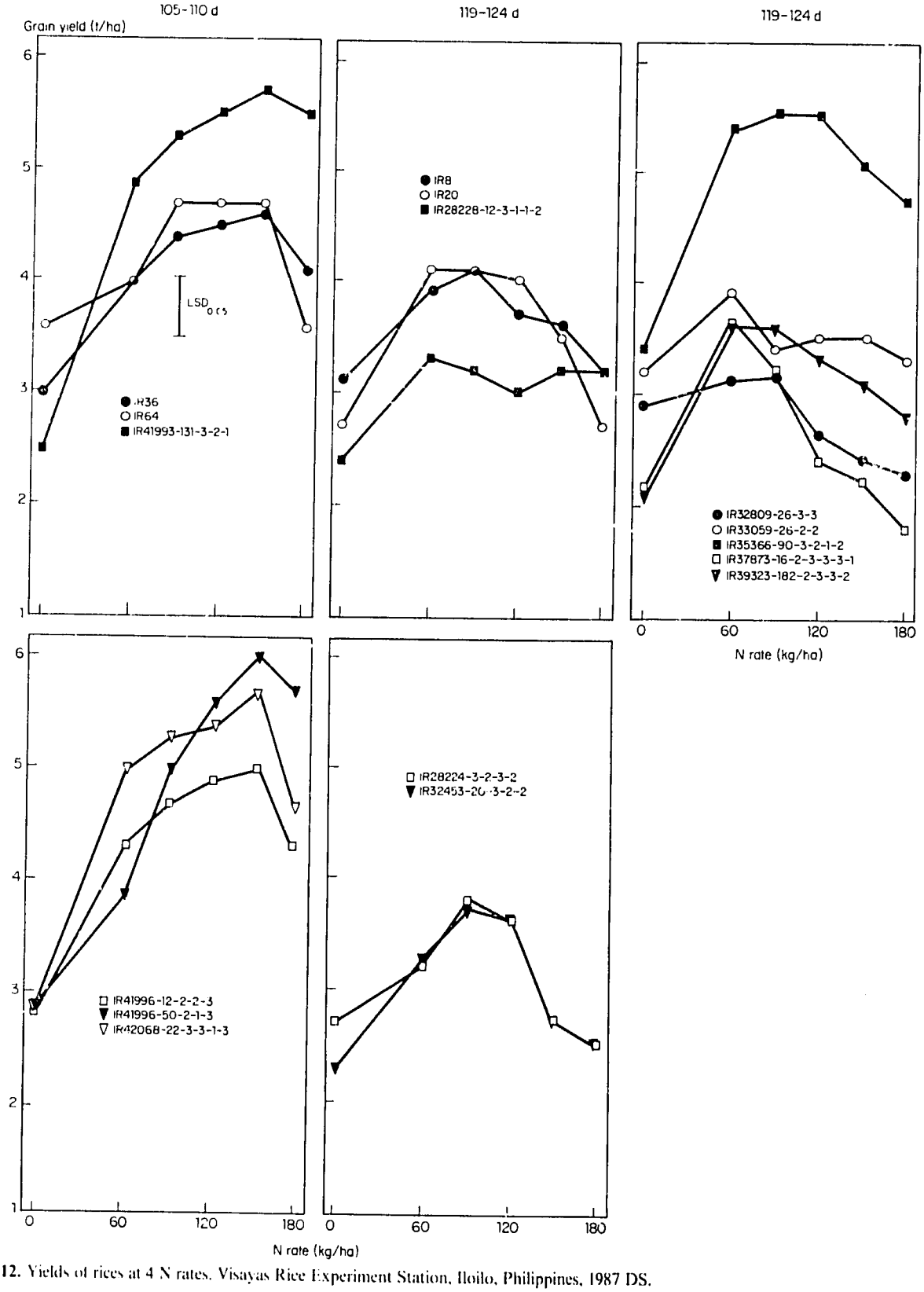
Photosynthetic efficiency (% E_u), crop growth rate (CGR), and leaf area index (LAI) were among the plant characters compared for elite lines and promising varieties. Cultivars almost similar in plant type, age 15 d, were transplanted on 8 Jan, spaced at 20 × 10 cm, and fertilized with 100-40-0 kg NPK/ha applied basally with 50 kg N/ha topdressed at panicle initiation (PI). IR64 early and late lines were selected by the difference in seedling vigor.

Table 7 summarizes the total dry weight, grain yield, and yield components of the seven elite lines

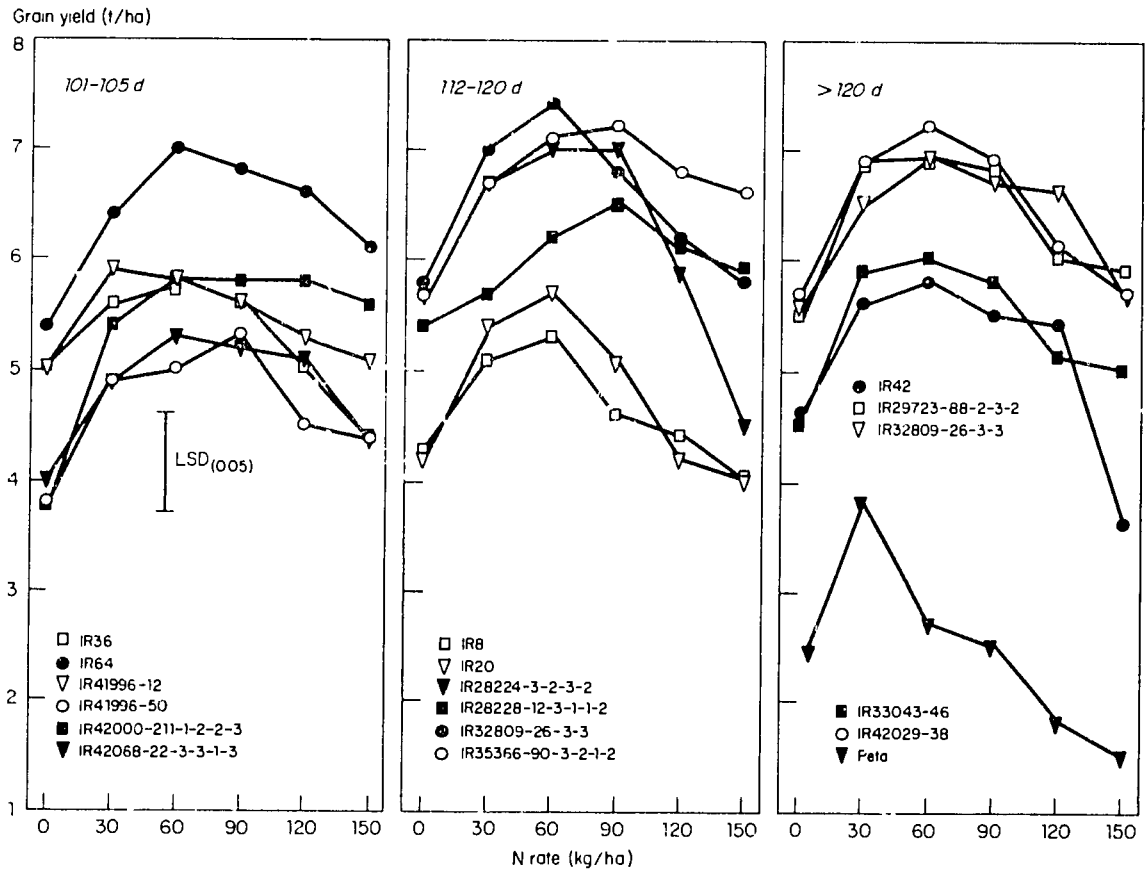
Table 7. Growth, grain yield, and yield components of some elite lines and cultivars.[a] IRRI, 1987 DS.

Variety or line	Growth duration (d)	Total dry weight (g/m²)	Grain yield (t/ha) at 14% moisture	Panicles (no./m²)	Spikelets (thousand/m²)	Filled grains (%)	1000-grain weight (g)
IR58	110	1560	6.6	603	34	79.2	21.5
IR32307-1-7-3-2-2	119	1760	8.8	621	43	86.8	21.1
IR64 early	120	1740	8.3	541	35	87.5	24.2
IR64 late	124	1685	8.0	541	34	85.0	24.6
IR64 PB	124	1655	8.0	611	37	86.7	23.9
IR2B224-3-2-3-2	131	1850	7.6	423	36	69.4	27.5
IR21820-154-3-2-2-3	131	1975	9.5	619	46	87.5	20.7
IR28228-12-3-1-1-2	131	1873	8.2	602	44	83.9	19.7
Suweon 332	132	1825	8.2	448	37	82.9	22.8
IR29723-143-3-2-1	132	2076	9.6	512	43	86.0	23.3

[a]Sown 24 Dec 1986, transplanted 8 Jan 1987 at 20- × 10-cm spacing.



12. Yields of rices at 4 N rates, Visayas Rice Experiment Station, Iloilo, Philippines, 1987 DS.



13. Yields of rices at 6 N rates. Visayas Rice Experiment Station, Iloilo, Philippines, 1987 WS.

compared with those of IR58, IR64 PB (Plant Breeding), and Suweon 332, a high-yielding indica-japonica rice from Korea. Six of the seven elite lines surpassed the three established varieties in total dry weight and grain yield. Of the early lines, IR32307-1-7-3-2-2 yielded best. Among the late maturers, IR21820-154-3-2-2-3 and IR29723-143-3-2-1 yielded best. Between IR64 PB and IR64 physiology variants (early and late) characters differed little in DS in contrast to 1986 WS, suggesting a seasonal effect.

The best yields were generally associated with high spikelet number (above 42,000), relatively good grain filling percentage (>85%), and medium size grain (above 21 mg). These components can serve as benchmarks in evaluating HYP of future cultivars.

Late-maturing lines showed higher maximum CGRs, obtained at heading time, than those of earlier rice cultivars under solar radiation and mean temperature regimes ranging from 416 to 564 cal/cm^2 per day and 24.3 to 27.0 °C (Table 8). In spite of relatively high LAIs (6-9.5), the tested cultivars showed comparable photosynthetic efficiency.

In the tropics, 2.5% E_u is considered highly acceptable. Although Suweon 332 had the highest CGR and %E_u around heading, its modest grain yield suggests that further evaluation is needed, especially of the physiological processes in the preheading and postheading stages and the influence of season on yield determinants during these stages.

VARIETAL DIFFERENCES IN SOIL NITROGEN UTILIZATION

Agronomy Department

Collaborative studies with the University of California, Davis, USA, continued to test ways to identify cultivars and production technology that

Table 8. Maximum crop growth rate (CGR) of some elite lines and cultivars and prevailing conditions.[a] IRRI, 1987 DS.

Variety	Growth duration (d)	Maximum CGR	Period	Heading	Conditions in the period			
					LAI	% Eu	T	S
IR58	110	26.0	14 Mar-28 Mar	13 Mar	9.0	1.82	26.8	533
IR64 early	120	28.4	19 Mar-6 Apr	18 Mar	6.0	2.07	26.7	514
IR64 PB	124	26.4	14 Feb-27 Feb	17 Mar	6.4	2.38	24.3	416
IR64 late	124	28.3	7 Mar-18 Mar	18 Mar	7.7	2.12	26.0	500
IR32307-107-3-2-2	119	27.8	3 Mar-18 Mar	16 Mar	7.5	2.09	25.4	497
IR28224-3-2-3-2	131	32.5	24 Feb-9 Mar	9 Mar	8.5	2.01	24.8	480
IR28228-12-3-1-1-2	131	32.5	20 Mar-27 Mar	27 Mar	9.2	2.20	27.0	554
IR21820-154-3-2-2-3	131	31.8	10 Mar-20 Mar	20 Mar	7.7	2.43	26.4	490
IR29723-143-3-2-1	132	33.6	20 Mar-30 Mar	30 Mar	9.5	2.23	27.0	564
Suweon 332	132	34.0	10 Mar-19 Mar	19 Mar	7.5	2.63	26.3	485

[a]CGR = dry wt/m² per day, heading = 10-20% of the tillers in a hill with panicles 1/3 to 1/2 already exserted, LAI = leaf area index, % Eu = photosynthetic efficiency, T = mean °C, S = cal/cm² per day.

increase yield at lower costs. A ranking procedure was developed to evaluate N use efficiency of varieties and lines treated with isotopically labeled fertilizer N and to compare that with data from unfertilized plots over six seasons on the IRRI farm.

Ranking procedure. The following parameters were used in developing the ranking procedure for each variety and line: a) two yield parameters [grain yield (Y) and panicle weight (WP)], b) three N efficiency parameters (Y/N_t, WP/N_t, and DM/N_t, where DM is straw dry weight and N_t is total N uptake), and c) for plots treated with labeled-N, the additional parameters WP/N_f, WP/N_s, DM/N_f, and DM/N_s, where N_f is N derived from fertilizer and N_s is N from the soil. The value of each parameter was normalized by expressing it as a fraction of the mean for all varieties and lines in a given season and fertilizer treatment. The sums of all normalized values were ranked with number one as the highest rank.

Testing the ranking system. Rankings were consistent from season to season (Table 9). Most rankings were similar for fertilized and non-fertilized plots. Growth duration affected the

Table 9. Cumulative rankings of best-performing varieties and lines evaluated by 5 parameters in fertilized and non-fertilized plots and by 9 parameters in fertilized plots. IRRI, 1987.

Variety or line	5-parameter[a] ranking	9-parameter[b] ranking
1982 DS and WS, 1983 DS, 33 varieties and lines		
IR15314-30-3-1-3	1	2
IR15323-78-1-3-1	2	4
IR19672-140-2-3-2-2	3	3
IR21912-56-3-1-2-2	4	9
IR22082-41-2	5	5
IR42	6	1
1983 WS, 1984 DS and WS, 24 varieties and lines		
IR13429-150-3-2-1-2	1	1
IR18349-135-2-3-2-1	2	2
IR21912-131-3-3-2-2	3	3
IR21912-56-3-1-2-2	4	4
IR13540-56-3-2-1	5	5
6 seasons, 12 varieties and lines		
IR15323-78-1-3-1	1	1
IR42	6	2
IR18349-135-2-3-2-1	2	3
IR21912-56-3-1-2-2	3	4

[a]Grain yield, grain yield/total N in plant, panicle weight, panicle weight/total N in plant, total dry matter yield/total N in plant. [b]Values in [a], plus panicle weight/fertilizer N, panicle weight/soil N, total dry matter yield/fertilizer N, total dry matter yield/soil N.

differences between rice varieties and lines. Early-maturing rices (100 d) produced lower yields and also had lower N use efficiency compared with medium- (110 d) and late-maturing (≥120 d) varieties and lines. Hence, early-maturing lines often ranked low (Table 10).

Correlations over six seasons between fertilized and nonfertilized plot rankings based on five parameters and between five and nine parameters were all significant, validating the system.

Applicability of the ranking system. To apply the system, 12 varieties and lines commonly used in 6 seasons were ranked overall, by fertilized or nonfertilized group, and by DS or WS (Table 11).

Table 10. Ranking of 24 varieties and lines based on 5 parameters[a] for fertilized and nonfertilized plots in 3 seasons. IRRI, 1987.

Variety or line	Ranking					
	1983 wet season		1984 dry season		1984 wet season	
	No N	30 kg N	No N	30 kg N	No N	30 kg N
100-d maturity						
IR8455-78-1-3-3	16	19	12	19	18	18
IR8608-167-1-2	21	24	19	18	24	24
IR9729-67-3	11	13	10	9	3	6
IR9752-1-2-1	15	20	18	22	15	20
IR19729-5-1-1-3-3	23	23	15	13	22	22
IR15429-268-1-2-1	24	22	14	10	23	16
IR19728-9-3-2-3-3	18	15	3	2	11	9
IR19735-2-3-2-1	17	12	6	14	17	17
110-d maturity						
IR36	19	16	20	20	13	13
IR50	22	20	23	17	12	12
IR13429-150-3-2-1-2	1	1	1	1	1	1
IR13427-40-2-3-3-3-3	20	18	24	23	16	23
IR13240-82-2-3-2-3-1	6	6	16	16	2	10
IR25588-32-2	10	9	22	6	8	11
IR18349-135-2-3-2-1	3	2	4	8	5	2
IR21912-56-3-1-2-2	5	3	8	4	4	7
120+-d maturity						
IR13540-56-3-2-1	4	5	13	12	6	4
IR21912-131-3-3-2-2	2	4	5	5	7	3
IR26	8	14	20	24	21	21
IR2863-38-1	14	10	17	21	20	15
IR42	7	8	11	11	13	5
IR8192-200-3-3-2-2	11	17	6	3	19	19
IR11248-148-3-2-3-3	9	7	9	15	10	14
IR15323-78-1-3-1	11	11	2	7	8	8

[a]Grain yield, grain yield/total N in plant, panicle weight, panicle weight/total N in plant, total dry matter/total N in plant.

The rices ranked consistently, particularly by season. IR15323-78-1-3-1 ranked first in three groupings, second in one, and third in another (Table 11). IR18349-135-2-3-2-1 ranked from 1 to 4, IR36 from 6 to 11, and IR42 from 5 to 7. On the other hand, early-maturing IR8455-78-1-3-3 ranked 12th in four groups and 11th in another.

Results suggest that N use efficiency can be evaluated without using expensive isotopically labeled fertilizer. Varieties and lines ranked well by this system can be used in breeding programs seeking to improve N use efficiency.

VARIETAL DIFFERENCES IN RESPONSE TO NITROGEN

Plant Physiology Department

Forty-five (1986 DS) and 62 (1986 WS and 1987 DS) varieties and advanced lines grouped as very early (<110 d), early (111-120 d), medium (121-130 d), or late (>130 d) maturing were planted at IRRI at 2 N levels, 0 and 90 kg/ha (60 kg basal + 30 kg topdressed at panicle primordia initiation, to study varietal differences in response to N.

Varietal differences in N absorption ability were observed up to the maximum tiller number stage in

Table 11. Ranking of 12 varieties and lines by 5 crop parameters[a] for 6 seasons (dry and wet), fertilized and nonfertilized groups. IRRI, 1987.

Variety or line	Ranking				
	6 seasons		6 seasons overall	3 seasons	
	Nonfertilized	Fertilized		Dry	Wet
IR8455-78-1-3-3	12	12	12	12	11
IR8729-67-3	6	3	4	7	2
IR19728-9-3-2-3-3	8	9	8	8	9
IR19735-2-3-2-1	9	10	11	6	12
IR36	10	6	9	11	6
IR50	11	8	10	10	10
IR13240-82-2-3-2-3-1	4	11	7	9	5
IR25588-32-2	7	5	5	3	8
IR18349-135-2-3-2-1	3	1	2	4	1
IR21912-56-3-1-2-2	2	4	3	2	4
IR42	5	7	6	5	7
IR15323-78-1-3-1	1	2	1	1	3

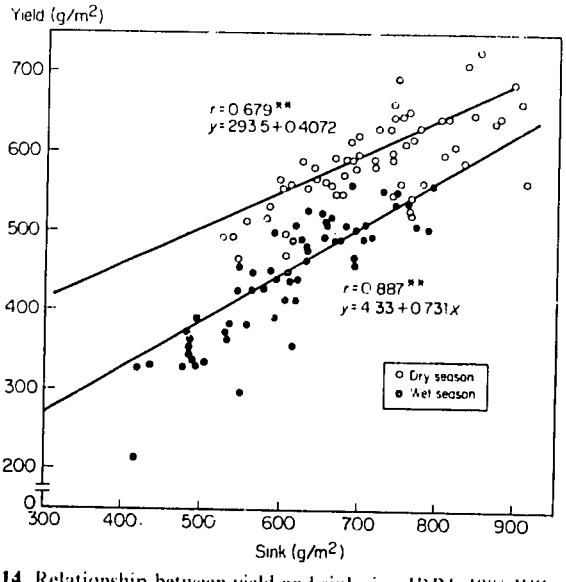
[a]Grain yield, grain yield/total N in plant, panicle weight, panicle weight/total N in plant, total dry matter/total N in plant.

both DS and WS. Thereafter, they were difficult to identify because the limiting factor in N absorption from maximum tiller number to flowering stage is the mineralization rate of soil organic N.

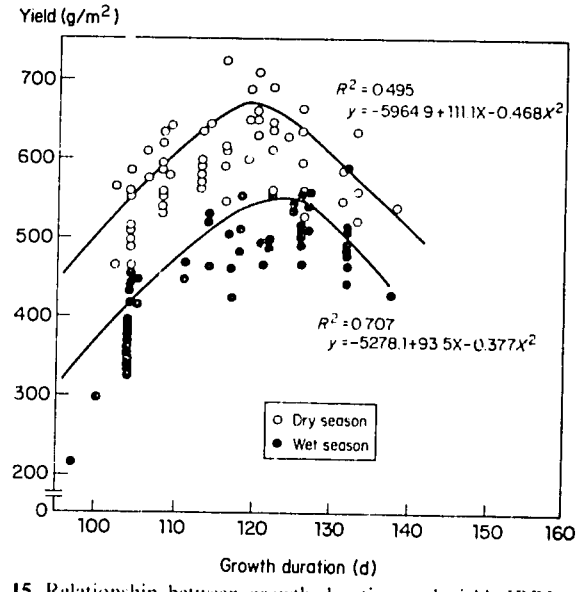
The amount of N in plants at critical growth stages under the same cultural practices was correlated with growth duration in DS (r= 0.74**) and WS (r = 0.90**). The amount of N in plants at flowering was correlated with the amount of sink and yield in DS (r = 0.93**) and WS (r = 0.89**). Yield was governed by the amount of sink despite big differences in percentage of ripened grains between DS and WS (Fig. 14). Sink contributed more to yield in DS than in WS.

The optimum growth duration for yield and sink was about 125 d in DS and WS (Fig. 15), though slightly shorter for yield than for sink size. Growth duration was negatively correlated with the percentage of ripened grains in both DS and WS, with r = -0.535** and r = -0.599** in 2 DSs. Optimum growth duration for ripening in WS was 120 d (R^2 = 0.318**).

The lower yield of very short-duration varieties is explained by the shortage of differentiated sink due to low N in plants at the late stage of spikelet initiation and low contribution of N to amount of sink in plants at flowering. High positive correlations of N absorption ability to yield, sink, N harvest index, and the contribution of N to sink



14. Relationship between yield and sink size. IRRI, 1986 WS and 1987 DS.



15. Relationship between growth duration and yield. IRRI, 1986 WS and 1987 DS

formation were likewise noted in short-duration lines (Table 12, 13). Therefore, the N absorption ability of plants at early growth stages is more important for short-duration varieties than for medium- and long-duration varieties.

The lower yield of long-duration varieties was attributed to degenerated sink caused by longer vegetative lag. Hence, the optimum growth duration can be explained primarily by the duration of vegetative lag.

There were positive correlations between the yields of rice grown under high and low N in both DS (r = 0.67**, r = 0.61**) and WS (r = 0.82**) and between the yields in DS and WS at both low N (r = 0.56**, r = 0.72**) and high N (r = 0.55**, r = 0.74**) levels.

Table 12. Correlation coefficients of N absorption ability[a] vs yield, sink, N harvest index, and sink/N. IRRI, 1986-87.

Growth duration (d)	Yield	Sink	N harvest index	Sink/N
104	0.74**	0.85**	0.81**	0.85**
114-117	0.72*	0.76**	0.42	0.52
125-127	0.37	0.57	0.39	0.50
132-134	0.57	0.80**	0.03	0.35

[a]N absorption ability = amount of N in plant at 3 wk after transplanting (WT).

Table 13. Nitrogen absorption ability, yield, and sink size of very early varieties. IRRI, 1986 WS.

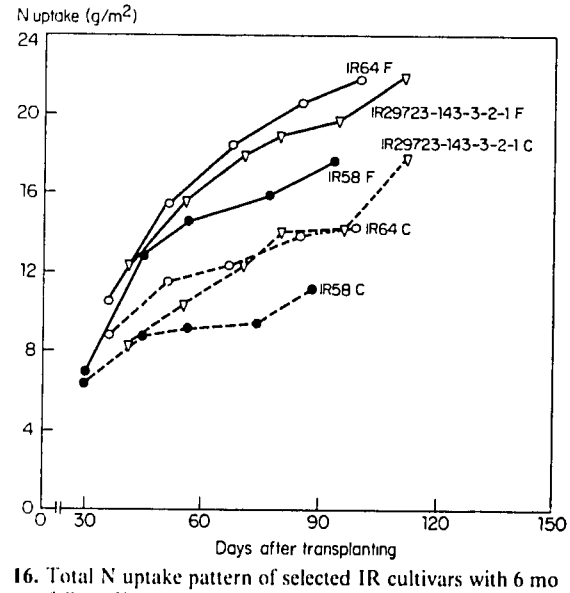
Variety or line	N in plant (g/m²)		Yield (g/m²)	Sink (g/m²)	Sink/N	N harvest index
	3 WT	Flowering				
IR58	3.02	7.35	369	531	72.2	59.4
IR28128-45-3-3-2	3.43	8.03	354	613	76.6	64.9
IR39357-91-3-2-3	3.11	7.58	383	557	73.5	58.8
IR39357-133-3-2-2-2	2.81	7.09	327	494	69.7	56.3
IR39385-20-1-2-1-1	3.21	7.56	365	528	69.8	62.7
IR39385-124-3-3-2-3	3.09	7.34	366	486	66.2	61.6
IR39422-19-3-3-3-3	3.03	6.66	375	468	70.3	62.4
IR39422-75-3-3-3-2	3.16	7.33	331	478	65.2	57.7
IR39422-163-1-3-2-2	2.59	6.73	333	428	63.6	54.3
IR41985-111-3-2-2	2.90	7.24	389	496	68.5	60.8
IR41985-172-3-3-3	3.16	7.55	383	534	70.7	59.4
IR41933-131-2-3-1	3.28	7.54	347	485	73.1	62.0
IR41933-196-2-2-1	3.57	8.15	394	596	64.5	63.5
IR25588-7-3-1	3.07	7.26	338	488	67.2	63.2
IR25621-135-1-1	3.01	7.35	337	504	68.6	58.0
IR29658-69-2-1-2	3.85	8.09	442	595	73.5	64.2
IR29262-94-2-1-3	3.39	7.78	453	586	75.3	62.5
IR29725-109-1-2-1	3.18	7.03	384	496	70.6	62.2
IR32429-81-2-3-3	3.41	8.14	416	602	74.0	64.9
IR32429-47-3-2-2	3.41	7.57	432	579	76.4	64.0
IR32429-122-3-1-2	2.48	6.85	327	420	61.3	56.0

PHYSIOLOGICAL CHARACTERISTICS

Plant Physiology and Agronomy Departments

Wet season fallow, nitrogen nutrition, and yields of cultivars with different growth durations (*Plant Physiology*). To evaluate interactions between cultivars with different durations (103-127 d) and N uptake, IR58, IR64, and IR29723-143-3-2-1 were grown in DS at IRRI. Continuous cropping was compared with a preceding WS fallow of 6 mo. All plots were fertilized with N applied split at 150 kg/ha and with P applied basal at 30 kg/ha. Plant density was 50 hills/m² and plot size 5 × 6 m. Heading was synchronized.

Test cultivars had similar total N uptake patterns. N uptake was markedly higher with wet fallow than with continuous cropping (Fig. 16). The improved N supply and absorption in wet fallow translated to higher total biomass production (Table 14). However, only the short-duration varieties IR58 and IR64 showed increased spikelet number and yield with increased biomass. Although medium-duration IR29723-143-3-2-1 showed increased biomass and slight increase in spikelet number, grain yield declined because of the marked decrease in ripening percentage with wet fallow. This underscores the greater potential of short-duration varieties to translate N supply and absorption into yield.



16. Total N uptake pattern of selected IR cultivars with 6 mo wet fallow (F) and continuously cropped (C) conditions. IRRI, 1987 DS.

It further shows that providing a fallow period can significantly increase yield. In the highly fertilized plots, fallow gave a higher N absorption rate throughout the growth stages. This means

Table 14. Effect of 6 mo wet fallow versus continuous cropping on the yield and yield components of selected IR cultivars.[a] IRRI, 1987 DS.

Variety or line	Growth duration (d)	Total biomass production (g/m²)	Grain yield (g/m²)	Spikelets (hundred/m²)	Grain filling (%)	1000-grain weight (g)
			Cropped			
IR57	103	1385	660	36.1	81.8	22.4
IR64	114	1385	600	27.8	89.9	24.4
IR29723-143-3-2-1	127	1845	790	38.5	86.8	23.5
			Fallow			
IR58	108	1570	680	41.8	75.7	21.6
IR64	115	1660	660	34.8	80.8	23.6
IR29723-143-3-2-1	126	2010	720	39.0	79.5	23.2

[a]Total biomass production, grain yield, and 1000-grain weight were measured at 0% moisture.

fallow treatment improves the available N supply and uptake, not only for initial growth but also throughout the growth stages, and that this available N is not compensated for by regular fertilizer application. Such higher N uptake throughout the growth stages needs investigation.

Physiological aspects of increasing yields of short-duration varieties (*Plant Physiology*). Four short-duration and medium-duration varieties (2 panicle number type and 2 intermediate type) and one check variety were transplanted in 1986 WS and 1987 DS under 2 N levels (0 and 90 kg N/ha, i.e., 60 basal + 30 topdressed) and 3 spacings (20 × 10 cm, 20 × 20 cm, and 20 × 30 cm) to determine effects on yield, yield components, and N-use efficiency.

Narrow spacing (20 × 10 cm) promoted N absorption at early growth stages, and enabled plants to reach the maximum tiller number stage earlier in both DS and WS, and in both short- and medium-duration varieties. The vegetative lag phase varied with spacing and variety as a function of growth duration. Narrow spacing lengthened the vegetative lag phase (Table 15, 16).

Narrow spacing increased the amount of N in plant, yield, sink, potential sink, and degenerated sink in both short- and medium-duration varieties. Increase in yield and sink due to narrow spacing was greater for the intermediate type than for panicle number type in short-duration varieties and likewise greater for short-duration than for medium-duration varieties. Narrow spacing increased the contribution of N to sink formation in the short-duration variety, but not in the medium-duration (Table 16). This observation can be explained by the relationship between N absorption and growth patterns of plants. Short-duration plants grown under lower plant density have a very short or negative vegetative lag phase (Table 15). Hence, they can still absorb large amounts of N after panicle primordia initiation. The contribution of N to sink formation varies with plant growth stage. N absorbed after panicle primordia initiation contributes less to sink formation. On the other hand, long-duration varieties grown under higher plant density have a longer vegetative lag phase, which increases the degenerated sink.

Higher sink and yield were obtained in the intermediate type with short-duration varieties. Intermediate-type plants, however, had higher sink degeneration than the panicle number type in both DS and WS plantings. Higher sink degeneration was noted under narrow spacing, but the values were too small to offset the amount of sink.

The panicle number type had higher percentages of ripened grains (Table 15). Narrow spacing did not reduce the percentage of ripened grains despite the greater amount of sink. The difference in the percentage of ripened grains between panicle number and intermediate types was too small to offset the yield.

To increase the yield of short-duration varieties, it is important to increase the amount of differentiated sink by increasing N absorption at early growth stages.

The coefficient of variation (CV) of yield and

Table 15. Effect of spacing and N level on yield and yield components of rice varieties and advanced lines of different panicle types.[a] IRRI, 1986 WS and 1987 DS.

N level	Spacing (cm)	Yield (g/m²)			Sink (g/m²)			Potential sink (g/m²)			Ripening (%)			Vegetative lag phase (d)		
		PN	I	Check	PN	I	Check	PN	I	Check	PN	I	Check	PN	I	Check
0	20 × 10	429	490	512	486	559	636	620	699	963	90	88	81	2 to 10	4	31 to 37
	20 × 20	381	433	455	434	503	570	551	621	864	89	87	80	−2 to 5	−1 to 0	27 to 30
	20 × 30	355	409	447	403	477	575	499	595	869	88	86	78	−4 to 3	−1	20 to 25
90	20 × 10	708	773	739	809	932	937	1057	1227	1344	89	83	79	2 to 10	4	32 to 37
	20 × 20	620	649	630	721	783	808	921	1035	1241	86	83	78	−2 to 5	−1 to 0	27 to 30
	20 × 30	568	605	592	682	740	766	876	1024	1207	84	82	78	−9 to 2	−9 to −2	20 to 25
CV total		30.0	34.1	19.8	26.5	28.6	18.6	29.9	30.1	18.6	9.8	9.4	7.8			

[a]Panicle number type (PN): IR58 (100-104 d in WS, 107-108 d in DS), IR64 (112 d in WS, 113-118 d in DS). Intermediate type (I): IR25588-7-3-1, IR29262-65-2-3-3 (104-106 d in WS, 109-112 d in DS). Check: IR36892-163-1-2-2-1 (130 d in WS, 135-140 d in DS).

yield components is higher in the intermediate type than in the panicle number type for short-duration varieties, and higher for short-duration than for medium-duration varieties (Table 15). Therefore, a panicle number type short-duration variety is less responsive to cultural practices or environment than is an intermediate type. However, a short-duration variety is more responsive to cultural practices and environment than is a medium-duration variety.

Characterization of varietal traits associated with high yield in broadcast seeded rice (*Agronomy*). Research was initiated during 1987 WS to ascertain desirable traits associated with high yield in broadcast seeded (BSR) and transplanted rice (TPR). Eight rices for each of three maturity groups were evaluated.

Grain yield significantly differed among rice varieties within each group. The effects of crop establishment method on grain yield varied among maturity groups. For early-maturing rice (group I), no grain yield difference was observed; for the medium-maturing (group II), yield was higher with BSR; and for the late-maturing (group III), yield was higher with TPR (Table 17). IR41985-111-3-2-2 and IR32429-47-3-2-2 gave the highest average yield in group I, IR35366-90-3-2-1-2 in group II, and IR28228-12-3-1-1-2 in group III.

RTV in TPR and lodging in BSR were observed in some varieties.

Factors affecting initial growth rates of rice cultivars (*Plant Physiology*). This study examined the effect of embryo size on initial growth rate of indica and japonica cultivars. Cultivars varying in embryo size were grown in a nutrient solution in the IRRI phytotron glasshouse under normal (29/21 °C) and low (21/15 °C) temperatures. After 2 wk, leaf area (LA) and seedling dry weight (SDW) were measured and N content of dried samples analyzed.

In both temperature ranges, embryo size significantly affected SDW of indica but not of japonica rices (Table 18). LA at 25 °C was about 3.6 times higher than at 18 °C and dry weight 2.2 times higher (Table 19). The effect of temperature on seedling growth would be chiefly through LA expansion rate, which is controlled by growth respiration rate.

Within the indica group, embryo sizes of

Table 16. Effect of spacing and N level on vegetative lag phase, N uptake, and N contribution to sink (S) and potential sink (PS). IRRI, 1986 WS.

Variety or line	N level (kg/ha)	Spacing (cm)	Growth duration (d)	Vegetative lag phase (d)	N uptake (g/m²) 3 WT	N uptake (g/m²) 5 WT	PS/N	S/N
IR64	0	20 X 10	112	10	2.49	4.89	96	79
		20 X 20	112	5	1.66	4.11	85	70
		20 X 30	115	−1	1.13	4.05	77	66
	90	20 X 10	112	10	3.18	5.80	100	76
		20 X 20	112	5	2.19	4.62	97	73
		20 X 30	115	−2	1.48	4.48	90	67
IR36892-163-1-2-2-1	0	20 X 10	130	31	2.53	5.04	115	76
		20 X 20	132	26	1.72	4.30	117	77
		20 X 30	132	20	1.21	3.95	123	77
	90	20 X 10	130	31	3.95	6.11	117	76
		20 X 20	132	26	2.31	5.09	115	75
		20 X 30	132	20	1.50	4.73	115	78

Table 17. Grain yield of transplanted and broadcast seeded flooded rice of different growth durations. IRRI, 1987 WS.

Entry	Grain yield[a] (t/ha) Transplanted	Broadcast seeded	Mean
Group I	*97-107 d*	*82-92 d*	
IR31802-48-2-2-2	3.6 bc	3.9 b	3.6
IR32429-47-3-2-2	3.8 b	4.8 a	4.3
IR39464-54-1-3-2-1-3[b]	3.7 b	3.7 bc	3.7
IR40804-176-2-2	3.8 b	3.9 b	3.8
IR41985-111-3-2-2	4.4 a	4.2 b	4.3
IR41996-50-2-1-3	3.7 b	3.7 bc	3.7
IR42000-211-1-2-2-3	3.9 ab	3.2 c	3.5
IR42015-129-3-3-3[b]	3.1 c	3.8 b	3.4
Group II	*108-115 d*	*93-102 d*	
IR35366-28-3-1-2-2	4.2 ab	4.2 bc	4.2
IR35366-90-3-2-1-2	4.7 a	5.2 a	5.0
IR39368-31-1-2[b]	3.4 c	3.6 d	3.5
IR42056-131-2-2-2-2	3.6 c	4.1 bcd	3.9
IR42074-230-2-1-3-3[b]	3.4 c	4.3 bc	3.8
IR44595-70-2-2-3[b]	3.8 bc	3.8 cd	3.8
IR44660-115-2-1-2-2	4.3 a	5.4 a	4.9
IR48525-100-1-2[b]	4.6 a	4.5 b	4.6
Group III	*123-132 d*	*107-117 d*	
IR28222-23-1-3-3-2	4.6 ab	4.0 b	4.3
IR28224-3-2-3-2	4.2 bcd	3.8 bc	4.0
IR28228-12-3-1-1-2	4.8 a	5.0 a	4.9
IR28228-119-2-3-1-1	3.8 d	3.4 cd	3.6
IR29723-88-2-3-3	4.1 bcd	3.2 d	3.6
IR32453-20-3-2-2	4.0 cd	3.4 cd	3.7
IR32809-211-2-2-3	4.4 abc	3.9 bc	4.2
IR33043-46-1-3	4.5 abc	4.4 cd	4.4

[a]In a column within a maturity group, means followed by a common letter are not significantly different at the 5% level. Seedling age at transplanting was 17 d. CV = 9%. [b]Plants established by transplanting were affected by RTV.

Table 18. Regression coefficients relating seedling dry weight to leaf area and embryo size, and leaf area to total N of cultivar groups.[a] IRRI, 1986.

Source	Embryo size	Leaf area	Total N
IRGC[b]	0.61**	0.95**	0.97**
PB[c]	0.17 ns	0.80**	0.57*
Indica	0.56 (0.51*)	0.95** (0.94**)	0.94**
Japonica	0.23 ns (0.52 ns)	0.87** (0.88**)	0.87**

[a]Low temperature values are in the parentheses. [b]International Rice Germplasm Center. [c]Plant Breeding Department, IRRI.

cultivars from the International Rice Germplasm Center were highly related to SDW; those from the Plant Breeding Department (PB) were not. The latter had higher initial growth regardless of embryo size (Table 20). Differences among cultivars depend on the LA expansion rate. However, the difference in initial growth in cultivars from different seed sources is due to the difference in embryo weight, which may depend on storage duration. The embryo weight of seeds stored for long periods may decline because they are viable and respire. Thus, in comparing varietal differences in initial growth rate, embryo weight of newly harvested material is recommended.

In both groups, LA was highly and positively related with SDW (Table 18). Multiple regression analysis revealed that among LA, specific leaf area (SLA), and embryo weight, LA contributed most to SDW followed by SLA (Table 21). Low embryo

Table 19. Effect of temperature on seedling growth of IR cultivars.[a] IRRI, 1986.

Cultivar	Leaf area (cm^2/plant)		Dry weight (mg/plant)	
	18 °C	25 °C	18 °C	25 °C
IR5	7.1	25.1	42.5	95.4
IR8	6.3	23.0	44.0	98.4
IR30	5.8	16.0	43.0	80.6
IR32	3.7	17.5	45.0	79.3
IR34	6.0	16.6	45.5	84.6
IR38	6.0	17.5	46.0	82.9
IR40	4.0	15.4	32.0	72.4
IR42	3.4	16.0	29.0	69.4
IR43	5.4	20.6	38.0	96.0
IR44	6.1	20.8	42.0	89.9
IR46	5.7	18.6	40.0	88.5
IR50	4.3	18.2	31.0	73.8
IR60	3.2	17.0	30.0	80.9
IR62	3.0	17.4	39.5	87.6
IR65	5.3	20.3	41.0	88.4
Av[b]	5.2	18.7 (360)	38.9	84.5 (217)

[a]Two hundred seedlings were grown in culture solution in the phytotron for 15 d after germination. Temperature shown is the average air temperature. Day and night temperatures were 29/21 °C and 21/15 °C. Average daily solar radiation during the period was 12.9 MJ/m^2. [b]Figures in the parentheses indicate the relative value of leaf area and dry weight at 25 °C to that at 18 °C.

Table 20. Initial growth rate of rice cultivars relative to newly harvested IR8 under normal temperature conditions. IRRI, 1986.

Cultivar	Source[a]	Ratio
Pokkali	4	1.21
BR4-10	4	1.21
Nona Bokra	4	1.20
Cheriveruppu	4	1.19
IR4595-4-1-13	4	1.17
Badal 64/1	4	1.14
At 69-5	4	1.13
Bg 367-4	4	1.11
Baishbish	1	1.08
BR4-10	1	1.06
Pokkali	1	1.05
Salumpikit	4	1.03
IR26	2	1.00
IR5	2	0.99
IR56	1	0.99
Chota Bawalia	1	0.99
IR54	2	0.95
IR34	2	0.95
IR44	2	0.94
Bg 34-8	1	0.94
KR1-24	4	0.94
M242	1	0.94
IR46	2	0.92
IR65	2	0.92

Table 20 continued.

Cultivar	Source[a]	Ratio
IR32	2	0.91
IR62	2	0.91
Bg 90-2	1	0.91
IR64	2	0.90
IR64	1	0.89
IR52	1	0.87
Leb Mue Nahng 111	1	0.87
IR46	1	0.86
IR36	4	0.86
IR38	2	0.86
IR42	2	0.86
IR30	2	0.84
Bluebonnet 50	1	0.84
Baok	1	0.83
IR48	1	0.83
IR60	2	0.82
Ishioka 9	3	0.82
IR5	1	0.80
IR58	2	0.79
Getu	4	0.78
IR50	2	0.77
Annapurna	4	0.77
IR45	1	0.76
IR40	2	0.75
IR62	1	0.75
Tamanishiki	3	0.73
Houyoku	3	0.68
Hounenwase	3	0.68
IR36	1	0.68
IR20	1	0.66
Hatsuboshi	3	0.65
Rikoto Norin 12	3	0.64
IR22	1	0.64
Akihikari	3	0.63
Toyonishiki	3	0.62
Mahsuri	4	0.62
Reimei	3	0.61
IR24	1	0.59
IR28	1	0.59
IR38	1	0.57
Nipponbare	3	0.56
Koshihikari	3	0.54
IR54	1	0.54
IR29	1	0.52
IR30	1	0.50
Tanginbozu	3	0.44
Kochihibiki	3	0.43
IR26	1	0.43

[a]1 = IRGC, 2 = Plant Breeding, 3 = Japan, 4 = IRGC, but multiplied new seeds.

weight seemed to be related to low LA development ability. Cultivars having higher SDW had lower SLA. Low SLA resulted in thicker leaves, higher N uptake per unit area, increased photosynthesis, and, consequently, dry weight increases. SLA was highly and negatively related with N uptake per unit area in both cultivar groups ($r = -0.83^{**}$ for

Table 21. Multiple regression analysis between seedling dry weight and 3 independent variables.[a] IRRI, 1987.

Source	DAS	r	R^2	Rate of standard partial regression coefficient (%)		
				X_1	X_2	X_3
			Indica			
IRGC	14	0.99	0.98	9.23	74.62	16.15
IRGC	16	0.99	0.98	1.44	75.28	23.28
PB	16	0.98	0.96	1.56	66.80	31.64
			Japonica			
Japan	16	0.90	0.95	1.50	63.98	34.52

[a]X_1 = embryo weight, X_2 = leaf area, X_3 = specific leaf area.

indica, r = -0.64** for japonica). Likewise, the increase in LA was highly related to total N uptake (Table 18), and this increase, in turn, was responsible for the high initial growth.

Effect of Crop Plus on rice growth and yield (*Plant Physiology*). Crop Plus, a biostimulant sprayed on rice, has been reported to increase its yield 12-13%. However, little is known about the physiological response.

A field experiment with four replications in 1987 WS determined how foliar applications of Crop Plus affect grain yield, total dry weight, and other plant characters at harvest. The field had a basal application of 100-30-0 kg NPK/ha. Aqueous solutions of Crop Plus at a rate equivalent to 0.61 liter/ha at 1 to 100 water dilution were sprayed on IR58, a 100-d cultivar, at the 3- to 5-leaf and PI stages. For grain yield, 7.5- × 10-m blocks were harvested. Other plant characters were taken from hills sampled from 1 m^2.

Crop Plus showed no effect on IR58 plant height, grain yield, total biomass, and panicle number. Further, panicle-to-straw and panicle-to-tiller ratios of treated and unsprayed plants were similar.

Plants were sprayed between 1000 and 1200 h, but rain fell on sprayed plants in late afternoon. This could explain the lack of effect. Growth duration might be another factor. Further experiments are necessary.

Seasonal variation in dark respiration rate of rice at panicle initiation and its relation to spikelet number (*Plant Physiology*). Spikelet number and dark respiration rate at PI show significant seasonal variation. A study to unravel these variations was conducted, using monthly planted rice at IRRI.

Dark respiration (R) can be represented as the summation of growth (Rg) and maintenance (Rm) components proportional to gross photosynthesis (Pg′) and to amount of protein (Pr), respectively. The equation is

$$R = kPg' + mPr \quad (1)$$

k = constant for growth respiration

m = constant for maintenance respiration

Respiration rate is significantly affected by protein amount (Pr). The ratio of R to Pr, R/Pr, represents the respiration rate at constant protein content and is influenced chiefly by the variation in growth component Rg as follows:

$$R/Pr = Rg/Pr + m \quad (2)$$

Since R/Pr is proportional to the ratio of dark respiration to N content (R/N), then R/N is largely affected by Rg/Pr. In this study, R/N at PI showed significant seasonal and varietal variations (Table 22).

Table 22. Seasonal variation in R/N value at panicle initiation. IRRI, 1987.

Transplanting time[a]	Respiration rate (R) (mg CO_2/ g DW per h)	Nitrogen (N) (%)	R/N (mg CO_2/ g N per h)
	IR58		
Mar	4.20	2.87	146
Apr	2.45	2.57	95
May	2.14	2.17	99
Jun	1.77	2.53	70
Jul	2.50	2.62	95
Aug	3.40	3.00	113
	IR64		
Mar	3.00	2.48	121
Apr	1.50	2.25	66
May	1.19	1.85	64
Jun	1.34	2.08	64
Jul	1.47	2.20	65
Aug	1.80	2.55	68
	IR29723-143-3-2-1		
Mar	1.70	1.80	94
Apr	0.81	1.32	61
May	0.56	1.32	42
Jun	1.11	1.72	65
Jul	1.03	1.69	61
Aug	0.99	2.32	43

[a]Planting density was 50 hills/m^2; fertilizer N was 150 kg/ha.

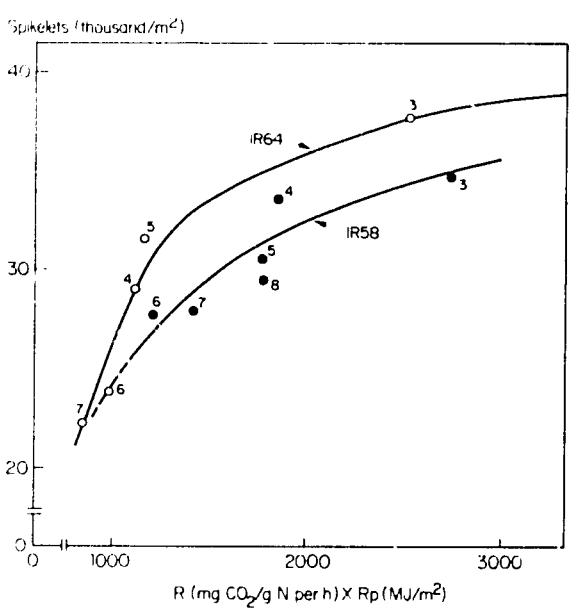
In months when spikelet numbers were higher, R/N was high. Close association between spikelet number and the product of R/N and solar radiation during the reproductive phase was observed (Fig. 17). R/N would determine potential spikelet differentiation ability while solar radiation during the reproductive phase would determine spikelet degeneration. Higher differentiation rate of spikelets may be accompanied by higher cell number and cell division, which requires higher protein synthesis. Higher protein synthesis results in higher respiration rate. Among growing seasons, higher R/N at PI is generally associated with higher Pr'/Pg' (Fig. 18, Table 22).

Growth respiration is determined by biological processes such as carbohydrate synthesis rate (C'), protein synthesis rate (Pr'), lipid synthesis (L'), etc. The relationship can be expressed as follows:

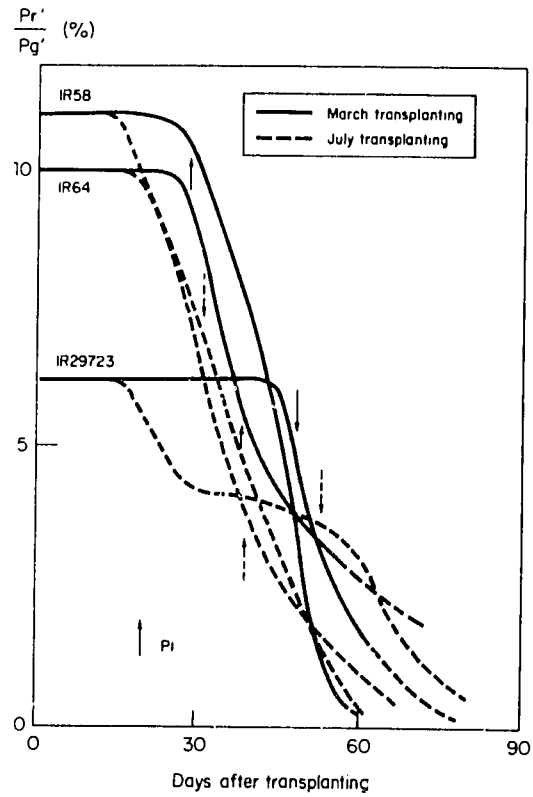
$$Rg = kpPr' + kcC' + klL' + \ldots \quad (3)$$

kp, kc, and kl are constants given by glucose consumed or CO_2 evolved to produce 1 g protein, carbohydrate, and lipid, respectively.

Higher Pr' is a determinant of higher Rg, since kp is 3 times higher than kc. Pr'/Pg' is approximately the ratio between Pr' and C', and the increase of Pr'/Pg' will indicate the increased rate of protein synthesis.



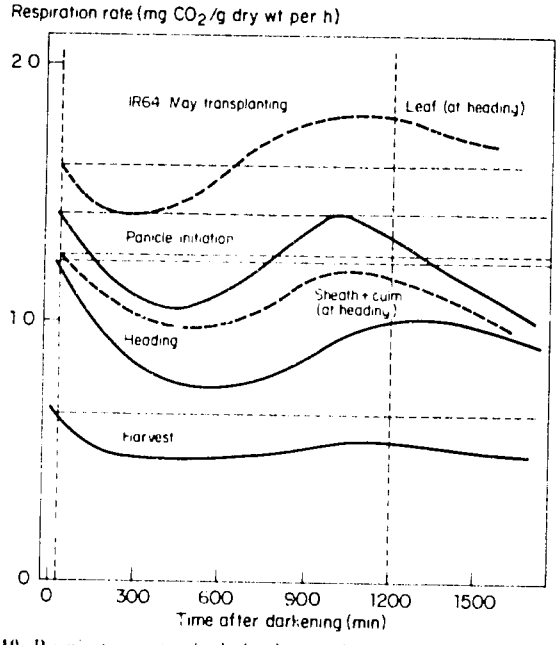
17. Relation between spikelet number (m²) and multiplied value of respiration rate at panicle initiation (R) and solar radiation (Rp) during reproductive phase. IRRI, 1987. Spikelet number and solar radiation were determined in 1986. Dark respiration was determined in 1987. Numbers on curves represent planting month: 3 = March, 8 = August.



18. Change of the ratio between protein synthesis rate (Pr') and gross photosynthesis rate (Pg') in relation to growth stage. IRRI, 1987.

The result indicates that the growth component of respiration varies significantly, depending on genetic and climatic factors. Plant growth, in turn, is significantly affected. Spikelet number can be manipulated by regulating growth respiration, while R/N value at PI can be a screening criterion for higher spikelet formation potential.

Effect of temperature on dark respiration of rice (*Plant Physiology*). A drawback in analyzing dark respiration is that its rate rarely stays constant even though environmental conditions are kept constant. Dark respiration varies with time, season, stage, temperature, and plant part (Fig. 19). Most respiration rates declined rapidly with the onset of the dark period. In the early morning, respiration rates gradually increased and reached a peak value, "morning surge" (Rs), then decreased gradually



19. Respiration rate of whole plant and plant parts of IR64 at different growth stages, measured at 25 °C, IRRI, 1987. Rd = daytime dark respiration.

and leveled off at a lower rate. Daytime dark respiration (Rd) can be extrapolated at time zero by following the pattern of the curve. Nighttime dark respiration rate (Rn) can be obtained by the average respiration of the materials placed in the respiration chamber at night. Generally, Rd is higher than maintenance respiration (Rm), but sometimes Rm is higher than Rd (Fig. 20).

It has been claimed that Rm represents mainly the maintenance component while its difference from R, R–Rm, represents the growth component, and that Rg is proportional to gross photosynthesis (Pg′) and is insensitive to temperature, while Rm is proportional to dry weight and has a temperature coefficient Q_{10} value of about two.

This concept is still controversial. It cannot account for the fluctuations in dark respiration rate at night as shown in Figure 19. The growth component is generally associated with several processes involving synthesis of protein, carbohydrate, lipid, etc. Thus, the growth component is a function of the synthesis rate of these compounds and was given by equation (3) in the previous section.

If the ratio of synthesis rate of each cell component to Pg′ is given by $\alpha, \beta, \gamma, \ldots$, then Rg is shown by the following equations:

$$Rg = kPg' = (kp.\alpha + kc.\beta + kl.\gamma + \ldots)Pg' \quad (4)$$

$$k = kp.\alpha + kc.\beta + kl.\gamma + \ldots \quad (5)$$

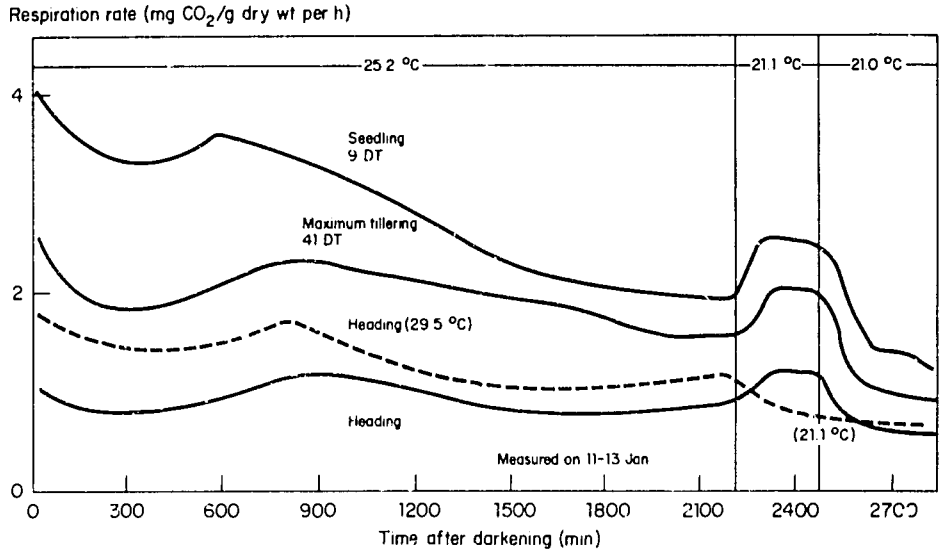
The equations express the association between Rg and Pg′. The important point is k, as expressed by equation (5), is always affected by the ratio of synthesis rate of each cell component to Pg′. The results in Figure 19 indicate that k rarely shows a constant value even within a day. However, when the ecological energy balance is analyzed, the averaged value of k for a long-term basis may show a relatively constant value. The small response of k to temperature can be attributed to Pg′, which already includes response to temperature. However, Rg itself will always be significantly affected by temperature.

The unstable pattern of dark respiration as shown in Figure 19 depends largely on variation in the synthesis rate of some cell components. Since Rg may involve light-sensitive reactions, switching these off may hasten the decline of the substrate pool after dark. The following (Rs) will be due to the activation of synthesis of some compounds. The pattern in Figure 19 indicates that the respiration related to synthesis of cell components becomes lower with the advancement of growth stage and differs for plant parts.

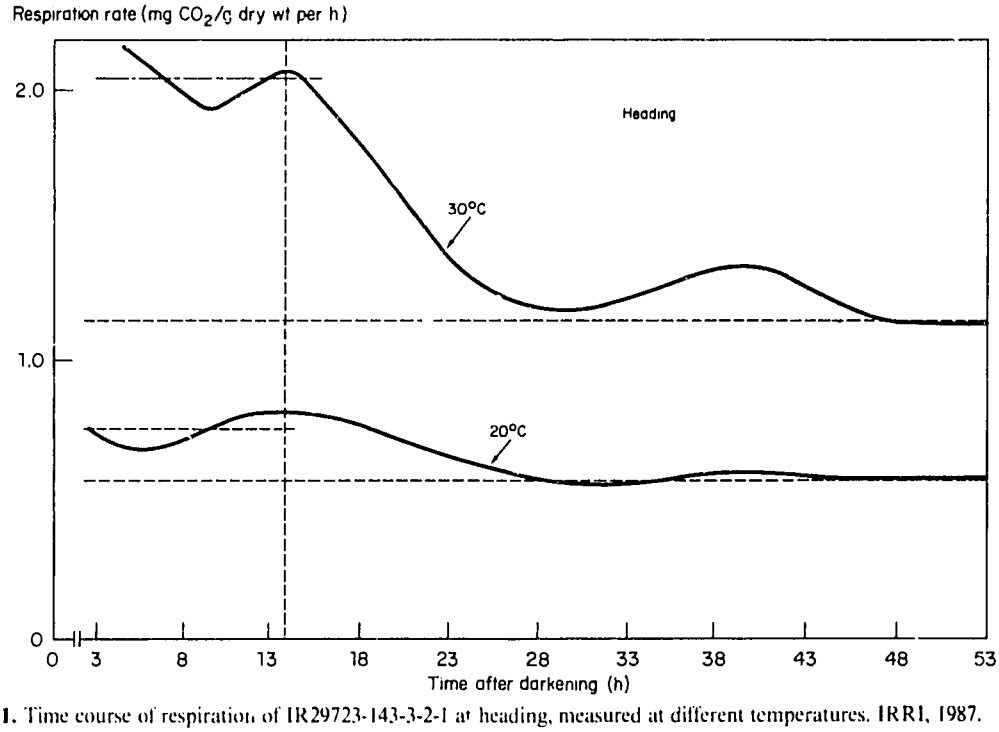
The Q_{10} of the reaction rate with time may help explain dark respiration.

Q_{10} at heading declined with the dark period. It was 3.2 at the onset of the dark period, 2.5 (after 15 h of dark period), when the "morning surge" was observed, and almost 2 after 38 h when maintenance respiration was dominant (Fig. 21). These changes in Q_{10} indicate that reactions at the onset of the dark period were more sensitive to temperature, and that the reaction rates then decreased, stabilizing at an average Q_{10} of 2. This may explain why leaf expansion shows such a dependence on high temperature. Earlier studies showed LA expansion rate at 28 °C to be 3 times higher than at 18 °C. We found similar results, indicating that growth, as in LA expansion, depends on Rg reactions that occur just after dark or with light and are highly temperature sensitive.

Sink formation profile in early-maturing IR cultivars (*Plant Physiology*). In the tropics, early-maturing rice cultivars enhance intensive cropping, which justifies improving their yield levels.



20. Time course of respiration rate of rice cultivar IR29723-143-3-2-1 at different growth stages with time after darkening, IRRI, 1987. Temperature of the material represented by the broken line was kept at 29.5 °C until 220 min, then lowered to 21.1 °C. Others were kept at the temperature at the top of the figure.



21. Time course of respiration of IR29723-143-3-2-1 at heading, measured at different temperatures. IRRI, 1987.

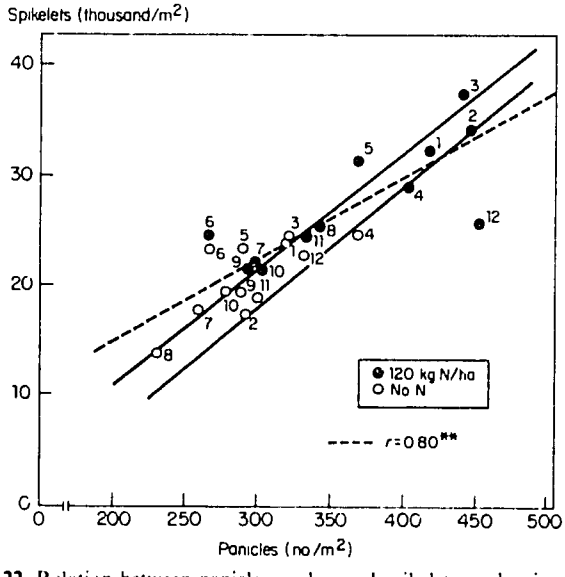
Yield variation in rices that mature in 100-115 d relates largely to differences in spikelet number (sink), in turn associated with irradiance level in the reproductive phase. This study attempts to explain how sink size variation develops.

Data from a year of monthly plantings beginning in January were used to analyze sink size variation in irrigated IR58 and IR64, two early cultivars. Seedling age, fertilizer rate, and plant density were the same for all transplanting months. Yield and

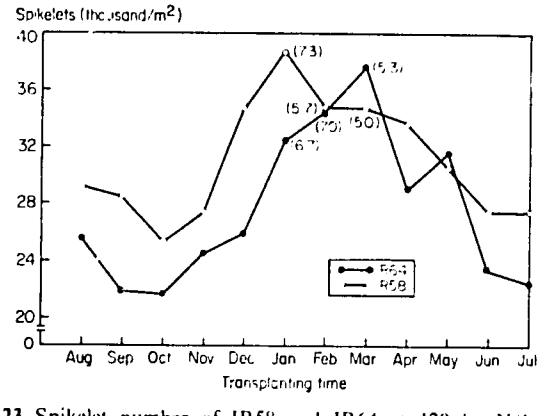
growth of these cultivars were evaluated in relation to irradiance and mean temperature at appropriate growth stages.

In early-maturing IR cultivars, sink size is related to the formation of panicles (Fig. 22). At similar panicle value, both low and high, the wide distribution of points seems to indicate that panicle size is also affected by season.

Sink size differs in IR58 and IR64, but profiles are similar (Fig. 23). Spikelet numbers and grain yields were high in the same months.



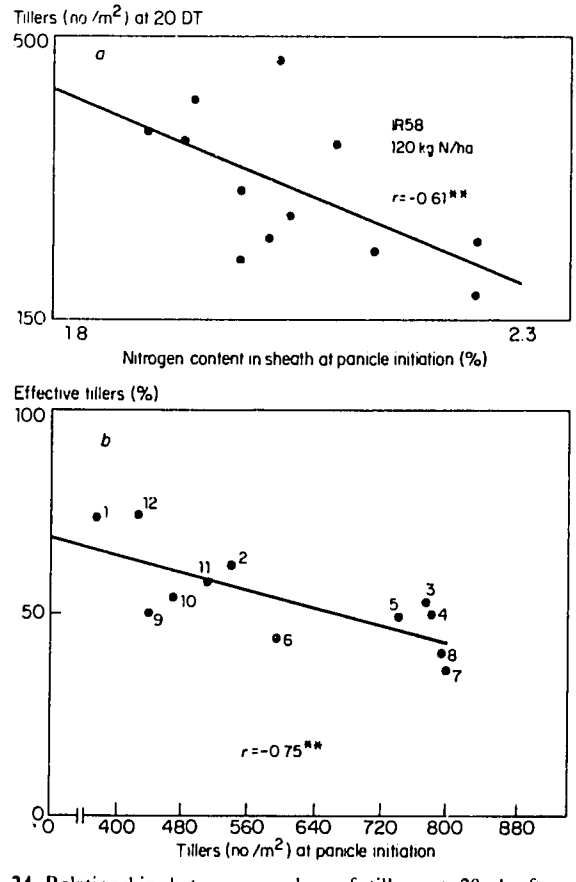
22. Relation between panicle number and spikelet number in IR64, IRRI, 1985-86. Numbers on curves represent planting month: 1 = January, 12 = December.



23. Spikelet number of IR58 and IR64 at 120 kg N/ha, transplanted monthly over a 1-yr period, IRRI, 1985-86. Figures in parentheses indicate 3 best monthly yields.

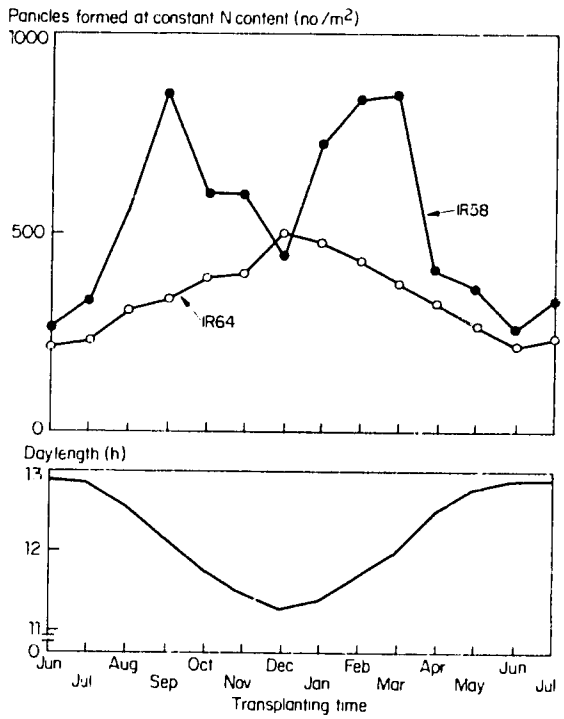
Sink formation ability is evaluated either by the size of sink produced per unit dry weight at heading or per N absorbed before heading. These two methods produced essentially identical profiles for IR58 and IR64.

Spikelet formation ability differs among rice cultivars and is negatively correlated with mean air temperature during the vegetative phase ($r = -0.78$ for IR64 and -0.77 for IR58). Similarly, grain yield and temperature during the vegetative phase are also highly negatively correlated—$r = -0.64$ for IR64 and -0.76 for IR58. Lower mean temperature seems to favor retention of more N in the sheath at PI. In contrast, high mean temperature during the vegetative phase decreased percentage of effective tillers because faster leafing and tillering significantly reduced sheath N at PI (Fig. 24).



24. Relationship between number of tillers at 20 d after transplanting and N content in the sheath at panicle initiation, and that between number of tillers at panicle initiation and percentage of effective tillers (no. of panicles divided by max no. of tillers) of IR58 with 120 kg N/ha.

Daylength influences panicle formation in rice cultivars, affecting their sink forming ability (Fig. 25). Panicle-forming abilities of IR58 and IR64 differ. As daylength decreased, the panicle-forming ability of IR64 increased and vice versa. With IR58, the trend was inconsistent, perhaps because of partitioning of photosynthates and N in the plant that could be related to hormone activity under photoperiod control.



25. Panicle formation ability in IR58 and IR64 at 120 kg N/ha as influenced by planting month. IRRI, 1985-86.

Biomass production and grain yield of IR cultivars in high-nitrogen water culture (*Plant Physiology*). Canopy architecture and nutrient uptake ability have been improved in most current high-yielding varieties. To estimate potential biomass production and yield, six recently improved IRRI cultivars were grown by water culture in a tank with high N application and in the field in DS (Table 23).

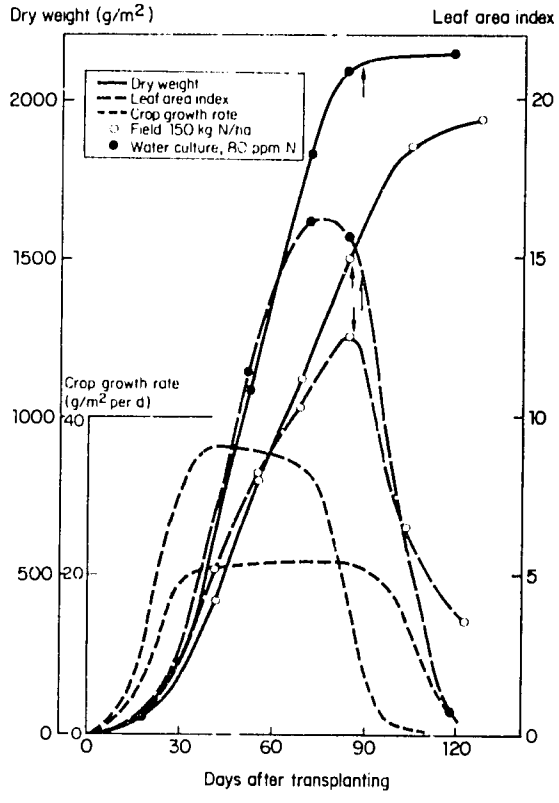
Planting density was 20 × 10 cm. The water culture experiment used a modified Yoshida's solution. N was kept at 40 ppm until 3 wk after transplanting, then was increased to 80 ppm. After heading, it was reduced to 60 ppm. Lodging was prevented. Field materials were grown simultaneously at 150 kg N/ha under favorable growth conditions.

In the tank, the highest biomass produced was about 22 t/ha for IR29723-143-3-2-1 (Fig. 26). Cultivars like IR44 and IR56, which have a canopy of droopy leaves, showed lower biomass production than those like IR29723-143-3-2-1 and IR58, which have erect leaves. Leaf erectness aids higher biomass production. Vigorous growth at early

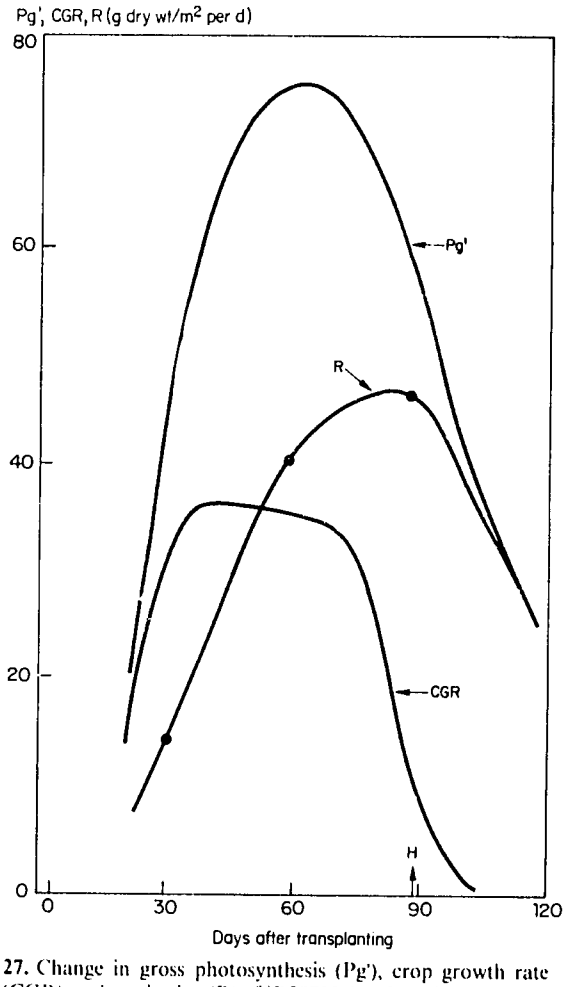
Table 23. Leaf area index (LAI) and crop growth rate (CGR) of rice varieties grown in a tank and in the field. IRRI, 1987 DS.

Variety or line	N[a] absorbed (g/m²)	Maximum LAI	Optimum LAI[b]	CGR at optimum LAI (g/m² per d)	CGR during heading (g/m² per d)
		In the field, at 150 kg N/ha			
IR58	21.8	9.3	8.4	38.0	35.0
IR28	22.1	9.8	6.5	34.0	30.0
IR56	22.4	9.1	7.1	33.0	27.5
IR64	20.6	7.5	7.3	29.4	26.7
IR44	20.9	9.7	7.5	35.4	23.5
IR29723-143-3-2-1	17.1	8.5	6.5	27.0	25.0
		In a tank, at 80 ppm N[c]			
IR58	37.7	14.7 (158)	10.5	37.0	23.5
IR28	39.2	16.3 (166)	9.5	45.0	25.7
IR56	37.6	16.0 (176)	10.0	37.0	23.6
IR64	37.4	13.7 (183)	8.5	40.0	17.8
IR25588-7-3-1	–	17.3	10.7	29.0	25.0
Guichao 2	40.5	14.2	12.5	37.0	30.5
IR54752A/IR29723R	39.2	16.2	8.0	42.0	12.0
IR8	47.8	20.2	10.0	47.0	6.0
IR29723-143-3-2-1	49.2	15.7 (185)	9.0	46.0	12.5
IR44	46.2	20.8 (214)	10.1	41.0	8.0

[a]N absorbed decreased after heading. In this table maximum rate through the growth stage is indicated. [b]LAI giving highest CGR. [c]Figures in parentheses indicate percentage increase over the field-grown materials.



26. Growth curves of medium-duration IR29723-143-3-2-1 grown in high-N water culture and in the field with favorable management. IRRI, 1987 DS.

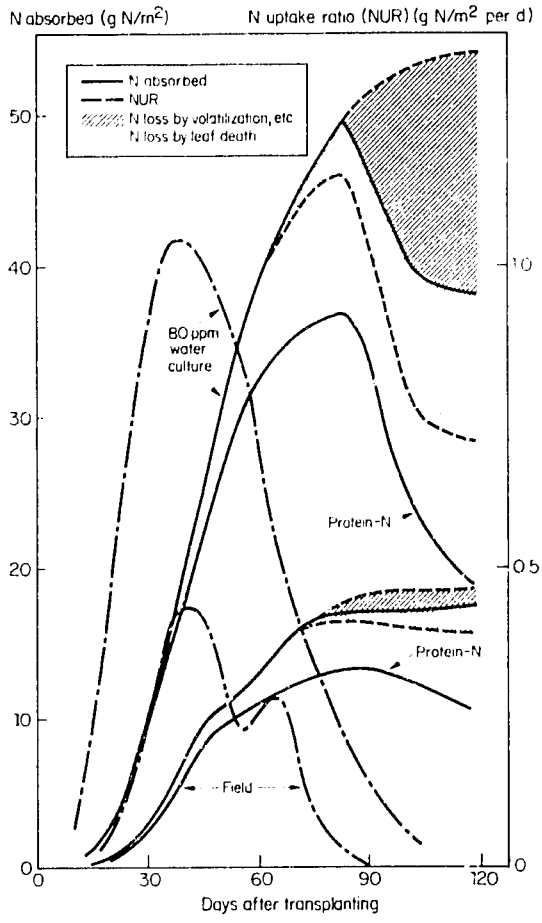


27. Change in gross photosynthesis (Pg'), crop growth rate (CGR), and respiration (R) of IR29723-143-3-2-1 in high-N (80 ppm) water culture, IRRI, 1987. H = heading.

stages due to high N in the culture solution was always followed by a sharp decline in growth at later stages due to enhanced dark respiration as high as 50 g dry weight/m^2 per day in IR29723-143-3-2-1 (Fig. 27). Thus, the culture solution produced little significant improvement of biomass compared with the field.

Photosynthesis rate or CGR can easily be manipulated by regulating N, and higher growth can be obtained at early growth stages. However, photosynthesis rate also accompanies increased respiration rate at later growth stages. Unless the ratio between photosynthesis rate and respiration rate is improved, increase in photosynthesis will not help improve rice biomass in tropical conditions. In the tank, the highest CGR was around 40 g/m^2 per day, the maximum LAI was more than 20, and total N uptake was 35-40 g N/m^2 in rice grown at higher N (Table 23, Fig. 28). In the field, identical materials grown under favorable management showed a CGR of only 30 g/m^2 per day, a maximum LAI of less than 10, and N uptake of 20-21 g N/m^2.

In the tank, grain yields were reduced, especially those of long-duration varieties (Table 24). Ripening percentage was positively related with CGR 5 d before and after heading ($r = 0.88$). The lower grain yield in the high-N plot is attributed to low ripening percentage due to lower CGR at heading because of overgrowth. The tank experiment indicates that grain yield is strongly affected by growth duration and N level. In the field with 150 kg N/ha and a plant density of 50 hills/m^2, grain yield varied little with growth duration between 110 and 140 d. In the tank with extremely high N, the optimum growth duration was about 100 d. Usually, optimum growth duration for high yield will be



28. N absorption and N uptake rate of IR29723-143-3-2-1 in the field and in high-N water culture. IRRI, 1987.

shorter with increasing N; however, it also will vary with the N uptake ability of the varieties used.

Rice panicle characteristics (*Plant Physiology*). One way to improve rice grain yield is to increase the number of high density (HD) grains per panicle.

Earlier results showed that HD grains (specific gravity >1.20) are usually on primary branches, and primary branches are correlated with number of vascular bundles and culm thickness. These panicle characteristics were studied in 10 IR varieties, 16 *O. glaberrima* accessions, and 15 lines from an upland cross.

The *glaberrimas* had comparatively more primary branches and more spikelets on primary branches, traits needed for HD grains (Table 25). The upland lines were next highest, followed by IR varieties. The *glaberrimas* had markedly fewer secondary branches and spikelets on secondary branches, characters producing more low-density grains. The lack of differences in total spikelets indicates that more primary branches and fewer secondary branches on the panicle can be obtained without reducing total spikelets per panicle.

Inner vascular bundles were most numerous in IR varieties; outer vascular bundles were higher in *glaberrimas*. Culm diameter varied little. Air space was less in the *glaberrimas*. The upland lines had thick culms, the IR varieties had thin culms.

Table 24. Grain yield and yield components of rice varieties grown in a tank and in the field. IRRI, 1987 DS.

Variety or line	Growth duration (d)	Dry matter production (g/m²)	Grain yield (g/m²) at 14% moisture	Panicles (no./m²)	Spikelets (thousand/m²)	Filled grains (%)	1000-grain wt (g)	Harvest index
			In the field, at 150 kg N/ha					
IR58	106	1623	913	775	47.0	90.3	18.9	49
IR28	110	1742	860	635	48.3	79.5	19.6	43
IR56	112	1717	907	645	46.4	82.0	20.9	46
IR64	117	1721	901	530	36.7	88.6	22.5	46
IR44	131	1838	822	565	41.1	81.3	21.6	39
IR29723-143-3-2-1	133	1915	1004	397	42.1	89.7	23.3	46
			In a tank, at 80 ppm N[a]					
IR58	103	1728 (106)	779 (85)	820 (106)	60.7 (129)	69.7	16.2	40
IR28	104	2073 (119)	862 (100)	630 (99)	46.8 (97)	80.3	20.1	36
IR25388-7-3-1	105	1936	779	555	48.8	71.7	19.5	35
IR56	110	1771 (103)	699 (77)	620 (96)	43.4 (94)	73.0	19.3	35
IR64	113	1877 (109)	619 (69)	504 (95)	38.6 (105)	61.[illegible]	23.0	29
IR54752A/IR29723-143-3-2-1	122	1845	295	5[illegible]	40.7	23.7	22.2	14
Guichao 2	113	2121	857	575	55.0	70.0	19.5	35
IR8	127	1960	377	460	29.1	52.8	21.5	17
IR29723-143-3-2-1	129	2194 (115)	569 (57)	580 (146)	47.5 (117)	53.5	19.6	23
IR44	133	1825 (99)	293 (36)	520 (92)	30.8 (73)	47.6	17.5	14

[a]Figures in parentheses indicate values relative to those of the field-grown materials.

Table 25. Range and mean of 10 panicle characters in 3 types of rice varieties. IRRI, 1987.

Character	Range			Mean		
	IR varieties	*O. glaberrima*	Upland rices	IR varieties	*O. glaberrima*	Upland rices
Primary branches (no.) (PB)	7.0 - 16.3	8.0 - 16.3	7.7 - 14.7	10.35 ± 0.74	13.12 ± 0.69	12.13 ± 0.51
Spikelets on PB (no.)	37.0 -124.0	51.0 - 139.0	38.3 - 91.3	60.22 ± 7.53	99.31 ± 6.90	70.58 ± 3.68
Secondary branches (no.) (SB)	18.8 - 34.8	2.2 - 27.7	5.7 - 39.0	26.74 ± 1.97	12.84 ± 1.93	26.98 ± 2.82
Spikelets on SB (no.)	60.3 -117.0	4.7 - 59.7	2.3 -130.7	87.31 ± 6.42	33.16 ± 5.61	84.97 ± 9.64
Total spikelets (no.)	100 -241	91 -199	51.0 -208.0	147.50 ± 12.23	132.37 ± 7.18	155.53 ± 12.74
Inner vascular bundles (no.)	14.0 - 25.5	13.7 - 18.7	9.0 - 22.7	19.93 ± 1.11	15.82 ± 0.39	15.97 ± 0.87
Outer vascular bundles (no.)	16.8 - 30.5	17.3 - 36.0	13.7 - 34.5	21.00 ± 1.16	34.11 ± 9.31	24.79 ± 1.68
Culm diameter (mm)	2.08- 3.17	1.64- 2.63	1.26- 3.04	2.33 ± 0.11	2.04 ± 0.06	2.40 ± 0.13
Air space (mm)	1.46- 2.38	0.81- 1.83	0.56- 2.07	1.73 ± 0.09	1.25 ± 0.06	1.53 ± 0.11
Culm thickness (mm)	0.26- 0.39	0.29- 0.54	0.31- 0.57	0.30 ± 0.01	0.40 ± 0.01	0.43 ± 0.02

Primary branch number correlated significantly with number of primary branch spikelets, total spikelets, and inner vascular bundles. In the upland lines, culm thickness correlated significantly with all characters studied; thus, it might be a useful measure of overall desirable traits.

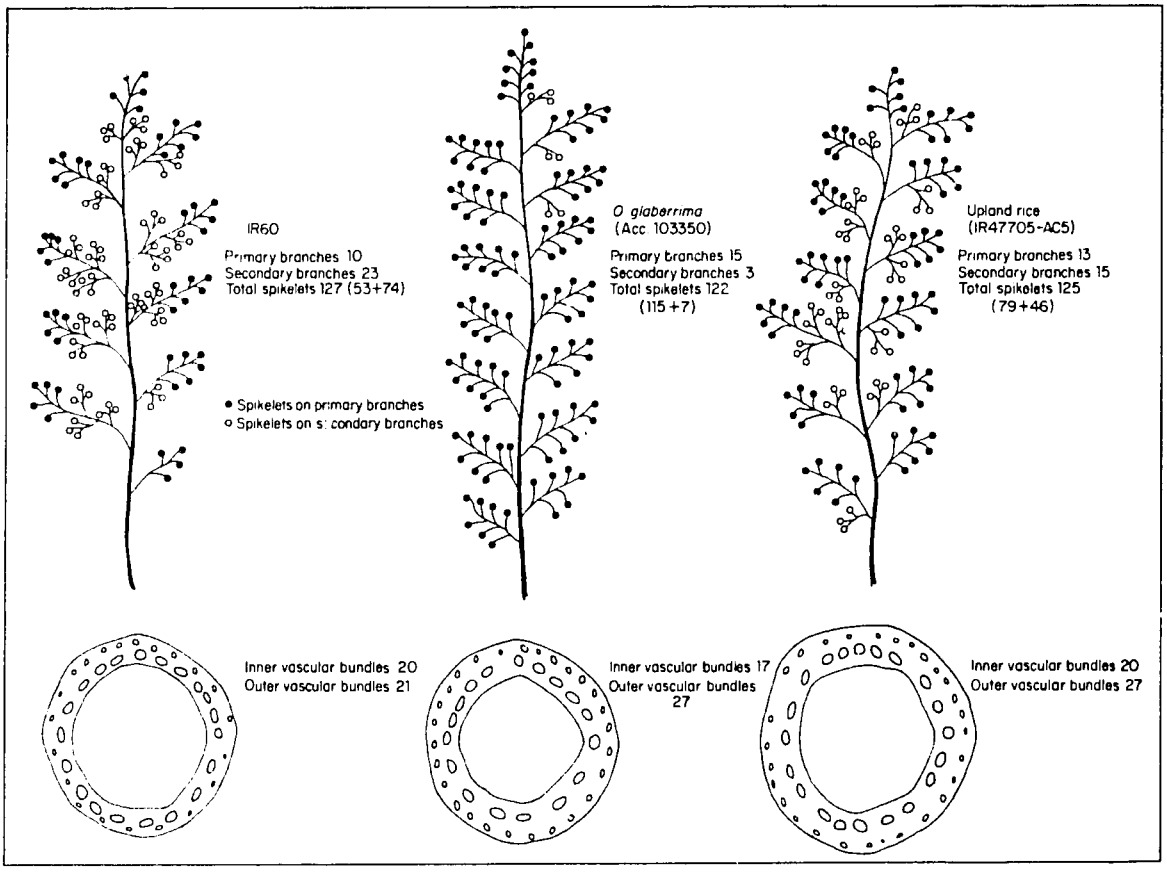
Figure 29 shows three distinct panicle types. *O. glaberrima* (Acc. 103350) has the highest number of primary branches and only three secondary branches. IR47705-AC5 has thicker culm and more vascular bundles than *O. glaberrima* and IR60. In future breeding programs, useful traits of the *glaberrimas* and upland lines could be transferred into the IR varieties to increase the number of HD grains.

Heterosis in rice panicle branches, spikelets, and vascular bundles (*Plant Physiology*). To increase primary branches, spikelets on primary branches, and vascular bundles, the heritability of these characters is needed. This study used seven crosses of HD grain parents and two low-density (LD) grain parents to assess heterosis for nine quantitative characters (Table 26).

The estimates of overall degree and direction of heterosis were significantly positive for secondary branches, spikelets on secondary branches, and inner vascular bundles, indicating dominance of higher values. Heterosis was negative for spikelets on tertiary branches and outer vascular bundles where genes of lower count dominated. Low or nonsignificant heterosis for primary and tertiary branches, spikelets on primary branches, and total spikelets may be the result of little genetic interaction or differences among parents.

The values for individual F_1 families, however, differed from the overall estimates for different characters in showing positive, negative, or no heterosis (Table 26). The F_1 means conspicuously deviated from the respective parental and midparental values, indicating nonadditive gene action in expression observed for most characters.

Substantial heterosis in the desirable direction was observed in characters like numbers of primary branches, spikelets on primary branches, and inner and outer vascular bundles. Three crosses among HD grain parents and one cross between HD and LD grain parents (P2/P9) exhibited positive heterosis for primary branches. The cross P2/P9 showed positive heterosis for all characters. Posi-



29. Panicle characteristics in 3 types of rices. IRRI, 1987.

tive heterosis for total spikelets was observed in all the crosses except P3/P8. Number of inner vascular bundles exhibited positive heterosis in most crosses, but outer vascular bundles did not.

Because panicles with more primary branches and spikelets on primary branches usually have more HD grains, substantial heterosis for these characters may lead to higher yield. The three

Table 26. Percentage of heterosis of 9 quantitative characters. IRRI, 1987.

Character	Cross or type[a]							LSD (0.05)
	P1/P2 (HD/HD)	P3/P4 (HD/HD)	P5/P2 (HD/HD)	P2/P6 (HD/HD)	P4/P7 (HD/HD)	P3/P8 (HD/LD)	P2/P9 (HD/LD)	
Primary branch (PB)	5.21	1.69	9.42	-1.38	-7.23	-9.31	3.35	1.82
Secondary branch (SB)	0	9.77	4.75	6.00	23.63	-5.93	35.34	6.75
Tertiary branch (TB)	-39.39	-80.95	-100.00	11.11	80.00	12.00	150.00	27.00
Spikelets on PB	13.64	1.31	15.36	-7.49	-18.48	-2.38	4.25	3.66
Spikelets on SB	0.67	11.78	4.89	15.63	32.85	-2.33	28.69	6.83
Spikelets on TB	-56.96	-88.73	-100.00	33.33	62.50	-18.99	122.00	19.70
Total spikelets	3.50	5.90	7.92	6.09	11.82	-2.67	19.51	3.12
Inner vascular bundles	4.86	2.15	1.07	1.73	-1.39	-0.44	9.33	1.68
Outer vascular bundles	1.79	-4.81	-11.34	-1.37	-11.24	-1.38	3.27	2.38

[a]P1 = IR32307-75-1-3-1, P2 = IR30, P3 = IR34615-75-1-1, P4 = IR29725-135-2-2-3, P5 = IR29692-117-1-2-2, P6 = IR35337-61-2-2-2, P7 = IR28211-43-1-1-1-2, P8 = IR32419-102-3-2-3, P9 = IR32385-37-3-3-3. HD = high density, LD = low density.

crosses with IR30 (P2) as a common parent have positive heterosis for the above characters and would be of value for increasing yield.

GENETICS OF PHOTOPERIOD SENSITIVITY

Plant Breeding and Plant Physiology Departments

Photoperiod sensitivity is an important breeding objective for rainfed areas where rainfall distribution is erratic or bimodal. Strongly sensitive cultivars will flower around the same date regardless of seeding and transplanting dates. The genetics of photoperiod sensitivity has been studied extensively, but much less is known about genetic control of critical daylength, another important varietal characteristic. This study on the inheritance of flowering behavior used five parents with different characteristics.

Basic vegetative phase. The basic vegetative phase (BVP) was measured as the number of days from seeding to PI under a 10-h photoperiod. BVP was shortest (10 d) in the weakly sensitive cultivar Nam Sagui 19 (Table 27). Genes for short BVP were partially to completely dominant. Although no cross showed a good fit to a simple genetic model, BVP was controlled by two to three genes of major effect in the parents studied. In segregating generations, short BVP tended to be associated with photoperiod sensitivity, but short BVP/insensitive and long BVP/sensitive types were also observed.

Photoperiod sensitivity. Photoperiod sensitivity was measured as the regression of days to flowering on seeding date for the parents. While the cultivars Sac Nau and Puang Rai 2 were clearly strongly sensitive, Nam Sagui 19 was less strongly so, and IR26760-27-1-3-2-1 was weakly sensitive (Table 27). In segregating populations, sensitivity was measured by planting early in the season (April). Usually, sensitive plants by their late flowering (October) could be separated from insensitive plants. In crosses with the early insensitive parent (IR58), sensitivity appeared controlled by one or two recessive genes, but exact segregation ratios were difficult to detect. With IR26760-27-1-3-2-1 as the "insensitive" parent, a single dominant gene controlled sensitivity in Sac Nau and Puang Rai 2 (Table 28). In the cross IR26760-27-1-3-2-1/Nam Sagui 19, two complementary dominant genes controlled sensitivity. With both dominant genes present, the plants were strongly sensitive; with only one present, the plants flowered earlier (i.e., were weakly sensitive). The cross PuangRai 2/Sac Nau did not show segregation, indicating that the same genes control sensitivity in these parents.

Critical daylength. The critical daylength was measured by subjecting the plants to different photoperiods. In the F_2 of the crosses Puang Rai 2/Nam Sagui 19 and Sac Nau/Nam Sagui 19, five tillers were separated from each plant, and the resulting clones were treated under five photoperiods. Both populations showed a good fit to the ratio 3:1 (short:long critical daylength), indicating that a single gene controlled critical daylength in the crosses (Table 29). Plants with a short critical daylength did not flower under the long-day treatment (14 h). Plants with a "long" critical daylength, including the parent Nam Sagui 19, flowered even under the longest daylength treatment used (14 h), although their heading was greatly delayed (Table 29). It is not clear if they

Table 27. Characteristics of the parents used in the genetic study of photoperiod sensitivity. IRRI, 1987.

Parent	Origin	Duration[a] (d)	BVP[b]	PSP[c]	Regression coefficient[d]
IR58	IRRI	101	29	16	0.07
IR26760-27-1-3-2-1	IRRI	145	45	75	−0.12
Nam Sagui 19	Thailand	122	10	114	−0.26
Puang Rai 2	Thailand	193	55	>135	−0.64
Sac Nau	Vietnam	190	17	>141	−0.57

[a]Measured from seeding on 18 Jun at IRRI. [b]The basic vegetative phase (BVP) was measured as the days from seeding to panicle initiation under a 10-h photoperiod. [c]The photoperiod-sensitive phase (PSP) was measured as the difference in days to flower under a 14- and 10-h photoperiod. [d]The regression of flowering duration on seeding dates was calculated for 11 dates of seeding (14 May-17 Oct) at IRRI. All coefficients were significant at the 1% level.

Table 28. Distribution of days to flowering (seeded 6 Apr) for parents, F_1, and F_2, and χ^2 analysis for goodness of fit to a single gene model. IRRI, 1987.

Cross[a]		Distribution of days to flowering																	F_2 range	F_2 ratio	χ^2
		90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250			
IR26760-27/NS19	P_1			13	1																
	P_2						5	10											86-150	7	1.017
	F_1									11	1								151-210	9	0.30<P<0.50
	F_2	24	31	42	29	31	15	9	12	58	55	36	26	2							
PR2/IR26760-27	P_1														1	6					
	P_2			11	3														112-170	1	2.546
	F_1													10	1				171-243	3	0.10<P<0.20
	F_2			2	14	23	19	19	18	7	0	11	34	106	84	36	1				
SN/IR26760-27	P_1													2	0	9					
	P_2			1	11														79-170	1	1.293
	F_1											1	10						171-227		0.20<P<0.30
	F_2				6	22	36	19	11	2	7	33	105	74	29	6					
PR2/NS19	P_1													1							
	P_2						1	14											138-174	1	2.524
	F_1											6	6						175-225	3	0.10<P<0.20
	F_2						8	19	29	23	38	74	102	49	29						
NS19/IR26760-27	P_1														1	5					
	P_2						5	6											129-174	1	0.015
	F_1											9							175-228	3	0.90<P<0.95
	F_2					1	3	26	39	22	28	89	92	39	15	4					
PR2/SN	P_1															8					
	P_2														8	4					
	F_1													1	6	4					
	F_2														64	185	17	3			

[a]NS = Nam Sagui 19, PR2 = Puang Rai 2, SN = Sac Nau.

Table 29. Distribution of days to flowering in F_2 populations of 2 crosses under 5 photoperiod treatments. IRRI, 19 Feb-16 Sep 1987.

Cross	Photoperiod treatment (h)	F_2 days to flowering													$\bar{X}$
		81-90	91-100	101-110	111-120	121-130	131-140	141-150	151-160	161-170	171-180	181-190	191-200	> 200	
PR2/NS19	11.5	1	45	70	51	26	8	10	0	1	0	0	0	0	111
	12	13	45	51	54	19	18	8	2	0	0	0	0	0	110
	12.5	0	0	4	22	15	9	4	6	14	28	29	20	66	160
	13	0	0	0	2	4	19	7	13	12	3	0	0	157	149
	14	0	0	0	0	0	0	3	11	23	8	5	5	162	168
SN/NS19	11.5	0	23	89	40	19	7	5	1	7	4	8	2	0	118
	12	6	69	63	25	8	9	5	2	3	6	1	5	0	113
	12.5	0	8	20	14	10	0	0	4	10	18	19	21	90	152
	13	0	0	4	13	11	10	13	0	0	1	0	0	162	129
	14	0	0	0	0	0	1	13	13	19	3	3	0	162	159

have a critical daylength longer than 14 h, or if there is no critical daylength. Heading in Nam Sagui 19 was delayed more than 50 d under the 14-h photoperiod compared with the 11.5-h photoperiod.

To determine if the gene controlling critical daylength was the same as that controlling photoperiod sensitivity, segregation for the isozyme gene *Pgi-2* was measured. This gene is closely linked to the major photoperiod sensitivity gene *Se-1*. In the cross IR26760-27-1-3-2-1/Nam Sagui 19, allele 1 of *Pgi-2* in Nam Sagui 19 was strongly associated with the sensitive recombinants, indicating that sensitivity in Nam Sagui 19 is conditioned by the *Se-1*. Likewise, in the cross Puang Rai 2/IR26760-27-1-3-2-1, *Pgi-2* allele 2 in Puang Rai 2 was strongly associated with the photoperiod-sensitive F_2 plants. In the cross Sac Nau/Nam Sagui 19, however, the alleles for *Pgi-2* segregated independently from the gene controlling critical daylength, indicating this gene is independent of the photoperiod-sensitive gene. To study the genetics of critical daylength in more detail, additional parents with a range of critical daylengths should be used.

Genetic evaluation and utilization (GEU) program

Grain quality and nutritional value

Cereal Chemistry, Plant Breeding, Agricultural Economics, and Statistics Departments, and Rice Farming Systems Program

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BREEDING PROGRAM AND EVALUATION

Cereal Chemistry, Plant Breeding, and Statistics Departments

Elite irrigated lines (*Plant Breeding and Cereal Chemistry*). Among five outstanding elite lines, only IR32453-20-3 had low protein content (Table 1). All had high amylose content (AC) except IR31868-64-2 with intermediate AC. Gelatinization temperature (GT) based on alkali spreading value was either low or intermediate, but gel consistency (GC) was hard for all samples except IR31868-64-2 (medium). The absence of a negative correlation between alkali spreading value and GC has been reported in recent years. IR31868-64-2 had the softest cooked rice, probably because of its lowest AC. IR32453-20-3 did not have the hardest cooked rice, despite its high Amylograph consistency, probably because of its low protein content. On the basis of cooked rice hardness and Amylograph consistency, intermediate-GT, high-AC rices IR28228-12-3 and IR32429-47-3 were not hard-textured despite their hard GC.

The 1987 dry season (DS) intermediate- and low-AC elite entries had 15 samples with >10% protein, probably since they were from the previous wet season (WS) crop. Some high-AC entries were classified as intermediate-AC, probably because of high protein content. High protein would also explain the high cooked rice hardness and Amylograph consistency of a few samples with ≥23% AC. With the 1987 WS entries, protein contents were average and, thus, cooked rice hardness and Amylograph consistency showed a narrower range (Table 1). With such a homogeneous set of samples, AC was no longer correlated with cooked rice hardness and Amylograph consistency, unlike in earlier crops. AC was significantly correlated only with GC ($r = -0.71^{**}$, $n = 14$). Cooked rice hardness and Amylograph consistency continued to be positively correlated, but GC and Amylograph consistency values were correlated significantly only in the DS samples. The low-GT samples were not necessarily the hardest cooked rices, although alkali spreading value and cooked rice hardness correlated significantly in both sets of samples ($r = 0.47^{*}$, $n = 27$; $r = 0.54^{*}$, $n = 14$). These results demonstrate the inadequacy of present methods to discriminate among rices of the same amylose type and the need for more basic studies on the thermomechanical properties of rice during cooking.

A waxy line, IR39368-31-1-2, was consumer-panel tested at the College of Human Ecology, University of the Philippines at Los Baños (UPLB), against traditional variety Malagkit Sungsong, both as raw rice and as *suman sa antala* (waxy rice-coconut milk cake). IR39368-31-1-2 was considered inferior to Malagkit Sungsong as raw rice and *suman sa antala*, despite the closeness of their starch properties. Malagkit Sungsong has shorter, aromatic grain.

Protein screening (*Cereal Chemistry, Plant Breeding, and Statistics*). For both the 1986 WS and 1987 DS replicated yield trial (RYT) crops, brown rice protein (BRP) and growth duration continued to be negatively correlated (Table 2).

Table 1. Physicochemical properties of milled rice of elite irrigated lines, IRRI, 1987.

Elite line	Protein (%)	Amylose (%)	Alkali spreading value	Gel consistency (mm)	Cooked rice Instron hardness (kg/7 cm²)	Amylograph consistency (BU)[a]
IR28224-3-2	8.8	26.0	6.9	31	9.8	245
IR28228-12-3	8.0	25.0	5.1	32	9.0	325
IR31868-64-2	8.0	22.6	3.8	53	7.8	200
IR32429-47-3	9.0	25.0	4.0	30	9.2	345
IR32453-20-3	6.4	26.0	7.0	30	8.7	630
		Intermediate-low amylose content entries[b]				
1987 DS	6-13	17-24	3-7	28-77	7-12	90-640
1987 WS	6- 9	19-24	3-7	32-75	6- 9	120-275

[a]BU = Brabender units. [b]From previous season; *n* = 27 in 1987 DS and 14 in 1987 WS.

Simple correlation coefficients between growth duration and BRP determined on the RYT entries for the last 10 yr showed consistent, significant, negative correlations between growth duration and BRP. Correlations involving grain yield were less consistent. Thus, breeding for earliness will not sacrifice protein content in rice grain. However, entries having higher grain yield and BRP than the check varieties IR36 and IR42 usually did not maintain their BRP rating in subsequent crops (Table 3). Elite lines will continue to be analyzed for milled rice protein content. Screening for BRP in the RYT may be discontinued until variability can be minimized.

Table 2. Simple correlation coefficients between rough rice yield, brown rice protein (BRP), and growth duration in replicated yield trials. IRRI, 1977-87.

Crop season	Entries (no.)	Simple correlation coefficients between		
		Yield vs BRP	Duration vs BRP	Yield vs duration
1987 DS	370	−0.02	−0.58**	−0.18**
1986 WS	347	−0.05	−0.61**	−0.43**
1986 DS	370	−0.34**	−0.39**	0.24**
1985 WS	370	−0.03	−0.57**	−0.22**
1985 DS	367	−0.12*	−0.49**	0.15**
1984 WS	416	−0.30**	−0.39**	−0.26**
1984 DS	507	−0.06	−0.36**	0.03
1983 WS	508	−0.19**	−0.39**	−0.39**
1983 DS	462	−0.33**	−0.58**	0.48**
1982 WS	456	−0.44**	−0.74**	0.36**
1982 DS	347	−0.10	−0.77**	0.01
1981 WS	391	0.08	−0.59**	−0.29**
1980 WS	555	−0.37**	−0.48**	−0.05
1980 DS	554	−0.43**	−0.82**	0.42**
1979 WS	554	−0.31**	−0.50**	−0.09*
1979 DS	555	0.33**	−0.32**	0.13*
1978 DS	363	0.23**	−0.45**	0.07
1977 WS	278	−0.03	−0.45**	0.16*
1977 DS	324	0.02	−0.40**	0.11*

Parents and lines—nonirrigated rice (*Plant Breeding and Cereal Chemistry*). *Rainfed lowland rice*. The varieties and lines were mainly high AC and varied in protein content (Table 4). Many of the high AC parents and lines had intermediate GT, and the rest had low GT. GC ranged from soft to hard. Length-to-width ratio (LWR) was variable.

Upland rice. Upland parents and lines had variable LWRs but were mainly intermediate to low AC (Table 4). All were nonpigmented except Red Dinorado. All parents had intermediate GT, but two lines had low GT. GC was mainly medium. Protein content was also very variable.

Thirteen traditional Philippine upland varieties and one from Sabah (Kalopak) of good eating quality generally had medium to long grains, intermediate AC, intermediate GT, and medium GC. Only one had a red pericarp. Azucena,

Table 3. BRP and rough rice yield of 4 selected replicated yield trial entries that were superior to check varieties IR36 and IR42 in one season.[a] IRRI, 1985 DS-1987 WS.

Variety or line	1985				1986				1987			
	DS		WS		DS		WS		DS		WS	
	BRP (%)	Yield (t/ha)	BRP (%)	Yield (t/ha)	BRP (%)	Yield (t/ha)	BRP (%)	Yield (t/ha)	BRP (%)	Yield (t/ha)	BRP (%)	Yield (t/ha)
IR28224-3-2-3-2	8.0	7.0	9.4	4.4	7.7	7.4	11.4	2.5	6.7	6.4	7.9	3.4
IR36	9.0	6.9	8.5	5.3	10.5	6.8	10.7	3.2	7.6	6.3	10.4	2.0
IR42	7.7	7.1	7.8	4.9	7.2	6.5	10.8	2.3	7.8	6.6	9.0	3.0
IR28228-119-2-3-1-1	9.6	7.0	7.9	4.0	7.1	6.9	10.0	2.0	7.6	5.3	9.5	3.7
IR36	8.7	6.3	8.5	5.3	10.5	6.8	10.7	3.2	7.7	4.8	11.2	3.0
IR42	8.2	7.0	7.8	4.9	7.2	6.5	10.8	2.3	7.2	6.2	9.2	3.1
IR35366-90-3-2-1-2	7.3	6.6	7.2	5.4	6.6	6.5	8.5	4.5	10.2	7.0	8.8	4.6
IR36	8.1	6.9	8.3	4.8	8.3	6.8	10.4	3.6	8.7	5.7	10.4	2.0
IR42	8.2	7.0	8.5	4.8	8.0	6.1	10.6	1.9	9.1	6.5	9.0	3.0
IR42015-83-3-3-2-3	–	–	9.6	5.0	8.8	6.9	11.7	4.2	9.1	6.6		4.4
IR36	–	–	8.2	5.0	8.6	7.1	11.6	2.9	7.5	5.2		1.9
IR42	–	–	7.6	4.9	7.6	6.0	11.1	1.5	8.4	7.0		1.8

[a]Underlined data for each line.

Table 4. Milled rice properties of nonirrigated varieties and lines. IRRI, 1987.

Culture type (mainly 1986 WS)	Type	Samples (no.)	Length-to-width ratio	Amylose type[a]				Protein (%)
				Wx	L	I	H	
Rainfed lowland	Varieties	10	2.1-3.2	0	1	0	9	8.3-10.2
	Lines	6	2.5-3.5	0	1	1	4	7.9-10.4
Upland	Varieties	8	1.7-3.3	0	3	5	0	6.8-10.4
	Lines	10	1.8-3.0	0	1	8	1	7.1- 9.6
Upland (Philippines/Sabah)	Varieties	14	2.2-3.0	0	2	10	2	–
Deepwater (Thailand)	Varieties	5	3.0-3.5	0	0	0	5	3.7- 6.5
Tidal swamp and saline-resistant	Varieties	21	2.1-4.1	2	1	0	18	6.7-11.9
Tidal and mangrove swamp (WARDA)	Varieties	27	2.1-3.2	0	0	0	27	6.2- 9.9

[a]Wx = waxy (0-2%), L = low (10-20%), I = intermediate (20-25%), H = high (>25%).

Kalopak, and Manong Balay were aromatic. Wagwag from Cotabato had intermediate AC, in contrast to the high AC of other Wagwag samples.

Deepwater rice. Five Thai deepwater rices showed typical long grains and all had high AC (Table 4), intermediate or low GT, and variable GC. Their protein content was the lowest of the samples analyzed. Head rice on milling (22-43%) was lower than that of irrigated rice. Grains were chalky, particularly those of RD19. Leb Mue Nahng 111 grain was aromatic.

Tidal swamp rice. Tidal swamp and saline-resistant rices differed in LWR but were mainly high AC (Table 4) and intermediate GT. The two waxy rices had low GT. The low-AC aromatic variety was Khao Dawk Mali 105, which is also classified as rainfed lowland. The high-AC rices had mainly intermediate GT and hard GC. Protein contents were variable.

Tidal and mangrove swamp rices from the West Africa Rice Development Association (WARDA) had grain properties similar to those of Asian tidal swamp rices (Table 4). Most of the samples had high AC, intermediate GT, and hard to medium GC. Protein content also showed a wide range.

Screening for stable head rice yield (*Cereal Chemistry and Plant Breeding*). The screening method investigated and adapted was to determine, with the aid of a fiber optics illuminator, the number of cracked brown rice grains when a randomly selected batch of 50 grains was soaked in water for 0, 5, 10, or 15 min. Rough rice was correspondingly stressed by soaking for 3 h in water, then air-dried; 5 g brown rice was milled in the Kett Pearlest mill to estimate head rice yield. Waxy rices could not be observed for cracking of brown rice because of their opaque endosperm. Shade-dried samples were preferred for the brown rice test because cracked grains were minimized. The remaining whole grains in samples with many cracked grains would have been more crack-resistant than the total sample and, therefore, may not have been representative.

Rough rice from the 1987 DS crop was shade-dried to 14-16% moisture to minimize cracking of starting materials. Even under those conditions, IR44 showed head rice of only 19-23%, and IR58 and IR60 had the highest head rice. Evidently, ripening conditions in 1987 DS elicited more grain moisture stress than earlier trials (46-72% head rice in 1985 WS and 40-71% in 1986 DS). Twenty-eight nonwaxy IR rices were compared for head rice before and after 3 h of soaking rough rice in water followed by milling with a Kett Pearlest mill, and for percentage of cracked grains on soaking brown rice in water at 0, 5, and 10 min (Table 5). Soaking brown rice for 5 min gave the best correlation between percentage of cracked grains in stressed brown rice and head rice of stressed rough rice ($r = 0.79^{**}$). However, head rice of unstressed grain correlated negatively with cracked brown rice grains before soaking ($r = -0.67^{**}$) and even with 5 min of soaking ($r = -0.60^{**}$). The similarity of results of rough and brown rices indicates that endosperm properties are more important than hull tightness for crack resistance. The soaking method gave more reproducible variety ranking than the 2 earlier drying methods with an infrared lamp or at 44-47 °C (Table 5).

Comparison of random grains and selected

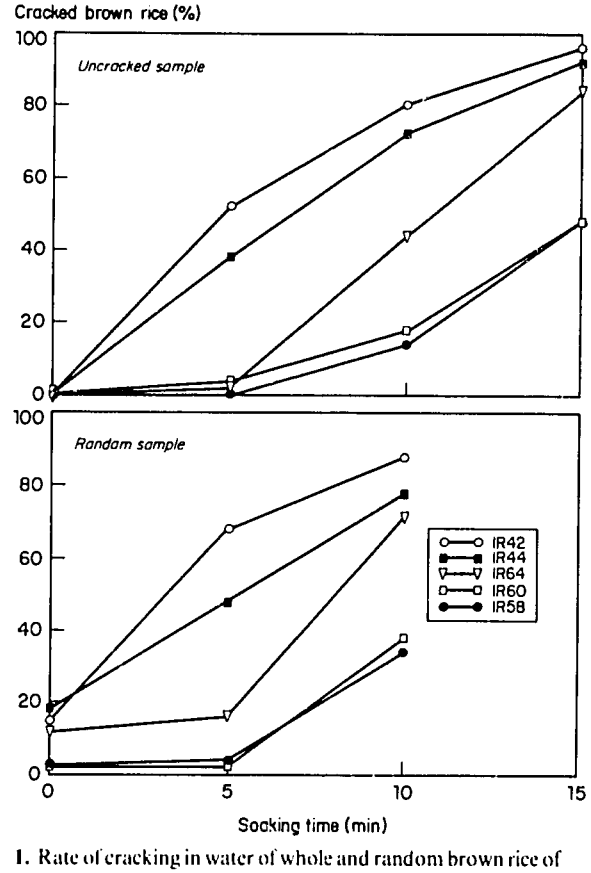
Table 5. Effects of indirect and direct methods of grain moisture adsorption stress on head rice yield of rough rice and on percentage of cracked brown rice in representative IR rices, IRRI, 1985-87.

Season	Treatment	IR42	IR44	IR36	IR64	IR58	IR60
			Head rice (%)				
1985 WS	Check (oven-dried)	67	60	52	62	67	70
	Infrared lamp drying	64	44	54	53	58	54
1986 DS	Check (oven-dried)	64	42	40	66	67	71
	Oven drying (44-47 °C)	55	39	31	60	61	69
1987 DS	Check (shade-dried)	40	23	27	54	70	68
	3 h in water	20	17	29	42	58	62
			Cracked brown rice (%)				
1987 DS	0 min soaking	30	36	16	12	2	2
	5 min soaking	68	48	16	16	4	2
	10 min soaking	88	78	24	72	34	38
			Translucency (%) of brown rice				
1987 DS		49	31	42	55	58	66

uncracked brown rices for the soaking test showed surprisingly similar varietal differentiation for unbiased and biased samples (Fig. 1). Differentiation, however, tended to be faster for random grains. Correlation coefficients between percentage of cracked grains for the 2 sets of samples showed the best correlation among values for 10-min soaking (r = 0.89**) and 5-min soaking (r = 0.81**), and for 10 min of soaking random grains and for 15 min of soaking uncracked grains (r = 0.81**) for 28 nonwaxy IR rices.

Differences in susceptibility to grain cracking under moisture adsorption stress were not simply related to starch endosperm properties. In fact, the best (IR58 and IR60) and the worst (IR44 and IR42) IR rices (Table 5) had high AC and low GT, but variable GC. In contrast, translucency of brown rice correlated with head rice yield before (r = 0.61**) and after (r = 0.47**) moisture stress and with percentage of cracked brown rice after 5 min (r = 0.42*) and 10 min (r = 0.38*) of soaking in water. Many chalky grains were thinner, and some were misshapen. Indian workers have shown that heterogeneity of endosperm in terms of chalky and translucent portions contributes to crack susceptibility.

The five 1986 Thai deepwater rices were also checked for crack resistance. When brown rice was soaked in water, Leb Mue Nahng 111 proved the most resistant and Plai Ngham the most susceptible. Selected 1986 WS samples of collected varieties grown at the Centro Internacional de Agricultura Tropical showed varietal differences in the extent



1. Rate of cracking in water of whole and random brown rice of IR rices differing in crack resistance. IRRI, 1987.

of brown rice cracking after ≥10 min of soaking. IRGA409 was the most resistant among four resistant rices, and Araure 2 and CICA8 were the most susceptible among three susceptible checks.

IR43 was the least susceptible to cracking among the susceptible checks. In studies at IRRI, only IR43 had moderate susceptibility to cracking.

Improved gel consistency test (*Cereal Chemistry*). In the standard method, variable data are obtained in GC values of samples of medium GC such as IR36. Hard values are obtained for IR36, which can be classified as medium by reducing sample weight to 85-90 mg. Cooling the gel for 25 min at 27 °C instead of in an ice-water bath differentiated the IR36 sample from IR42 in the 1986 WS pair, but not in the 1987 DS pair (Table 6). Softer values were also obtained for IR62, C4-63G, and IR64. Using larger (16 × 150 mm) tubes improved the sensitivity of differentiating hard-GC IR42 from medium-GC IR36, but could not differentiate between soft and medium GC. Instron cooked rice hardness of high-AC rices, however, showed similarly softer values for medium- and soft-GC than for hard-GC samples. Harder gels were obtained in 0.15 N KOH than in 0.2 N KOH despite the higher rice concentration. Interestingly, Akibare showed harder gels than Milyang 23, except in the larger tube using 0.15 N KOH. IR42 in 1986 WS and IR36 in 1987 DS were difficult to distinguish except also in 0.15 N KOH. The use of 145 mg flour in 3 ml 0.15 N KOH in the larger tube gave the best overall GC differentiation.

Amylose content (*Cereal Chemistry*). Recent studies have shown that colorimetric amylose assay overestimates true AC because 1) higher iodine complexing of high-AC rices is due to amylopectin-iodine complexing from the longer-chain fraction, and 2) the potato amylose standard is only about 80% pure. However, because of the widespread use of the colorimetric amylose values since the 1960s, the method should be continued but termed "apparent amylose." Using the amylose-amylopectin standard and assuming 90% starch in milled rice dry weight have resulted in values as low as 24% for some high-AC (>25%) samples. Recent studies showed that the green color obtained with iodine using acetate buffer in the standard procedure was due to excess iodine, which is readily degraded at alkaline pH and results in a blue color.

Considering our experiments over the last few years, we recommend using a simplified amylose assay, but neutralizing the alkaline milled rice suspension with acetic acid before adding iodine reagent, and using potato amylose and waxy rice (amylopectin) for the standard curve. The total starch content of milled rice should be reduced from 90% to 70% on a dry basis in the standard mixture by reducing amylopectin to conform with amylose values from the original Williams procedure. To obtain more accurate results in research

Table 6. Effect of room-temperature cooling, use of a larger tube, more gel, and 0.15 N KOH on the gel consistency readings of selected milled rice flours. IRRI, 1987.

Sample	Gel consistency (mm)				
	Standard procedure[a]	Room-temperature cooling	Room-temperature cooling and 16 × 150 mm tube	16 × 150 mm tube, room-temperature cooling	
				145 mg flour/ 3 ml 0.15 N KOH	150 mg flour/ 3 ml 0.2 N KOH
IR42, 1987 DS	27	28	14	20	36
IR42, 1986 WS	27	44	22	41	94
IR36, 1987 DS	27	41	28	54	86
IR36, 1986 WS	32	83	49	60	127
IR62	34	86	62	84	134
C4-63G	44	80	64	82	122
IR64	53	100	66	82	132
Akibare	34	32	24	91	68
Milyang 23	42	58	54	88	86
IR65	86	88	79	89	101
Malagkit Sungsong	82	94	76	96	101
LSD (5%)	5	9	12	8	5

[a]100 mg flour in 2.0 ml 0.2 N KOH in 13 × 100 mm tube, and 0.2 ml 0.025% bromthymol blue in 95% ethanol; 0.3 ml dye solution for 145-150 mg flour.

studies, samples should be preferably defatted with 95% refluxing ethanol rather than use undefatted check samples of known defatted milled rice amylose as standards.

GRAIN QUALITY AND NUTRITIONAL FACTORS

Cereal Chemistry, Agricultural Economics, and Plant Breeding Departments, and Rice Farming Systems Program

Country samples (*Cereal Chemistry*). Cooperative analysis of national samples from 6 countries was undertaken as part of the periodic assessment (every 5 yr) of their quality characteristics (Table 7). Egyptian rices showed mainly the typical short grain type except for one line. More intermediate- and high-AC lines were included, but all had low GT. Higher-AC rices tended to have harder GC and higher cooked rice hardness values.

French varieties showed a narrow AC range of 19-21%, except for Arlesienne with 25% amylose. All had low GT, and medium GC corresponded to the higher AC samples. LWR was variable. Marathon had 4.9% protein and Stirpe 136-7T 5.2%.

Philippine traditional lowland varieties were variable in starch properties but were mainly intermediate AC. Two each of the six waxy rices had the three GT types. Two had red pericarp and two others (waxy) had purple-black color. The samples also differed widely in protein content, cooked rice hardness, and LWR.

Rices from Sierra Leone were predominantly high AC, intermediate GT, and hard to medium GC. All four low AC rices had high intermediate GT. They had wide ranges of protein content, cooked rice hardness, and LWR.

Spanish rices were similar in grain properties except for the wide range in protein content. No long-grain variety was represented.

Rices from the USSR had low AC, but the 3 with lowest AC (16%) had high intermediate GT. Variety Kulon had the longest grain (5.9 mm).

Market samples (*Cereal Chemistry and Agricultural Economics*). Market samples were obtained from the Philippines and Madagascar in cooperative studies with agricultural economists on consumer demand for rice grain quality. Madagascar rices are discussed in the section on Cooperative Country Projects. The samples had 5-14% protein, and many were red pericarped and undermilled.

The Philippine samples were obtained in Nueva Ecija, Manila, Cebu, Iloilo, Davao City, and Cotabato. The DS samples obtained had predominantly high AC, followed by intermediate-AC or waxy rice, except in Iloilo, where intermediate-AC rices predominated. Waxy rices were called Malagkit or Pilit. Purple-pericarped Tapol waxy brown rice was marketed in Cebu and Mindanao; it gave Kett whiteness readings of only 7-12%. Two apparently low-AC rices with 14 and 17% AC were represented only in Iloilo and were actually a mixture of waxy and nonwaxy grains. Head rice had an overall range of 20-95% and tended to be higher for waxy rices.

Thai export rices (n = 98) were collected in 1986 for quality evaluation. Milled grain lengths were 6.3-7.3 mm and widths 2.0-2.3 mm, except for a

Table 7. Range of milled rice properties of national variety samples, IRRI, 1987.

Country	Samples (no.)	Amylose content[a]	Gelatinization temperature[b]	Gel consistency[c]	Protein (%)	Cooked rice Instron hardness (kg/7 cm²)	Length-to-width ratio
Egypt	3 varieties	L>H	L>I	S>H	6.5- 8.6	6.0- 8.5	1.7-2.0,2.7
	9 lines	L, I>H	L	S, H	6.6- 9.7	5.7-11.2	1.7-2.3,3.0
France	11 varieties	L>I	L	M, S	4.9- 7.8	5.4- 8.0	1.6-2.6
Philippines	20 varieties	I>Wx>H>L	L>I>HI	H>M>S	8.2-12.6	6.2-11.7	2.0-3.7
Sierra Leone	40 varieties	H>L, I	I>L>HI	H>M, S	5.3- 9.0	5.6-10.6	1.8-3.4
Spain	5 varieties	L	L	S	6.4- 9.0	5.5- 6.3	1.7-2.3
USSR	10 varieties	L	L>HI	S>M	5.7- 7.4	6.4- 8.4	1.5-2.2

[a]Wx = waxy (0-20%), L = low (10-20%), I = intermediate (20-25%), H = high (>25%). [b]Based on alkali spreading value: L = low (6-7), I = intermediate (4-5), HI = high-intermediate (3). [c]S = soft (61-100 mm), M = medium (41-60 mm), H = hard (27-40 mm).

few short-grain rices, which were 6.0-6.6 mm long and 2.1-2.6 mm wide. Protein content was 5.5-8.0%. Nonwaxy, nonaromatic rices were mainly intermediate- and high-AC samples, except for one sample with low AC. Aromatic rices (jasmine rice) were mainly low AC except for one high AC out of nine samples for whole grain and one each of intermediate and high AC out of seven broken samples. Waxy rices had either long or short grains, but all were still ≥6 mm long. Brown rice samples were represented. Parboiled brown rice had the lowest Kett whiteness values of 13-15%, followed by parboiled milled rice (17-25%), raw brown rice (23-24%), raw milled rice (35-46%), and waxy milled rice (46-50%).

Two milled rice samples of Thai-grown Basmati rices were assessed for grain quality. The samples had properties similar to those of Punjab-grown Basmati in terms of aroma, amylose content, grain length, and elongation during cooking. They were somewhat undermilled and had variable endosperm chalkiness, with higher GT and harder GC than Pakistani Basmati rice.

Artificial yellowing of rice grain (*Cereal Chemistry*). Additional studies were undertaken on varietal differences in yellowing of moist rough and milled rice at 60 °C using surface-sterilized grains in vials. Four-day storage resulted in increased yellow and red grains for all 6 rices at all moisture contents (12, 14, 16, 18, and 20%), but a decrease in whiteness value of brown rice occurred at 14% moisture and higher. Varietal differences in degree of yellowing were not simply related to AC and GT (Table 8). Daily sampling of IR64 rough rice showed that most of the color changes occurred within the first 2 d of treatment at 14% moisture but continued, particularly at 20% moisture. Actual grain temperatures were no higher than 64.9 °C, indicating some grain heating during incubation at 60 °C. Yellow colors of brown and milled rices were highly correlated (r = 0.91**, n = 21). Similar relative color changes were noted for stored milled rice of three varieties.

Kett whiteness values (17-24%) correlated significantly with whiteness by the Minolta Chromameter (59-66%) for brown rice ($r = 0.91$**, n = 21). Corresponding values were 31-46% and 69-76% for milled rice ($r = 0.90$**, n = 49).

Rices with similar starch properties (*Cereal Chemistry*). Three pairs of rices with similar starch properties previously assessed by American and European panels for cooked rice properties were assessed by a Filipino consumer panel at the Human Nutrition and Foods Department, College of Human Ecology, UPLB. The pairs could not be readily distinguished by current screening methods. The panel showed a preference for low-AC over intermediate-AC rices (Table 9). Low-AC Milyang 23 rated highest in both raw and cooked forms and was preferred to Akibare. Koreans prefer Akibare to Milyang 23, reflecting the preference by Filipinos for a less sticky rice than the japonica variety Akibare. Milyang 23 is an indica/japonica rice. IR64 was whiter than C4-63G and was preferred to C4-63G despite its higher AC. In an earlier panel evaluation in Batangas, Philippines, consumers also preferred low-AC rices to C4-63G. Panelists again preferred the traditional aromatic variety Malagkit Sungsong to IR waxy rices, particularly as *suman sa antala*. Malagkit Sungsong has a

Table 8. Changes in Chromameter white (L), yellow (a), and red (b) values of brown rice from rough rices stored at 60 °C at 14% moisture for 4 d. IRRI, 1987 WS.

Variety	Milled rice		White (L)		Yellow (a)		Red (b)	
	AC	GT	Check	Stored	Check	Stored	Check	Stored
IR43	17	L	59.5	57.1	17.3	18.3	1.9	2.9
IR48	24	L	58.9	58.0	16.2	18.0	0.5	1.8
IR64	23	I	63.2	61.3	16.7	18.0	−1.2	1.7
IR42	26	L	58.7	58.2	17.2	19.3	1.8	2.8
IR32[a]	26	L	59.7	57.5	[illegible]	17.7	2.1	2.7
IR60	27	I	59.0	57.7	17.5	19.0	2.2	3.6
LSD (5%)				0.3		0.1		0.06

[a]GT was atypical of IR32.

Table 9. Physicochemical properties of milled rice of 3 pairs of varieties with similar starch properties and of IR29. College of Human Ecology, UPLB-IRRI, 1986-87.

Sample	Length-to-width ratio	Apparent amylose content (%)	Alkali spreading value	Gel consistency (mm)	Cooked rice		Mean panel score[a]	
					Hardness (kg)	Stickiness (g/cm)	Raw	Cooked
			Nonwaxy					
Akibare	1.7	19.2	7.0	34	6.2	49	-0.32 b	-0.10 b
Milyang 23	2.4	19.6	7.0	42	6.0	45	0.40 a	0.46 a
C4-63G	3.2	20.6	3.0	44	7.3	20	-0.27 b	-0.53 c
IR64	3.3	23.2	3.0	53	6.7	18	0.19 a	0.17 ab
			Waxy					
Malagkit Sungsong	1.7	1.1	6.2	82	3.0	38	0.28 a	0.54 a
IR65	3.1	1.7	6.8	86	4.4	70	0.14 a	-0.31 b
IR29	3.1	2.0	7.0	99	3.0	74	-0.42 b	-0.23 b
LSD (5%)					0.4	7		

[a]By 30 Filipino consumer panelists. Means were calculated based on 1 = 1.03, 2 = 0.30, 3 = -0.30, and 4 = -1.03 for nonwaxy set of 4 samples and 1 = 0.85, 2 = 0, and 3 = -0.85 for waxy set of 3 samples. Means in the same column and rice type followed by the same letter are not significantly different at the 5% level by DMRT.

shorter, bolder grain, is aromatic, and results in a tacky *suman sa antala*. The results verified the inadequacy of present screening methods to detect quality differences among rices of similar starch properties.

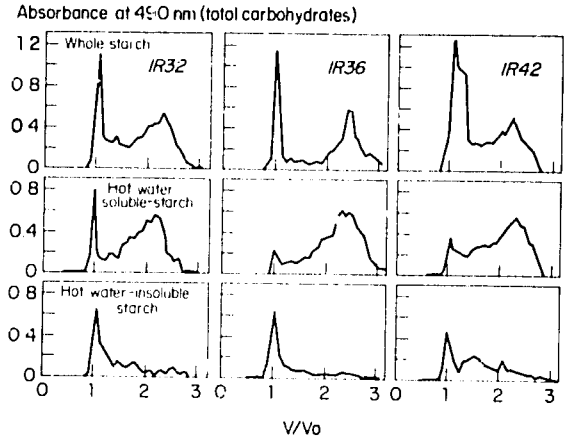
Rice products (*Cereal Chemistry*). *Parboiled rice*. In 12 rices parboiled for 30 min at 100 °C and for 10 min at 120 and 127 °C, apparent AC was the major factor influencing properties such as brown rice bending hardness, head rice yield, equilibrium water content, GC, gel viscosity, and cooked rice hardness and stickiness. GT was an important factor only in rices parboiled at 100 °C, probably because it affected the parboiling rate at that temperature. Differences in degree of parboiling because of differences in GT resulted in different relationships of parboiled rice properties to raw rice quality factors on samples parboiled at 100, 120, and 127 °C. Amylograph viscosity decreased with increasing severity of parboiling. Thus, raw rice quality factors, particularly apparent AC, may be used to index parboiled rice quality in breeding programs.

The GC of brown and milled rice in 0.2 N KOH was confirmed to soften on parboiling. Differences in gel viscosity were present even after defatting or dispersion in 90% dimethyl sulfoxide, suggesting that starch decomposition rather than undispersed starch fraction (amylose-lipid complex or retrograded starch) was the cause of reduced gel viscosity.

Undigested starch in tapuy fermentation. In earlier studies, the starch content of residual mash from *tapuy* fermentation was 1.4-1.9% in waxy rice, 4.2-18.6% in low-AC rice, and 30.5-38.2% in intermediate- and high-AC rice. AC in dry residual mash also increased with AC of milled rice (r = 0.88**, n = 10) and corresponded to 58-92% of mash starch content (mean 73%). Results confirmed that amylopectin is more digestible or fermentable than amylose during *tapuy* fermentation from boiled rice.

Starch studies (*Cereal Chemistry*). Leaching out of starch during cooking was studied on purified rice starch granules differing in AC and GT. Results confirmed that amylose rather than amylopectin was preferentially extracted during cooking. Sepharose CL-2B fractionation of whole starch, and hot-water-soluble and insoluble fractions of high-AC rice starches differing in GC confirmed this observation (Fig. 2). Amylopectin (V/Vo = 1) eluted ahead of amylose (V/Vo = 2-3) on gel filtration (where Vo = void volume and V = sample elution volume). Hard-GC IR42 had a major V/Vo 1.5 peak in the water-soluble fraction. All fractions stained blue with iodine, with amylopectin sometimes giving a purplish blue color.

Protein studies (*Cereal Chemistry*). *Variety identification*. The applicability of reversed-phase high performance liquid chromatography (HPLC) of brown rice prolamins developed on US rices for variety identification was studied on milled rice

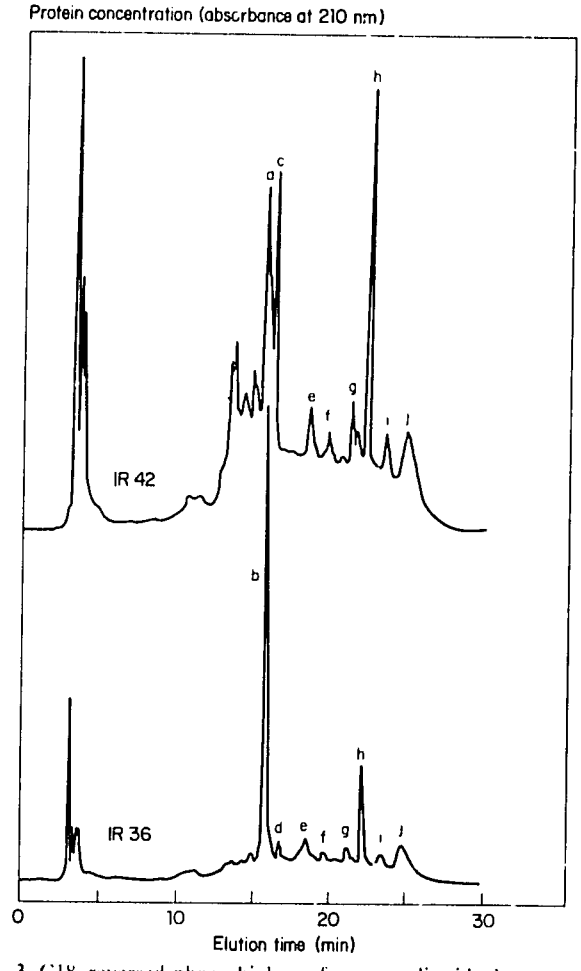


2. Sepharose CL-2B gel filtration elution patterns of whole starch and hot-water soluble and insoluble fractions of purified starch granules of high-AC rices with soft (IR32), medium (IR36), and hard (IR42) gel consistency. IRRI, 1987.

samples of IR2071 sister line varieties IR36 and IR42, in cooperation with chemists at the United States Department of Agriculture (USDA) U.S. Grain Marketing Research Laboratory, Manhattan, Kansas. IR36 and IR42 HPLC patterns (Fig. 3) were consistently different in samples from three locations in the Philippines in peaks a-d. The method, however, cannot be used for classifying IR varieties into groups with similar genetic backgrounds as was done earlier for US rices.

Exploratory studies were also undertaken by chemists at the USDA Northern Regional Research Center, Peoria, Illinois, on reversed-phase HPLC of sodium dodecyl sulfate-thiol extracts of whole protein of milled rice flour from Beaumont, Texas, and IRRI for variety identification. Most varieties can be identified by reversed-phase HPLC, but problems requiring prior solution were changes in chromatogram pattern 1) during storage of protein extracts for a few days, and 2) by defatting with 1-butanol. Rice proteins were unusually more difficult than wheat proteins to fractionate by reversed-phase HPLC.

Propanol as prolamin extractant. The solvent 55% 1-propanol had been reported to be a better extractant of prolamin (alcohol-soluble protein) than 70% ethanol. Confirmation on IR36 and IR42 brown and milled rices showed 5-6% prolamin in total protein using 55% 1-propanol instead of 3% using 70% ethanol by direct extraction from the grain flour. Sodium dodecyl



3. C18 reversed-phase high performance liquid chromatography patterns of 70%-ethanol prolamin extract of IR42 and IR36 milled rices. U.S. Grain Marketing Research Laboratory, Manhattan, Kansas, and IRRI, 1987. Letters refer to band names.

sulfate-polyacrylamide gel electrophoresis showed mainly the molecular weight 16,000 subunit of prolamin and a reduction of this contaminant subunit in glutelin.

Thiamine and riboflavin in brown rice (*Cereal Chemistry and Plant Breeding*). IR brown rices from 1987 DS and five pigmented traditional Philippine lowland rices from 1986 WS were analyzed for thiamine (vitamin B_1) and riboflavin (vitamin B_2) (Table 10). IR varieties overlapped in thiamine content with pigmented rices but had lower riboflavin levels than colored rices, particularly purple rices. IR8 brown rice had the highest thiamine content, and IR56 brown rice had the highest riboflavin level. Vitamin levels were not

Table 10. Range[a] of BRP, and thiamine and riboflavin content of brown rice of 30 IR rices and 5 traditional Philippine lowland varieties. IRRI, 1987.

Brown rice	Pericarp color	Crop	BRP (%)	Brown rice	
				Thiamine (μg/g)	Riboflavin (μg/g)
30 IR varieties	White	1987 DS	7.5 (6.6- 8.9)	3.6 (2.9-5.2)	0.75 (0.52-0.90)
		1987 WS	8.6 (7.7-10.0)	3.6 (2.6-5.2)	0.81 (0.64-0.98)
Azucena	Red	1986 WS	10.4	4.2	0.82
Carreon	Red	1986 WS	10.1	3.3	1.05
Makapilay Pusa	Pink	1986 WS	11.2	4.2	1.32
Pirurutong	Purple	1986 WS	12.3	3.6	2.67
Tapol	Purple	1986 WS	10.5	4.6	4.03
LSD (5%)				0.7	0.23

[a]Values in parentheses.

significantly correlated with BRP in the IR rices, but BRP and riboflavin levels became significantly correlated (r = 0.66**) when the higher BRP pigmented rices were included. In the WS crop, IR58 had the highest thiamine content and IR56 had the highest riboflavin level. Thiamine and riboflavin levels were not correlated in both crops. Thiamine levels were positively correlated in the 2 crops (r = 0.38*), and so with riboflavin level (r = 0.49**). Season had no effect on thiamine content, but riboflavin content tended to be higher in WS.

Nutritional properties of additional nonrice crops (*Cereal Chemistry and Rice Farming Systems Program*). Five additional legumes and proso millet from the Asian Rice Farming Systems Network (ARFSN) were analyzed for nutritional composition. All legumes were low yielding (Table 11). All were low in fat content, but legumes had higher protein content than proso millet. Bambara groundnut had higher energy content than the others, probably because of its higher fat content. All legume proteins were adequate in lysine, and only moth bean protein was deficient in the sulfur amino acids cysteine + methionine. Proso millet protein was deficient in lysine, which is typical of cereal protein.

BY-PRODUCTS AND RESIDUES

Cereal Chemistry and Rice Farming Systems Program

Straw protein in farmers' fields (*Cereal Chemistry and Rice Farming Systems Program*). Rice straw samples in the ARFSN in Santa Barbara, Pangasinan, were collected in 1986 WS from cooperator

Table 11. Grain yield and grain properties of 5 legumes and proso millet. IRRI, 1987.

Crop[a]	Samples (no.)	Yield (t/ha)	Moisture (%)	Crude fat (%)	Crude protein (%)	Energy content[b] (kJ/g)	Lysine[c] (g/16 g N)	Cysteine + methionine (g/16 g N)
Bambara groundnut	5	–	15	3-4	17-19	17.5	7.9	3.5
Black gram	5	1.0-1.3	15-17	1	24-25	16.0	7.5	3.6
Common bean	5	0.7-1.0	15	2	15-20	16.2	7.6	3.6
Moth bean	3	1.9-2.0	11-15	1	20-22	16.5	7.7	2.9
Tepary bean	4	2.1-2.6	14	2	15-17	16.3	7.6	4.0
Proso millet	4	1.3-2.1	14-15	1-2	10-11	16.4	2.1	6.6
LSD (5%)				0.2		0.2	0.1	0.2

[a]*Voandzeia subterranea* (L.) Thouars, *Vigna mungo* (L.) Hepper, *Phaseolus vulgaris* L., *Vigna aconitifolia* (Jacq.) Marichal, *Phaseolus acutifolius* A. Gray, and *Panicum miliaceum* L., respectively. Mainly 1985 DS crop. [b]Mean of 2 samples with extremes in crude fat content. [c]Mean of 2 samples with extremes in protein content.

Table 12. Protein content of total straw of medium- and early-maturing varieties in farmers' fields in the Asian Rice Farming Systems Network, Santa Barbara, Pangasinan, Philippines, 1986 WS. IRRI, 1987.

Variety	Samples (no.)	Straw protein content (% N X 6.25)	
		Range	Mean
	Medium-maturing		
IR5	1	4.6	4.6
IR42	15	3.1-6.6	4.7
IR48	6	3.2-5.4	4.3
Milagrosa	1	3.6	3.6
	Early-maturing		
IR36	8	4.5-6.1	5.1
IR54	1	5.6	5.6
IR60	10	4.1-5.6	4.8
IR62	4	4.2-5.1	4.7
IR64	9	3.8-5.0	4.6
IR65	3	3.6-5.6	4.4

farmers who planted early- and medium-maturing rice varieties, and were analyzed for protein content. No very early rices were represented. No clear-cut trend occurred between growth duration and protein content of straw (Table 12). Only one sample each of IR36 and IR42 exceeded 6% protein, the minimum feed protein content required to maintain ruminants.

Chemical studies on straw (*Cereal Chemistry*). The cutin (surface wax) content of rice hulls (dry basis) was estimated as 6.7% for IR29 and 5.7% for IR32. These values were higher than those we reported for rice straw (2.0-2.8% dry basis). Cooperative study of the chemical composition of harvest IR36 straw fractions at the Department of Biochemistry, La Trobe University, Victoria, Australia, confirmed glucose and xylose as the major sugars of nonstarch polysaccharides (Table 13). Methylation and acetylation-methylation

Table 13. Chemical composition of harvest IR36 rice straw fractions. Department of Biochemistry, La Trobe University, Victoria, Australia, and IRRI, 1987.

Constituent	Composition (% dry basis)		
	Leaf blades	Leaf sheaths	Stems (culms)
Crude fat	5	2	2
Free sugars (glucose)	5	3	4
Free phenolics (*p*-coumaric acid)	2	1	1
Starch	0.4	0.6	0.4
Nonstarch polysaccharides	34	42	44
Arabinose	2	2	2
Xylose	10	12	13
Galactose	3	3	2
Glucose	17	23	25
Uronic acids	2	2	2

studies showed glycosidic linkage mainly at the C4-position in both glucose and xylose in nonstarch polysaccharides of all straw fractions.

Feeding trials straw (*Cereal Chemistry*). Two feeding trials, using growing grade beef cattl (Brahman/native) at the Institute of Animal Science, UPLB, determined the relative feed value of IR36 and IR58 harvest straws and IR36 stubble. IR36 and IR58 were grown in 1986 DS and had similar in vitro dry matter (44-49%) and organic matter digestibilities (49-52%). In trial 1, ad libitum daily roughage dry matter intakes of 4 cattle for 25 d were 68.0 g/kg $W^{0.75}$ metabolic body size for IR36 straw and 69.8 g for IR36 stubble and were highly significantly higher than dry matter intake of 57.8 g for IR58 straw. A confirmatory ad libitum trial on 5 cattle for 38 d also showed higher dry matter intakes of 96.6 g/kg $W^{0.75}$ for IR36 straw than the 85.6 g for IR58 straw. Concentrate intake was at about 1% of live weight.

Genetic evaluation and utilization (GEU) program

Disease resistance

Plant Pathology and Plant Breeding Departments, International Rice Germplasm Center, and International Rice Testing Program

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IRTP DISEASE RESISTANCE TRIALS

International Rice Testing Program and Plant Pathology Department

Disease evaluation results obtained from the 1986 International Rice Testing Program (IRTP) disease screening nurseries were analyzed in 1987. The best performing entries across locations are indicated in Table 1. Entries in IRTP yield nurseries that were rated resistant to specific diseases at certain locations are given in Table 2. More detailed information on IRTP disease nursery results is given in the IRTP section of this report.

BACTERIAL BLIGHT

Plant Pathology and Plant Breeding Departments, International Rice Germplasm Center, and International Rice Testing Program

Screening (*Plant Pathology, Plant Breeding, International Rice Germplasm Center, and International Rice Testing Program*). In 1987, we screened a total of 61,382 rice entries for bacterial blight (BB) resistance to 2 races of *Xanthomonas campestris* pv. *oryzae* (Xeo)—race 1 and 2 (Table 3). These materials included not only those from IRRI, but also those from national programs.

Partial resistance (*Plant Pathology*). Varying methods were used to compare the BB resistance of a number of moderately resistant (MR) and moderately susceptible (MS) cultivars (Table 4).

Lesion extension on 55-d-old plants following clip-inoculation appeared to be linear, beginning at 4-5 d after inoculation (DAI) and continuing until the lesion had reached the leaf sheath, or until the leaf was senescent. Lesions extended faster on highly susceptible cultivars than on MR cultivars.

Bacterial counts from expressed leaf sap of infected leaves showed that clip-inoculation deposited about 2×10^4 colony-forming units (CFU)/cm leaf width and increased to about 5×10^9 CFU/cm by 5 DAI. Bacterial populations did not increase further in the next 6 d, until 11 DAI. The highly susceptible TN1 and IR9101-L showed higher concentrations of bacteria per leaf than 4 MR cultivars at 11 DAI.

The incidence of symptoms in small (100-hill) screenhouse plots was measured throughout the

Table 1. Best performing entries in the 1986 disease nurseries.

Nursery[a]	Entries rated resistant	
International Rice Bacterial Blight Nursery (27)	Kuntlan, BR161-2B-53, BR51-282-8/HR29, IR54, RP2151-173-1-8, RP2151-192-1, RP2151-192-2-5, RP2151-33-2, RP2151-40-1	
International Rice Blast Nursery (20)	Raminad Str. 3, IRAT146, Iri 370, Tetep, IR17525-7-19-1-3-3-2, IR27325-27-3-3, IR31892-100-3-3-3-3, IR31892-46-3-2, IR32429-148-1-3-3, IR32799-107-3-3-2, IR32830-23-2-2, IR34583-19-3-3, IR37704-131-2-1-3-2, IR39326-146-3-1-3, IR39326-9-2-2-3, IR39422-75-3-3-3-2, IR39423-125-1-2-2, Milyang 82, Sangju 4, IRAT144	
International Rice Tungro Nursery (9)	*Field*	*Greenhouse*
	BR1356-32-1-3	ARC11554
	BR308-B-2-3	Tilakkachari
	IR28228-119-2-3-1-1	IR29723-17-3-2-1
	IR28228-12-3-1-1-2	IR29725-109-1-2-1
	IR29725-109-1-2-1	
	DM25	
	IR28228-96-3-2-1-3	
	IR28238-109-1-3-2-2	
International Rice Ufra Screening Set (2)	Bazail 65, CNL319, CNM539, Karkati 161, NC487-77	

[a]Number of trials is indicated in parentheses.

Table 2. 1986 IRTP yield nursery entries rated resistant to various diseases at sites with high disease pressure (location average ≥5.0).

Disease	Nursery[a]	Location	Entries[b]
Leaf blast	IRYN-VE	Los Baños, Philippines	IR31775-30-3-2-2-2, IR39357-133-3-2-2-2, Lu Hong Zhao
	IRYN-E	Los Baños	IR29658-69-2-1, IR31802-48-2-2-2, IR31868-64-2-3-3-3, IR32843-92-2-2-3
	IRYN-M	Bumbong Lima, Malaysia	IR28224-3-2-3-2, ITA123, P1274-6-8M-1-3M-1, IR31809-83-3-2-2
		Los Baños	IR28224-3-2-3-2, IR31809-83-3-2-2, ITA123, P1274-6-8M-1-3M-1
	IURYN-E	Los Baños	IRAT110, N22
	IURYN-M	Quintana Roo, Mexico	BR319-1, IR5931-113-1
	IRRSWYN-E	Los Baños	IR5853-198-1-2
	IRRSWYN-M	Los Baños	Mat Candu
Neck blast	IRYN-E	San Dionisio, Philippines	DR33, IR13240-108-2-2-3, IR13524-21-2-3-3-2-2, IR31805-20-1-3-3, S287b-39-1-3
	IRYN-M	Pusa, India	BG380-2, BR4-34-13-5, BW293-2, C1333-4, DR31, IR18349-135-2-3-2-1, IR28224-3-2-3-2, ITA123, OR447-20
	IURYN-E	Santo Tomas, Philippines	RAU4008-4, Dinalaga
Bacterial blight	IRYN-VE	Milyang, Korea	IR39357-91-3-2-3, IR39357-133-3-2-2-2,
		Chainat, Thailand	C1158-7, IR31779-19-3-3-2-2
		Comilla, Bangladesh	C1158-7, IR31779-19-3-3-2-2, IR39357-133-3-2-2
		Mingora, Pakistan	BR203-193-1-J/1, BR4-9-16-3-1, IR31787-16-1-2-3-2, IR39357-91-3-2-3, Wei You 64
	IRYN-E	Bumbong Lima	IR28128-45-3-3-2, PDR76-D10-D8-D1, SPRLR76102-26-1-1
		Los Baños	Chianung sen yu 26, IR32419-81-2-3-3
		Chainat	C662083, IR32429-122-3-1-2, SPRLR76102-26-1-1
		Comilla, Bangladesh	Chianung sen yu 26, IR31805-20-1-3-3, IR31868-64-2-3-3-3, IR34615-4-2-3, PDR76-D10-D8-D1
		Joydebpur, Bangladesh	PDR76-D10-D8-D1
		Kankai, Nepal	IR31805-20-1-3-3, IR32419-81-2-3-3, SPRLR76102-26-1-1
		Mingora, Pakistan	Chianung sen yu 26, C662083, DR33, IR31802-48-2-2-2, Lu Chao 1, MTU5410-14
	IURYN-E	Los Baños	IRAT110, CR155-5029-216, IR19793-25-2-2, IR25588-7-3-1, IR9761-19-1
		Cuenca, Philippines	IR10198-66-2, IR25588-7-3-1, NDR83
		Santo Tomas	IR10198-66-2, NDR84
	IRRSWYN-M	Comilla, Bangladesh	BRB8-2B-74, BR222-B-358, BR51-74-6/J1, IR21037-2-1-2E-P1, KDML65-GU-45-45, Mat Candu, RP1057-184-5-3-2
		Kankai, Nepal	BRB8-2B-74, BR222-B-358, IR13610-72-2-2E-P2, RP1057-184-5-3-2
Rice tungro virus	IRYN-VE	Los Baños	IR13539-100-2-2-2-3, IR31779-19-3-3-2-2, IR32429-47-3-2-2, IR39357-133-3-2-2-2, IR50
	IRYN-E	Bumbong Lima	IR28128-45-3-3-2, IR34615-4-2-3, IR36, S287b-39-1-3
		Joydebpur	IR13240-108-2-2-3, IR36, PDR76-D10-D8-D1, UPLRi-4
	IRYN-M	Bumbong Lima	IR28224-3-2-3-2, IR28228-12-3-1-1-2, IR35353-94-2-1-3, IR42, S512b-199
		Los Baños	IR29723-143-3-2-1

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Table 2 continued

Disease	Nursery[a]	Location	Entries[b]
Sheath blight	IRYN-VE	Los Baños	IR22107-14-2-1
	IRYN-E	Los Baños	DR33, Iri 352
	IRYN-M	Los Baños	BR316-15-4-4-1
	IURYN-E	Los Baños	IRAT110, RAU4004-105
	IURYN-M	Los Baños	B3623g-Tb-49, IR43, IR7805-22-3-1
	IRRSWYN-M	Los Baños	BR222-B-358, BR51-74-6/J1, IR14497-15-2, IR33421-110-1-3-2
Sheath rot	IRYN-VE	Comilla	BR4-9-16-3-1, C1158-7, IR13539-100-2-2-2-3, IR32429-47-3-2-2, IR50
	IURYN-E	Los Baños	Kinandang Patong
		Cuenca	CR155-5029-216, IR9761-19-1, NDR84
		Santo Tomas	N22
	IURYN-M	Santo Tomas	B2992b-Tb-73-4-2-3-3-3-2, IR12979-24-1 (Brown), TNAU6464
Brown spot	IRYN-E	San Dionisio	IR13240-108-2-2-3, IR32429-122-3-1-2, IR34615-4-2-3, SPRLR76102-26-1-1
Leaf scald	IRYN-M	Barisai, Bangladesh	BW293-2, IR21734-16-3-2-2-2, IR28228-12-3-1-1-2, IR42
		Joydebpur	IR21734-16-3-2-2-2
Narrow brown leaf spot	IURYN-E	Ilagan, Philippines	N22
	IURYN-M	Ilagan	BR319-1, IR13754-5-2, IR7805-22-3-1, IR7835-28-2-4
Ragged stunt virus	IRYN-VE	Los Baños	IR39385-124-3-3-2-3

[a]IRYN-VE = International Rice Yield Nursery-Very Early, IRYN-E = International Rice Yield Nursery-Early, IRYN-M = International Rice Yield Nursery-Medium, IRRSWYN-E = International Rainfed Rice Shallow Water Yield Nursery-Early, IRRSWYN-M = International Rainfed Rice Shallow Water Yield Nursery-Medium, IURYN-E = International Upland Rice Yield Nursery-Early, IURYN-M = International Upland Rice Yield Nursery-Medium. [b]Entries rated 0-3 for reaction to the disease at each location.

Table 3. Breeding materials and varieties screened for resistance to *Xanthomonas campestris* pv. *oryzae* races 1 and 2. IRRI, 1987.

Nursery[a]	Entries (no.) with given disease score[b]						Total (no.)
	1	3	5	7	9	1/7[c]	
IRTP nurseries	279	3	3	142		1	428
	(22)	(12)	(16)	(379)			(429)
Plant Physiology materials	3	20	22	137	11	4	197
Korean lines	527	2		936	85		1,550
			(21)	(1,529)			(1,550)
Tissue culture plants	54	5		1			60
Shuttle breeding, 1987 DS	1,128			713		553	2,394
1987 WS	204			421	127	1	753
Wide hybridization, 1987 DS	309	2		19		2	332
Headrows, 1987 DS	85	6		498	9	2	600
	(3)	(27)	(4)	(560)	(6)		(600)
Headrows,1987 WS	384	10	7	91			492
	(19[illegible])		(1)	(189)		(138)	(520)
USDA material		43	51	113		3	210
		(3)	(11)	(227)		(2)	(243)
Germplasm bank, 1987 DS	28	34	13	2,278	574	2	2,929
1987 WS	320	57	62	3,435		42	3,916
Hybridization block, 1987 DS	147			115	10		272
	(15)			(43)	(48)		(106)
1987 WS	49	17	20	35			121
	(43)	(58)	(63)	(62)			(226)

Continued on opposite page

Table 3 continued

Nursery[a]	Entries (no.) with given disease score[b]						Total (no.)
	1	3	5	7	9	1/7[c]	
Observational yield trial, 1987 DS	297	20	11	78			406
	(1)	(23)	(119)	(259)	(4)		(406)
1987 WS	501	45	10	147	26		729
	(28)	(28)	(1)	(666)	(6)		(729)
Replicated yield trial, 1987 DS	333	7		48		388	
	(12)	(81)	(128)	(173)	(2)	(4)	(400)
Irrigated lowland replicated	360	7	4	25		4	400
yield trial, 1987 DS	(19)	(30)	(118)	(224)		(9)	(400)
Irrigated lowland observational	491			96	9		596
yield trial, 1987 DS	(4)	(6)	(476)	(4)			(490)
Upland replicated yield trial	69	10	20	51			150
		(38)	(44)	(68)			(150)
Upland observational yield trial	49	18	59	65			191
	(14)	(27)	(55)	(54)			(150)
Lowland observational yield trial	1,220	16	31	151	17	7	1,442
	(127)	(89)	(42)	(1,005)	(14)	(3)	(1,280)
Rainfed lowland observational yield trial	(548)	(10)	(10)	(66)		(16)	(650)
Pedigree nurseries	34,947			4,923	1,973	333	42,176
	(5,313)			(3,134)	(678)	(89)	(9,214)
Total	41,825	401	482	14,858	2,831	985	61,382
	(6,337)	(430)	(639)	(9,114)	(714)	(309)	(17,543)
							61,901
							(17,556)

[a]DS = dry season, WS = wet season, USDA = United States Department of Agriculture. [b]Number of entries reacting to race 2 is in parentheses. [c]Segregating.

Table 4. Summarized results showing moderate resistance to bacterial blight (BB) in 6 rice cultivars, as assessed by the daily rate of lesion increase, the *Xanthomonas campestris* pv. *oryzae* (Xco) counts in expressed leaf sap, and the incidence of secondary infections. IRRI, 1987.

Test	TN1	IR9101-L	IR28	IR40	BR51	Cisadane
Rate of lesion increase[a] (cm/d)	2.56	2.07	1.32	1.37	1.58	1.16
CFU/leaf X 10^8 at 12 DAI[b]	10.0	15.5	5.7	6.5	4.2	2.7
Percentage of hills with symptoms[c]	32.5	37.5	32.3	13.7	27.8	26.6

[a]5-20 d after inoculation (DAI) at maximum tillering (MT), race 6 Xco isolate (PXO 99) clip-inoculated at 5 X 10^8 colony-forming units (CFU)/ml, average of 3 replications. Phytotron, 1987 DS. [b]MT, race 2 Xco isolate (spectromycin-resistant, no. 306) clip-inoculated at 1 X 10^9 CFU/ml, average of 4 replications. Isolation on peptone sucrose agar + 100 μg spectromycin/ml. Greenhouse, 1987 WS. [c]70 d after seeding (DAS), race 2 Xco isolate (IRN 812) spray inoculated at 20 DAS, average of 3 replications. Screenhouse, 1987 WS.

crop growth period following inoculation 1 d before transplanting. The highly susceptible (HS) cultivars TN1 and Biplab and the line IR9101-L showed equal or higher incidences (percentage of hills with symptoms) than MR and MS cultivars from 21 until 77 DAI.

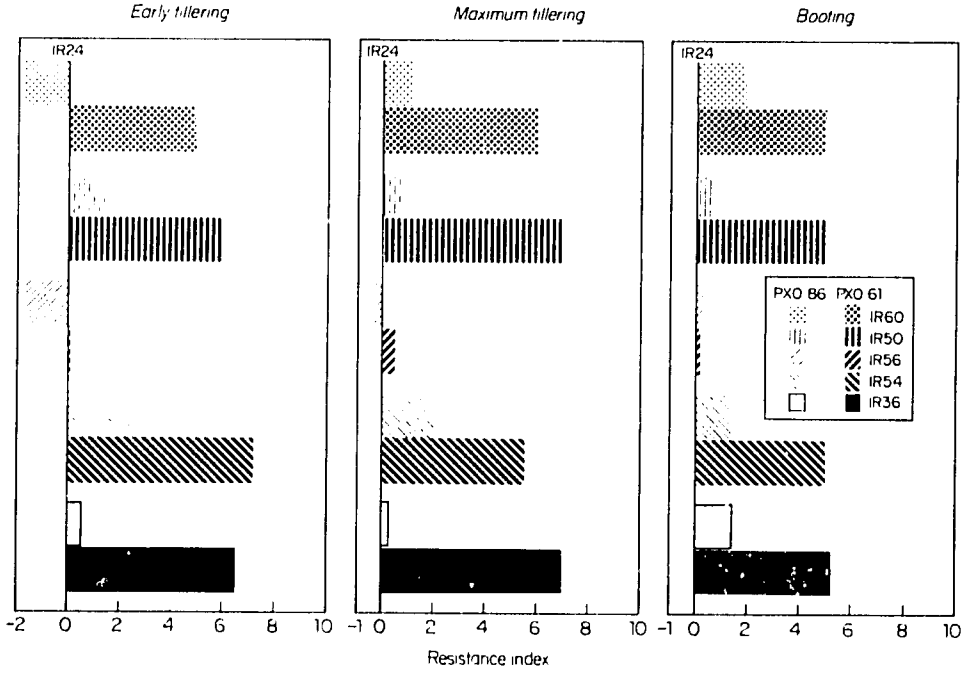
Background resistance (*Plant Pathology*). In the Philippines, rice with the *Xa-4* gene for resistance to race 1 of Xco is faced with the virulence of race 2, the predominant bacterial pathogen. Although more than 80% of the rice area is planted to cultivars with such resistance, BB has occurred endemically in specific localities. The disease has not reached epidemic proportions in all areas planted to such cultivars. Also, the level of infection varies among these cultivars despite their having

the same gene, *Xa-4*, for resistance. Research was therefore undertaken to assess the disease resistance of these cultivars to both virulent and avirulent races. IR24, apparently carrying no major genes for BB resistance, served as the susceptible (S) check. Infection of hills and leaves per hill was measured at three growth stages. The relative resistance index (RI), proposed to measure the resistance of the test cultivars, was calculated in comparison with the amount of disease on IR24.

Table 5. Resistance or susceptibility of IR cultivars carrying the *Xa-4* gene for BB resistance to 2 races of *Xanthomonas campestris* pv. *oryzae* at 3 growth stages.[a] IRRI, 1986 DS.

Cultivar	Hill or leaf infection (%)											
	PXO 61						PXO 86					
	Early tillering		Maximum tillering		Booting		Early tillering		Maximum tillering		Booting	
	Hill	Leaf	Hill	Leaf	Hill	Leaf	Hill	Leaf	Hill	Leaf	Hill	Leaf
IR24[b]	91.6	29.6	91.6	23.8	52.0	14.8	73.0	23.8	87.6	25.6	75.0	24.0
IR56	91.6	28.4	87.4	17.0	52.0	9.6	95.8	30.8	91.6	20.0	73.0	13.4
IR50	45.8	11.4	50.0	5.4	8.2	0.8	98.0	31.8	100	21.4	70.8	16.8
IR60	43.8	11.8	33.4	3.2	4.2	0.2	91.6	29.2	77.0	14.4	58.4	10.0
IR42	37.6	11.2	6.2	0.2	–	–	70.8	23.0	60.4	12.0	–	–
IR22	33.4	7.2	12.4	1.8	–	–	75.0	25.0	62.4	12.4	–	–
IR58	33.4	6.8	18.8	1.8	4.2	0.6	58.4	16.8	81.2	20.8	70.8	20.8
IR62	27.0	7.4	29.2	3.8	10.4	2.2	68.8	17.8	79.0	19.4	70.8	18.2
IR36	27.0	9.6	20.8	1.6	–	0	66.6	15.6	85.4	16.4	60.4	9.2
IR20	25.0	7.6	12.4	1.6	14.6	1.8	43.8	22.4	58.4	13.2	56.2	12.0
IR54	20.8	5.6	35.4	2.2	2.2	0	39.6	11.8	67.6	24.0	60.8	21.8
IR26	18.8	3.8	6.2	0.6	2.0	0.4	75.0	26.2	64.6	19.8	60.4	18.6

[a]Mean of 2 replications. [b]Susceptible check.



1. Relative resistance index of IR varieties to races 1 (PXO 61) and 2 (PXO 86) of *Xanthomonas campestris* pv. *oryzae*, based on hill infection as compared with that of IR24, the susceptible variety, at 3 growth stages. IRRI, 1987.

$$RI = \frac{DL \text{ of IR24} - DL \text{ of IR cultivar}}{100}$$

where DL = disease level (% hill or leaf infection).

A wide range of hill and leaf infection percentages with the two races was observed among IR cultivars (Table 5). The infection percentage with a virulent race (PXO 86) was higher than that with an avirulent race at both maximum tillering and booting. With the avirulent race the means were considerably less and were variable. The RIs of these cultivars infected with the avirulent race based on hill infection also increased as the plants matured (Fig. 1). The RIs with the virulent race also increased. The data suggest that these cultivars possess a distinct background resistance that increases as the plant matures. At early tillering, background resistance may not be shown.

Lesion expansion of individually infected leaves was another parameter analyzed to indicate background resistance. Table 6 shows the resistance or susceptibility of IR cultivars based on mean lesion area expressed as percentage of relative resistance to IR24 measured at 15 DAI at 3 growth stages. The IR cultivars showed a high percentage of relative resistance to avirulent races typified by PXO 61 (race 1), PXO 112 (race 5), and PXO 71 (race 4). To the virulent races that matched the

Table 6. Resistance or susceptibility of IR cultivars based on mean lesion area at 15 d after inoculation, expressed as percentage of relative resistance compared with IR24,[a] the susceptible check, to virulent and avirulent races of *X. c.* pv. *oryzae*, IRRI, 1987.

Cultivar	Relative resistance[b] (%)					
	Avirulent race			Virulent race		
	PXO 61	PXO 112	PXO 71	PXO 86	PXO 79	PXO 99
			20 DAS			
IR26	66.3 a	45.2 a	51.1 a	0.4 b	2.6 a	0.0 a
IR22	63.6 ab	34.9 a	7.5 c	0.0 b	−14.2 a	0.5 a
IR20	62.9 ab	40.6 a	18.9 abc	2.3 b	−6.1 a	5.1 a
IR54	61.8 ab	52.7 a	44.5 ab	20.8 ab	7.8 a	1.7 a
IR58	61.2 ab	41.2 a	37.8 abc	3.9 b	−3.4 a	0.0 a
IR48	60.1 ab	40.0 a	40.2 abc	42.8 a	4.7 a	0.7 a
IR36	51.2 ab	40.9 a	10.0 bc	−0.2 b	−8.1 a	0.0 a
IR42	48.9 ab	43.4 a	16.5 abc	23.3 ab	−0.4 a	0.5 a
IR62	27.4 b	39.9 a	25.3 abc	18.0 ab	3.8 a	0.0 a
			40 DAS			
IR54	40.9 a	28.1 a	29.7 ab	12.4 a	2.0 a	26.8 a
IR26	37.8 a	26.1 a	37.4 a	−0.0 ab	−1.6 a	15.3 ab
IR20	36.9 a	23.7 a	23.1 abc	3.8 ab	−2.4 a	12.6 ab
IR58	36.4 a	17.7 a	27.3 abc	7.7 ab	−6.6 a	5.7 bc
IR22	35.2 a	23.5 a	34.4 a	−2.4 b	−0.1 a	15.6 ab
IR48	35.1 a	23.2 a	13.8 bc	10.5 ab	3.6 a	12.5 ab
IR42	34.4 a	27.9 a	13.6 bc	6.5 ab	−4.4 a	6.8 ab
IR36	34.4 a	20.8 a	20.3 abc	−3.6 b	−5.1 a	10.1 bc
IR62	31.8 a	20.9 a	11.5 c	−0.1 ab	−8.4 a	−2.2 c
			60 DAS			
IR54	19.5 a	19.8 a	19.3 a	11.4 a	7.5 a	20.7 a
IR26	19.5 a	19.4 a	18.7 a	0.2 a	−1.2 a	14.9 ab
IR22	19.5 a	20.2 a	13.3 a	−0.6 a	3.1 a	8.4 ab
IR58	18.7 a	19.4 a	14.5 a	−0.4 a	−0.1 a	7.7 b
IR48	17.5 a	15.4 a	12.2 a	6.1 a	7.9 a	11.6 ab
IR36	17.1 a	13.5 a	9.5 a	−2.4 a	−3.3 a	4.3 b
IR62	16.6 a	18.4 a	7.3 a	−0.1 a	−2.4 a	11.6 ab
IR42	16.2 a	16.2 a	9.9 a	−1.3 a	0.9 a	10.3 ab
IR20	13.4 a	15.6 a	16.0 a	4.0 a	4.1 a	8.4 ab

[a]Estimated on the basis of lesion area. Within a column for each number of days after seeding (DAS), treatment means followed by a common letter are not significantly different at the 5% level by DMRT. [b]0 = as susceptible as IR24, + = more resistant, and − = more susceptible than IR24.

gene *Xa-4*, the relative resistance percentage was low. In all cases, the V × I interaction was not significant, indicating that background resistance apparently does not interact with the races.

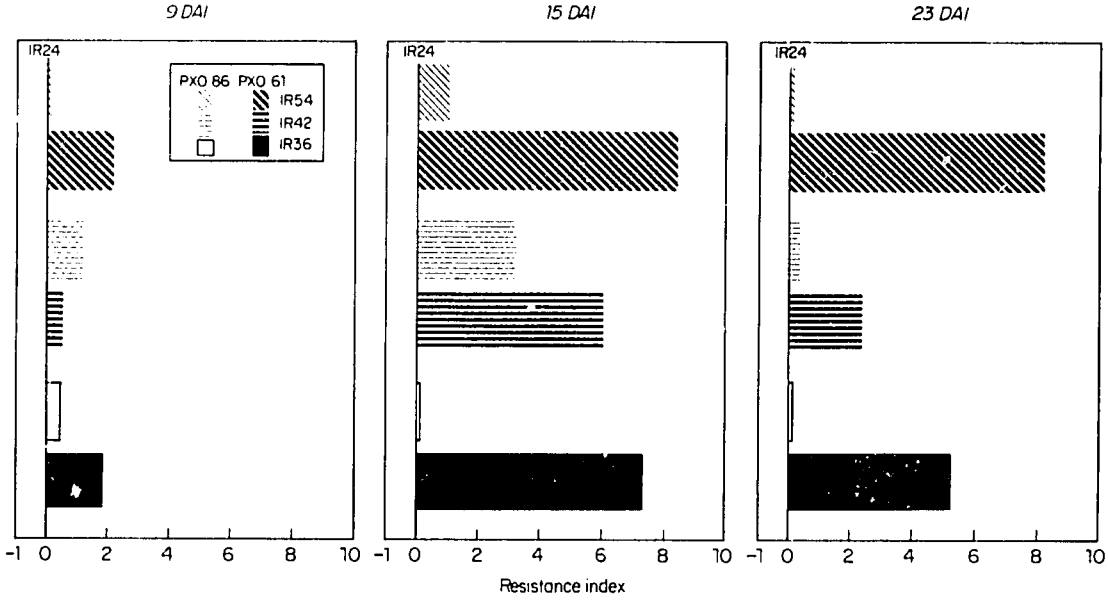
To determine the effect of *Xa-4* and the corresponding background resistance on selected IR cultivars, the RIs to PXO 61, avirulent to *Xa-4*, and to the virulent PXO 86 were compared. At 20 d after seeding (DAS), *Xa-4* showed its effect as indicated by high RI to PXO 61 at different DAI (Fig. 2). The background resistance was indicated by the RI unmatched by PXO 86. Lesion expansion may be a better parameter to detect both the effect of *Xa-4* and background resistance at an early stage. At 40 and 60 DAS, the lesions ceased to expand as the plants matured, and the RI values decreased.

Using lesion expansion as a parameter can demonstrate background resistance of rice cultivars to BB. Such measurement may accurately assess resistance as the variance seems to be smaller. The data also indicate that lesion expansion varies among cultivars. These studies suggest that IR24 may not be the most appropriate S check. If a more susceptible cultivar is used, perhaps the difference may be more evident and the background resistance more accurately distinguished and compared.

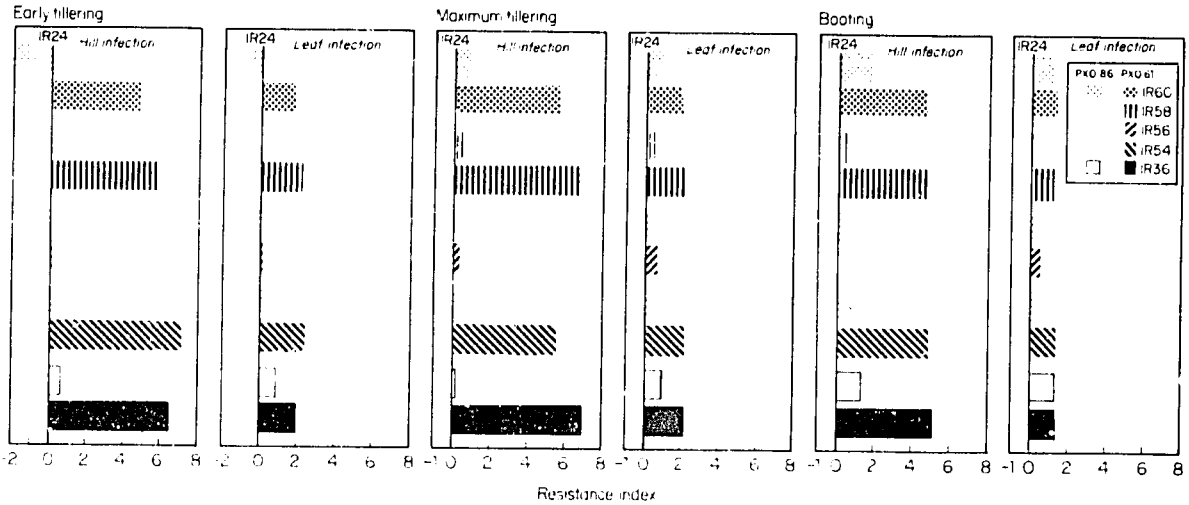
The background resistance expressed at the seedling stage by some cultivars such as IR54, IR58, or IR36 may be carried-over to later stages (Fig. 3), while in some cultivars such as IR60, background resistance may be expressed only at later stages. This variation in resistance expression according to the growth stage indicates that the background conferring added resistance in different cultivars may be different. The effect of background resistance appears to be partial.

Response of IR20 and Perum Karuppan to varying doses of Xco races (*Plant Pathology*). The resistance of Perum Karuppan (PK) was found to be similar to that of Zenith and Wase Aikoku (Annual report for 1986). We observed that the resistance of PK and similar varieties to race 1 at different growth stages differs from that of IR20. The effect of inoculum dose on the expression of resistance of PK and IR20 was determined. Using six doses of inoculum of incompatible isolate PXO 61 and compatible PXO 86 — ranging from a mean of 3 CFU/leaf to 3.3×10^3 CFU/leaf estimated 1 h after inoculation — the leaf infection and lesion areas of PK were compared with those of IR20. IR24 served as the S check.

IR20 and PK showed high leaf infection with PXO 86 at a mean dose of 1.9×10^2 CFU/leaf,

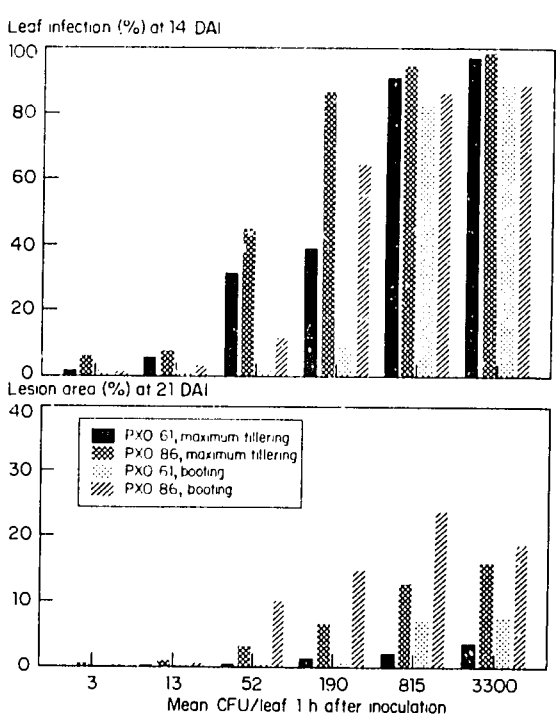


2. Relative resistance index of IR varieties to races 1 (PXO 61) and 2 (PXO 86) of *Xanthomonas campestris* pv. *oryzae*, based on lesion expansion as compared with that of IR24, the susceptible variety, at 3 periods after inoculation. IRRI, 1987.

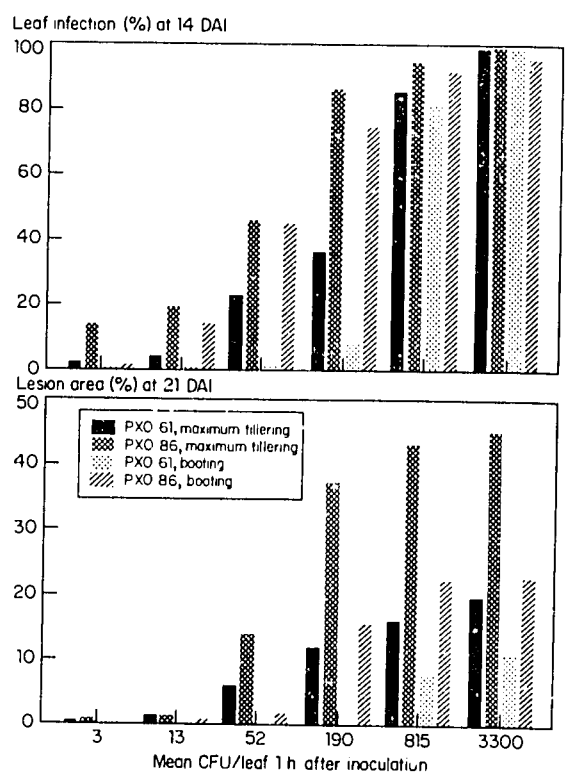


3. Relative resistance index of selected IR varieties at 3 growth stages to races 1 (PXO 61) and 2 (PXO 86) of *Xanthomonas campestris* pv. *oryzae*, based on hill and leaf infections as compared with those in IR24. IRRI, 1987.

while with incompatible race PXO 61, leaf infection was high at 8.2×10^2 CFU/leaf at both maximum tillering and booting (Fig. 4, 5). Lesion areas showed the difference between the two varieties. IR20 was S to PXO 86 and resistant (R) to PXO 61 at 8.2×10^2 CFU/leaf and higher. PK was S to PXO 86 at maximum tillering and booting, and to PXO 61 at maximum tillering only. At booting,

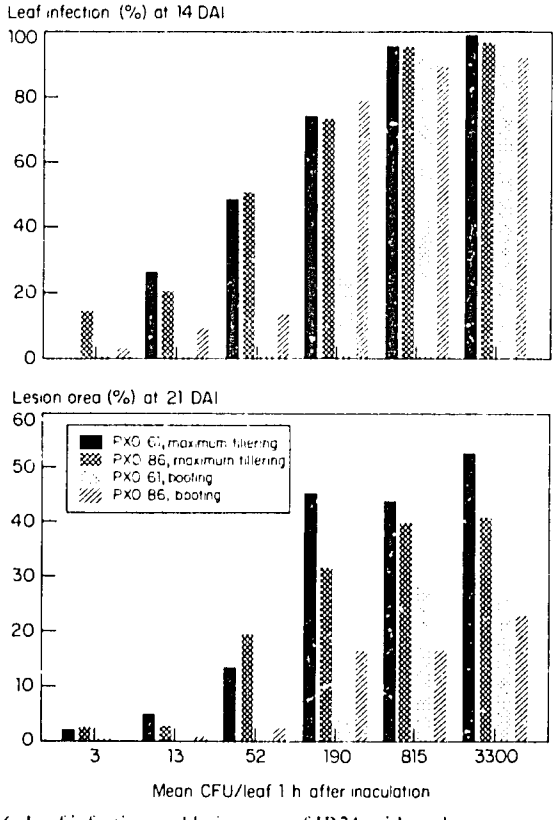


4. Leaf infection and lesion area of IR20 at varying doses of initial inoculum at maximum tillering and booting, IRRI, 1987. CFU = colony-forming unit.



5. Leaf infection and lesion area of Perum Karuppan at varying doses of initial inoculum at maximum tillering and booting. IRRI, 1987.

PK was R to PXO 61 even at the highest mean dose of 3.3×10^3 CFU/leaf, indicating that the resistance functions against PXO 61 at booting but not against PXO 86, the compatible race. PK appears to differ from Zenith and Wase Aikoku, which are both R to PXO 86 at booting. IR24 showed high leaf infection and lesion area at a mean dose of 1.9×10^2 CFU/leaf at maximum tillering; at booting, these reactions occurred at 8.2×10^2 CFU/leaf (Fig. 6).



6. Leaf infection and lesion area of IR24, with no known gene for BB resistance, at varying doses of initial inoculum at maximum tillering and booting. IRRI, 1987.

The relative resistance of PK and IR20 was further estimated by the ratio of their lesion areas. IR20 was twice as R as PK to PXO 61 at maximum tillering, but at booting they were similar (Table 7). The ED_{50} and the estimated relative potency of both varieties pointed to a similar tendency in resistance to PXO 61; against PXO 86, the difference between IR20 and PK at maximum tillering and booting based on lesion area and ED_{50} was not great, as they are both S to the race (Table 8).

Genetic analysis of moderate resistance (*Plant Pathology*). A half diallel of four MR or MS and two highly susceptible (HS) cultivars was made. F_1 plants were clip-inoculated at maximum tillering with race 6 isolate PXO 99. Plants were HS in most cases (Table 9), indicating that the moderate resistance of the parents is predominantly recessive. The four MR cultivars do not appear to have many genes for resistance in common. The F_2 analysis is in progress.

Japan-IRRI collaborative project on bacterial blight (*Plant Breeding and Plant Pathology*). We continued work with the Tropical Agriculture Research Center in Japan under a project funded by the Japanese Government. See the section on Cooperative Country Projects for details.

Table 7. Lesion area and estimates of relative resistance, median effective dose (ED_{50}), and potency of varieties having either *Xa-4*[a] (IR20) or *Xa-4*[b] (Perum Karuppan) genes for BB resistance to PXO 61 at maximum tillering and booting. IRRI, 1987.

Variety	Maximum tillering			Booting		
	Lesion area[a]	Relative resistance		Lesion area[b]	Relative resistance	
IR24	53.0	1.0000		30.74	1.0000	
Perum Karuppan (*Xa-4*[b])	19.8	2.6767	1.0000	10.99	2.7971	1.0000
IR20 (*Xa-4*[a])	8.3	6.3855	2.3855	7.6	4.0447	1.4461
	ED_{50}	Potency		ED_{50}	Potency	
IR20	17.32	1.0000		21.33	1.0000	
Perum Karuppan	5.51	3.1433	1.0000	17.83	1.1963	1.0000
IR24	1.52	11.3947	3.6250	10.49	2.0334	1.6997

[a]Based on initial inoculum of 1.0×10^3. [b]Based on initial inoculum of 4.1×10^3.

Table 8. Lesion area and estimates of relative resistance, median effective dose (ED_{50}), and potency of varieties having either *Xa-4*[a] (IR20) or *Xa-4*[b] (Perum Karuppan) genes for BB resistance to PXO 86 at maximum tillering and booting. IRRI, 1987.

Variety	Maximum tillering			Booting		
	Lesion area[a]	Relative resistance		Lesion area[b]	Relative resistance	
IR24	40.1	1.0000		23.1	1.0000	
Perum Karuppan	43.3	0.9261	1.0000	22.8	1.0132	1.0000
IR20	39.6	1.0126	1.0934	18.9	1.2184	1.2025
	ED_{50}	Potency		ED_{50}	Potency	
Perum Karuppan	6.69	1.0000		25.27	1.0000	
IR20	4.97	1.3461	1.0000	14.26	1.7721	1.0000
IR24	2.85	2.3474	1.7438	7.69	3.2861	1.8544

[a]Based on initial inoculum of 1.0×10^3. [b]Based on initial inoculum of 4.1×10^3.

Table 9. Mean lesion lengths of parent varieties and F_1 progeny 14 d after clip-inoculation with race 6 (PXO 99) of *Xanthomonas campestris* pv. *oryzae*.[a] IRRI screenhouse, 1987 DS.

Female parent	Mean lesion length (cm)[b]					
	TN1	IR9101	IR28	IR40	BR51	Cisadane
TN1	26.3	26.1	27.8*			28.2*
IR9101		23.3				
IR28		25.4*	14.0			
IR40	27.3*	24.3*	–	18.2		
BR51	24.9*	23.6	20.6*	15.7	13.7	
Cisadane		27.4*	21.1*	20.9	21.4	20.2

[a]* = significantly different from the midparent value (p = 95%). (–) = insufficient plants for accurate assessment. [b]Male parents listed across top.

BACTERIAL LEAF STREAK

Plant Pathology Department

Screening upland rice germplasm for resistance. Bacterial leaf streak (BLS) occurs on rice planted under both lowland and upland conditions during the wet season (WS). In 1987 WS, the disease was severe on upland rice on the IRRI farm. The infection was observed at all crop growth stages from seedlings to mature plants.

We scored upland rice breeding materials in the field based on natural infection; 504 entries—303 progenies of IR upland crosses and 201 upland varieties—were screened for BLS resistance. UPLRi-5 and Kinandang Patong were used as check varieties. Plants receiving 30 and 90 kg N/ha were scored between the late vegetative phase and early flowering following the *Standard evaluation system for rice* (SES).

Reactions of parent entries used in the crosses are given in Table 10. Twenty-seven of the 303 IR upland lines tested at the 2 N levels had 9% or less leaf area infection. Only five IR upland crosses and three upland varieties—namely, Agulinha Branco,

Table 10. Natural mean leaf area infection with bacterial leaf streak (BLS) of parents used in upland rice breeding with 30 and 90 kg N/ha. IRRI upland rice farm, 1987.

Parent entry	Leaf area infection (%)			
	3 upper leaves		Lower leaf portion	
	30	90	30	90
UPLRi-7	2.0	4.0	20.0	20.0
IRAT177	2.0	9.0	8.0	5.0
Kinandang Patong	3.3	3.3	9.3	10.6
Palawan	7.0	5.3	26.6	30.0
UPLRi-5	10.9	13.1	48.1	47.2

Table 11. Reactions[a] of rice varieties to BLS at seedling and maximum tillering stages to Philippine *X. c.* pv. *oryzicola* isolates 3, 93, 127, 128. IRRI, 1987.

Variety	Mean lesion area (%)							
	Seedling				Maximum tillering			
	3	93	127	128	3	93	127	128
CNA4206	5.0	0.0	26.5	0.3	0.3	0.2	9.2	0.0
IR58	7.7	20.7	33.3	13.5	0.8	0.3	23.3	1.3
IR38	8.3	4.5	13.7	8.8	0.4	0.0	20.0	0.5
IR56	9.2	7.5	0.4	16.7	0.9	0.0	25.0	0.8
Palawan	10.0	20.0	64.2	15.2	1.5	0.5	15.0	1.7
IR40	10.2	15.9	0.2	30.8	2.7	0.2	39.2	1.3
IR8	11.2	23.3	21.2	7.0	4.6	0.0	25.8	0.6
Kinandang Patong	15.0	10.3	18.3	4.0	0.7	0.5	5.7	6.0
IR50	32.5	15.0	43.3	30.8	2.7	0.4	24.2	2.9
IR60	41.7	29.2	1.1	19.2	1.5	0.4	34.2	3.3

[a]Scores were taken 14 d after inoculation.

Iniap 415, and Bolibod Natural were HS at both N levels. Further investigation is needed, although the effect of the two N levels on leaf infection was insignificant.

Evaluation of varieties for resistance. To understand resistance to BLS, we evaluated 10 selected varieties at the seedling and maximum tillering stages using isolates 3, 93, 127, and 128 of *X. c.* pv. *oryzicola*. The percentage of lesion area was taken at 14 DAI on 3 leaves/tiller. The mean lesion area infections of three replications with six plants per replication are given in Table 11.

Variety-isolate interaction was observed. Most varieties were more S at the seedling stage than at maximum tillering. Only isolate 127 produced high infection at maximum tillering. CNA4206 showed low infection except with isolate 127 at the seedling stage.

BLAST

Plant Pathology and Plant Breeding Departments

Screening (*Plant Pathology and Plant Breeding*). During 1987, 110,058 materials from the Genetic Evaluation and Utilization (GEU) program, national programs, the International Rice Germplasm Center, and IRTP were tested for blast (Bl) resistance in the IRRI nursery (Table 12).

To maintain a diversity of *Pyricularia oryzae* races for screening, populations of the fungus virulent on Carreon, UPLRi-5, and IR442-2-58 are being maintained in the nursery.

Evaluation of GEU elite lines (*Plant Pathology and Plant Breeding*). Using an upland nursery miniplot technique, WS elite lines and rainfed lowland elite lines were evaluated for Bl resistance relative to the partially R check IR36 and the S check IR50. IR64, a relatively new and widely cultivated variety, and several elite lines showed a slow rate of disease progress similar to that of IR36, probably indicating similar levels of partial resistance to Bl (Table 13, 14). Lines with resistance similar to that of IR36 will likely have sufficient Bl resistance in lowland fields.

Table 12. Source and number of materials tested at the IRRI blast nursery, 1987.

Source		Entries (no.)
F_2		9,045
Pedigree nurseries		88,397
Irrigated lowland	64,907	
Rainfed lowland	21,116	
Deepwater	2,374	
Yield trials, elite lines, and hybridization block		4,718
National programs		3,405
IRGC accessions		3,670
IRTP nurseries		734
Tissue culture-derived plants		89
Total		110,058

Table 13. Relative area under disease progress curve (RADPC) and percentage of diseased leaf area (DLA) of GEU elite lines and a few IR and Peta varieties evaluated for resistance to blast in upland nursery miniplots.[a] IRRI, 1987.

Line or variety	RADPC[b]	DLA[b] (%)
IR44530-41-1-2-1	0.00	0.00
IR39323-182-2-3-3-2	0.03	0.07
IR42015-83-3-2-2-2	0.12	0.23
IR37721-9-2-1-3	0.14	0.37
IR41993-131-2-3-1	0.22	0.53
IR39368-31-1-2	0.51	1.00
IR39357-133-3-2-2-2	0.55	1.67
IR41999-139-1-1-2-3	0.58	1.00
IR32429-47-3-2-2	0.71	2.33
IR42068-22-3-3-1-3	0.79	3.33
IR31868-64-2-3-3-3	0.86	4.33
IR32429-122-3-1-2	1.03	4.00
IR28224-3-2-3-2	1.11	5.00
IR41985-111-3-2-2	1.15	3.67
IR32429-68-3-3-3	1.48	5.00
IR41996-118-2-1-3	1.48	5.33
IR33059-26-2-2	1.84	7.67
IR12979-24-3-4	2.01	8.33
IR41985-77-3-3-3	2.15	8.33
IR29429-B-3-B-2-3	2.40	7.67
IR13754-6-3	2.53	8.67
IR39674-13-3-3-3	2.53	8.33
IR10147-113-5-1-1-5	2.54	11.67
IR32021-B-1-B-5-2	2.71	12.33
IR5931-113-1	2.74	14.00
IR35366-28-3-1-2-2	2.77	13.00
IR40720-72-1-2	3.16	14.67
IR41996-163-2-1-2	3.17	20.00
IR41996-12-2-2-3	3.48	16.33
IR42028-50-2-1-3-2-2	3.51	20.00
IR26957-86-2	3.55	14.67
IR41985-98-3-1-3-2	3.78	13.33
IR33043-46-1-3	3.85	24.00 PR
IR13754-5-2	4.30	21.33
IR12721-5-1-1-3	4.40	17.33
IR54	4.48	22.33
IR19319-1-2-1-1-2	4.82	27.33 PR
IR33238-25-2-3-2	5.75	37.33 PR
IR32453-20-3-2-2	5.85 PR	33.33 PR
IR64	5.92 PR	25.00 PR
IR41996-50-2-1-3	5.96 PR	34.00 PR
IR44595-70-2-2-3	6.25 PR	37.33 PR
Peta	6.26 PR	30.00 PR
IR29723-88-2-3-3	6.66 PR	34.00 PR
IR37873-16-2-3-3-3-1	6.70 PR	28.33 PR
IR28226-12-3-1-1-2	6.99 PR	42.33 PR
IR26958-34-2	8.33 PR	44.67 PR
IR21820-154-3-2-2-3	8.57 PR	39.00 PR
IR46	8.62 PR	46.67 PR
IR36 (partially resistant check)	8.97 PR	36.67 PR

Continued on next column

Table 13 continued

Line or variety	RADPC[b]	DLA[b] (%)
IR42000-211-1-2-2-3	9.90 PR	38.33 PR
IR20	10.89 PR	48.00 PR
IR35366-90-3-2-1-2	10.53 PR	53.33
IR35366-62-1-2-2-3	11.93 PR	52.33
IR19431-72-2	12.37 PR	68.33
IR42	13.10 PR	54.00
IR8	13.19	59.00
IR39357-71-1-1-2-2	14.48	66.67
IR34686-179-1-2-1	15.38	66.67
IR27095-20-18	16.83	66.67
IR42029-38-1-3-3-2	17.28	59.00
IR32809-26-3-3	24.13	82.67 S
IR50 (susceptible check)	31.52 S	92.33 S

[a]Mean of 3 replications. [b]Figures followed by PR are not significantly different from the partially resistant IR36; those followed by S are not significantly different from the susceptible IR50.

Table 14. RADPC and percentage of DLA of rainfed lowland breeding lines and other varieties evaluated for resistance to blast in upland nursery miniplots.[a] IRRI, 1987.

Line or variety	RADPC[b]	DLA[b] (%)
IR43485-15-3-42-3	0.17	0.83
IR43485-40-2-42-2	0.30	1.00
IR41054-81-2-3-2	0.48	1.00
IR29341-15-2-1-1	0.48	1.67
IR43570-2-2-2-1	0.56	2.67
IR43582-119-1-1-2	0.64	3.00
IR28224-3-2-3-2	0.70	2.67
IR13240-108-2-2-3	0.90	3.33
IR43485-22-2-2-2	1.07	4.67
IR36974-13-3-3-3	1.12	2.33
IR41111-113-1-2-1-2	1.51	4.67
IR44915-356-2-1	1.80	7.00 PR
IR42247-1-2-1-2-1	1.89	5.67
IR54	1.89	6.00
Mahsuri	2.70 PR	12.33 PR
IR43568-14-1-1-2	2.97 PR	9.67 PR
IR38699-49-3-1-2	3.93 PR	16.33 PR
IR64	4.01 PR	17.33 PR
IR42266-11-2-2-3	4.10 PR	27.33 PR
IR36 (partially resistant check)	4.20 PR	18.33 PR
IR42253-63-1-2-3	4.65 PR	22.00 PR
IR43518-62-2-2-1-3	5.26 PR	22.33 PR
IR28526-44-1-1	5.70 PR	33.33 PR
IR21567-9-2-2-3-1-3	5.78 PR	29.67 PR
IR33238-25-2-3-2	5.85 PR	31.00 PR
IR19319-5-3-3-2-1	6.36 PR	33.00 PR
IR42342-40-3-3-2-3	6.79 PR	31.67 PR
IR48	7.27	36.67
IR19319-1-2-2-2-2	7.78	40.00
IR13146-45-2-3	7.86	40.00

Continued on next page

Table 14 continued

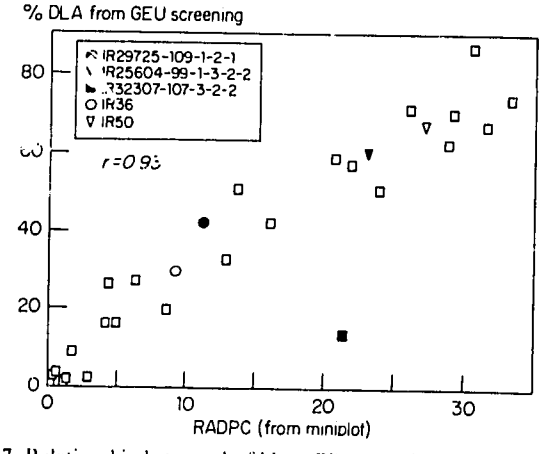
Line or variety	RADPC[b]	DLA[b] (%)
IR43520-93-3-3-3	8.91	43.33
IR43010-20-2-1-3	10.28	44.00
IR19431-72-2	10.45	57.33
IR21188-15-2-2-3-3-3-1-1	10.48	44.00
IR43518-66-2-3-2-3	10.56	44.33
IR42266-73-1-2-2	11.24	51.67
IR42273-72-1-1-2-3	11.62	55.67
IR29692-99-3-2-1	12.58 S	54.00
IR37094-14-2-2-1-2	15.09 S	68.33 S
IR33380-60-1-2-2	15.23 S	76.33 S
IR26933-16-2-3	15.41 S	73.33 S
IR50 (susceptible check)	16.51 S	79.33 S
IR29725-22-3-3-3	16.97 S	76.00 S
IR66	17.20 S	70.67 S
IR42241-76-2-[illegible]-3	19.26 S	80.00 S
IR37096-[illegible]	19.74 S	90.00 S
IR42253-14-1-3-2	20.42 S	89.33 S

[a]Mean of 3 replications. [b]Figures followed by PR are not significantly different from the partially resistant IR36; those followed by S are not significantly different from the susceptible IR50.

In the trial with rainfed lines, IR66 showed higher disease incidence than was recorded in previous tests (Table 14). This variety will be retested in 1988. Variety Mahsuri was more resistant than expected, since it is known to be HS to Bl in Bangladesh, India, Malaysia, and Nepal. Perhaps Mahsuri has partial resistance specific to Philippine isolates of *P. oryzae*, as was found with Korean japonica varieties.

Nursery and field tests for resistance (*Plant Pathology*). Trials in 1986 compared neck Bl resistance that was scored in irrigated lowland fields with leaf Bl resistance measured in upland miniplots. Miniplot results were expressed as the relative area under the disease progress curve (RADPC). To verify previous miniplot results, Bl data for the entries were collated from previous GEU nursery tests. The SES scores were converted to diseased leaf area percentage, and the means were calculated and adjusted for differences between tests using the mean of the common check cultivar IR36. The data were highly correlated ($r = 0.93$) with the miniplot results, although IR32307-107-3-2-2 appeared to be an outlier (Fig. 7).

In 1987, the lowland trial was repeated as in the previous year, except that seeding was staggered to synchronize flowering dates. Neck Bl resistance



7. Relationship between leaf blast (Bl) scores from a miniplot trial and Bl data from GEU screening trials, IRRI, 1987. DLA = diseased leaf area, RADPC = relative area under the disease progress curve.

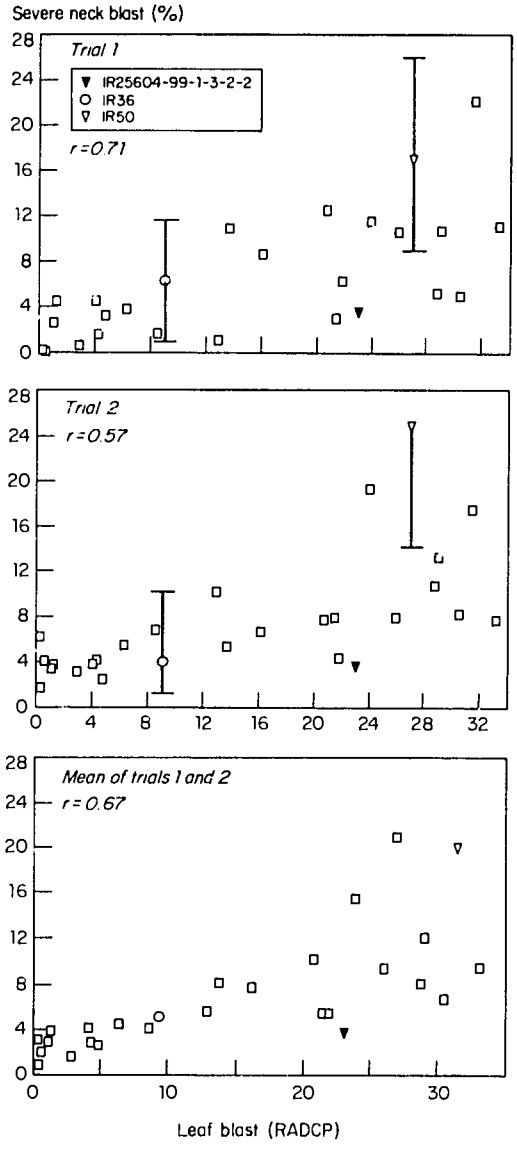
was scored as the percentage of severely infected neck nodes.

The results from the 1987 trials were similar to those of 1986, but the incidence of neck Bl was lower in 1987 (Fig. 8). The neck Bl scores were positively correlated with the miniplot leaf Bl results, although the correlation coefficients were lower than in the previous trials.

As in the previous trials, some lines such as IR25604-99-1-3-2-2 appeared to be exceptions to the general relationship (Fig. 8). The data indicate that the nursery tests alone are insufficient to fully describe the Bl resistance of a prospective variety. Neck Bl resistance testing is necessary.

Race-specific partial resistance to blast in japonica rices (*Plant Pathology*). Most of 53 japonica rice cultivars and breeding lines tested for resistance to Bl disease in nursery trials in Korea and the Philippines showed complete resistance at one or both locations. Most of 24 entries that tested qualitatively susceptible at both locations showed slower disease progress in the Philippines. Korean isolates were more aggressive than Philippine isolates, but both were equally aggressive on the S check. The results suggest that race-specific partial resistance caused the slow disease progress on japonica rices in the Philippine nursery test. See the section on Cooperative Country Projects for more information.

Inheritance of partial resistance in indica rices (*Plant Breeding and Plant Pathology*). Rice



8. Relationship between leaf Bl as measured in miniplots and neck Bl as measured in lowland trials, IRRI, 1987. Vertical bars indicate no significant difference from the susceptible check (IR50) or the partially resistant check (IR36).

cultivars with complete resistance to Bl generally become S within a few years of their release. Interest has focused on partial resistance as a means of increasing the durability of resistance. Inheritance of partial resistance to leaf Bl measured by lesion number (LN) and lesion size (LS) was investigated in crosses involving four indica cultivars: partially R IR36 and Milyang 42, and S IR50 and Milyang 57. Greenhouse-grown plants at the partially extended six-leaf stage were inoculated with a conidia suspension derived from a monoconidial isolate of *P. oryzae*. Broad-sense and narrow-sense heritabilities were relatively low for both traits (Table 15). Significant differences in both LN and LS between F_3 families selected from the most R and most S F_2 families were observed for crosses between R and S parents.

F_2 populations were also grown in the field Bl nursery and subjected to naturally occurring inoculum. The RADPC was calculated based on percentage of DLA from 22 to 39 d after seedling emergence. Broad-sense heritability was very low for both of the R/S crosses tested (0.14 and 0.16). Selection for partial resistance under field conditions would be possible in these crosses, but progress would be slow.

The number of genes controlling partial resistance in these parents could not be determined because of the difficulty of measuring the trait accurately enough to detect small differences. These results imply polygenic inheritance. Low heritabilities indicate that selection may be postponed to later generations, when replicated trials can be done. Selection in earlier generations under natural infection may also be effective in eliminating susceptible plants.

Influence of water deficit on components of resistance (*Plant Pathology*). In a greenhouse

Table 15. Broad-sense (h^2_B) and narrow-sense (h^2_N) heritabilities in 5 crosses for relative lesion number and lesion size. IRRI, 1987.

Cross	Lesion number			Lesion size		
	h^2_B	h^2_N[a]	h^2_N[b]	h^2_B	h^2_N[a]	h^2_N[b]
IR36/IR50	0.38	0.33	0.11	0.67	0.43	0.18
Milyang 42/IR50	0.50	0.38	0.17	0.47	0.40	0.28
IR36/Milyang 57	0.27	0.18	–	0.41	0.33	–
Milyang 42/Milyang 57	0.25	0.19	–	0.42	0.30	–
IR36/Milyang 42	0.20	–	0.10	0.35	–	0.13

[a]Estimates of h^2_N from F_2 and backcross data. [b]Estimates of realized h^2_N from F_3 data.

experiment, we examined the effects of pre-inoculation water deficit on components of Bl resistance. Water was withheld from 4 rice varieties with differing degrees of resistance to the disease until the leaves were rolled tightly (score 5) at noon. The plants were then watered, and inoculated the following morning.

Stress slowed leaf elongation. To compare stressed plants with unstressed plants of the same leaf stage, additional seedings were made after the initial seeding. Plants sown after the main seeding that were at the same leaf development stage as the stressed plants at inoculation were chosen as checks. For convenience, we refer to this treatment as the physiological check, even though the later-sown plants likely differed physiologically from the stressed plants.

In all varieties, the highest lesion number was observed in the water-deficit treatment (Table 16). Lesion number in the stressed treatment was higher than in the physiological check, showing that water deficit had a direct effect on leaf susceptibility. The increased lesion number on stressed plants was not due to differences in leaf development stage.

The water-deficit treatment increased lesion number, even in the two more R varieties, Kinandang Patong and IAC47. Our methods did not allow us to ascertain if the degree of increase varied with variety. To measure varietal differences in the changes in susceptibility induced by water

Table 16. Relative infection efficiency (lesions/100 cm² leaf) in 4 varieties subjected to water deficit and in unstressed checks of the same chronological and physiological age after inoculation with *Pyricularia oryzae*.[a] IRRI, 1987.

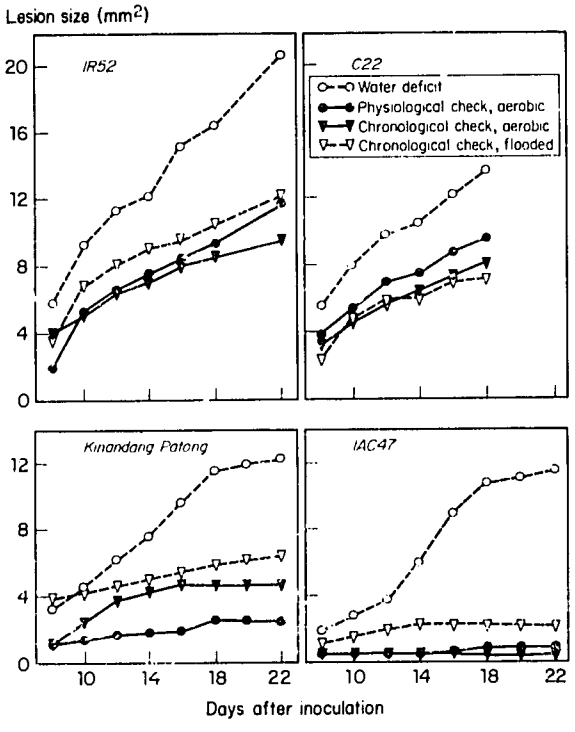
Treatment	Relative infection efficiency			
	IR52	C22	Kinandang Patong	IAC47
	Unstressed			
Chronological check, flooded				
Leaf 8	2.6 b	0.4 a	0.2 a	0.2 a
Leaf 7	0.4 a	0.1 a	0.0 a	0.0 a
Chronological check, aerobic				
Leaf 8	2.5 b	1.1 a	0.3 a	0.1 a
Leaf 7	0.3 a	0.1 a	0.0 a	0.0 a
Physiological check, aerobic, leaf 7	4.0 b	0.8 a	0.2 a	0.0 a
	Water deficit before inoculation			
Leaf rolling score 5, leaf 7	11.4 c	8.9 b	1.0 b	0.9 b

[a]In a column, means followed by a common letter are not significantly different at the 1% level by DMRT.

Table 17. Latent period (LP), sporulation (S) (conidia/lesion per d), and infectious period (IP) in 4 varieties subjected to water deficit and in unstressed checks of the same chronological and physiological age after inoculation with *Pyricularia oryzae*.[a] IRRI, 1987.

Treatment	IR52			C22			Kinandang Patong			IAC47		
	LP (d)	S	IP (d)	LP (d)	S	IP (d)	LP (d)	S	IP (d)	LP[b] (d)	S	IP (d)
	Unstressed											
Chronological check, flooded, leaf 8	5.5 a	36 a	3.5 a	5.9 a	57 a	3.0 a	6.0 a	19.0 a	2.0 a	6.3	0 a	0 a
Chronological check, aerobic, leaf 8	5.0 a	67 a	4.0 a	5.3 a	56 a	8.5 ab	5.5 a	0 a	0 a	6.0	0 a	0 a
Physiological check, aerobic, leaf 7	5.2 a	132 a	4.5 a	5.0 a	194 a	4.5 a	5.3 a	0 a	0 a	–	0 a	0 a
	Water deficit before inoculation											
Leaf rolling score 5, leaf 7	5.2 a	328 b	17.0 b	5.3 a	203 a	14.8 b	4.6 a	44.0 a	8.5 a	5.8	43.0 b	1.5 b

[a]Latent period calculated as $LP = \sum_{i=0}^{n} Pi\ Ti$, where Pi = proportion of total sporulating lesions appearing on ith day, Ti = ith day after inoculation, and n = number of days after inoculation. [b]For all replications of the physiological checks and some replications of the other treatments, no lesions appeared and no statistical comparisons were possible.



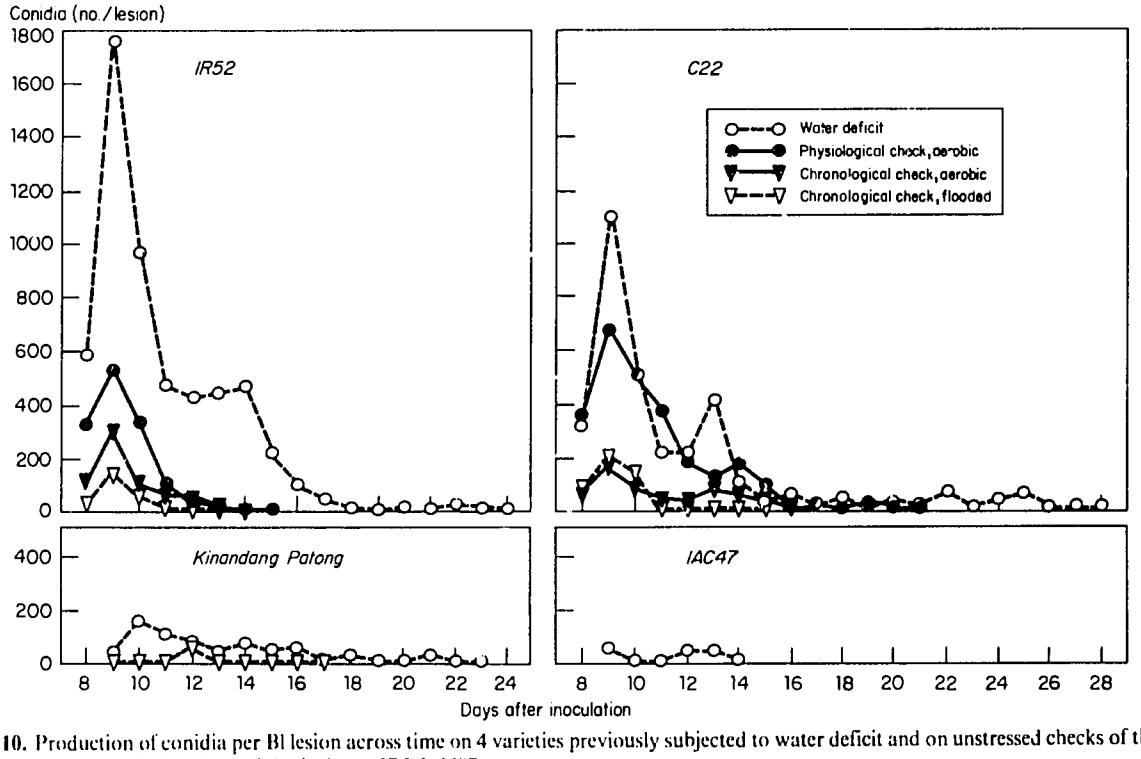
9. Bl lesion growth on 4 varieties subjected to water deficit and on unstressed checks of the same chronological and physiological age. IRRI, 1987.

deficit, polycyclic field tests would probably be required.

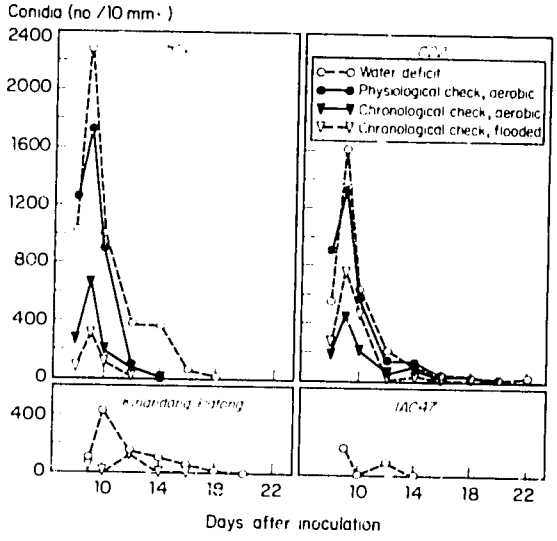
No significant differences in mean latent period were observed (Table 17). Previous work indicated that latent period is less important than lesion number in determining differences in partial resistance among varieties. This study also indicates that latent period is not an important component of increased susceptibility induced by water deficit.

Water-deficit treatment increased the rate of lesion growth in all varieties (Fig. 9).

Production of conidia was higher in the water-deficit treatments of IR52 and IAC47 than in the unstressed checks (Table 17). The differences in C22 and Kinandang Patong were not statistically significant, but the trends were similar. No conidia were produced from lesions in unstressed IAC47 plants, but lesions in the water-deficit treatment did. In all cultivars, conidial production was highest in the water-deficit treatment 9 d after inoculation, then gradually declined (Fig. 10). When expressed in terms of conidia per lesion area, water deficit tended to increase sporulation, particularly in IR52, C22, and Kinandang Patong (Fig. 11).



10. Production of conidia per Bl lesion across time on 4 varieties previously subjected to water deficit and on unstressed checks of the same chronological and physiological age. IRRI, 1987.



11. Production of conidia per 10 mm² of BI lesion area on 4 varieties previously subjected to water deficit and on unstressed checks of the same chronological and physiological age. IRRI, 1987.

Water deficit also prolonged the infectious period of lesions in all varieties (Table 17).

Pre-inoculation water deficit increased the susceptibility of rice leaves to infection by *P. oryzae* in all varieties tested. Not only was lesion number greatly increased, but lesion size increased, sporulation per lesion increased, and the period of lesion sporulation was prolonged. There was some indication that water deficit also increased sporulation per lesion area, and thus favored both establishment and subsequent growth of the pathogen.

LEAF SCALD

Plant Pathology Department

Screening for resistance. A detached-leaf technique was used to evaluate 284 germplasm bank accessions for leaf scald (LSc) resistance. The test plants consisted of entries from 6 varietal groups classified by isoenzyme analysis: 120 from group I (indica), 99 from group IV (japonica), and 65 from groups II-V (marginal groups restricted to the north of the Indian subcontinent). Lesion length was measured 72 h after inoculation of 15 leaves/accession with a single isolate of *Gerlachia oryzae*.

The mean lesion length of each group differed. Groups III, IV, and V tended to have shorter lesions than groups I and II (Table 18). Within group VI, the accessions from the tropics had longer lesions than those of temperate origin (Table 18).

Group I showed the broadest range of lesion lengths, encompassing both the most LSc-R and the most LSc-S accessions tested (Fig. 12). The distribution of group II lesion lengths was skewed toward increased length, and the mode for the group was 32 mm; in contrast, the mode for group V was 26 mm (Fig. 12).

Correlation analysis showed no relationships between lesion length and leaf length or width.

No completely R accessions were found, as would be expected for a necrotrophic pathogen like *G. oryzae*. However, a range of susceptibility to LSc exists within the accessions tested, and the variation is related to the varietal groups, especially in groups II-VI.

SHEATH BLIGHT

Plant Pathology Department

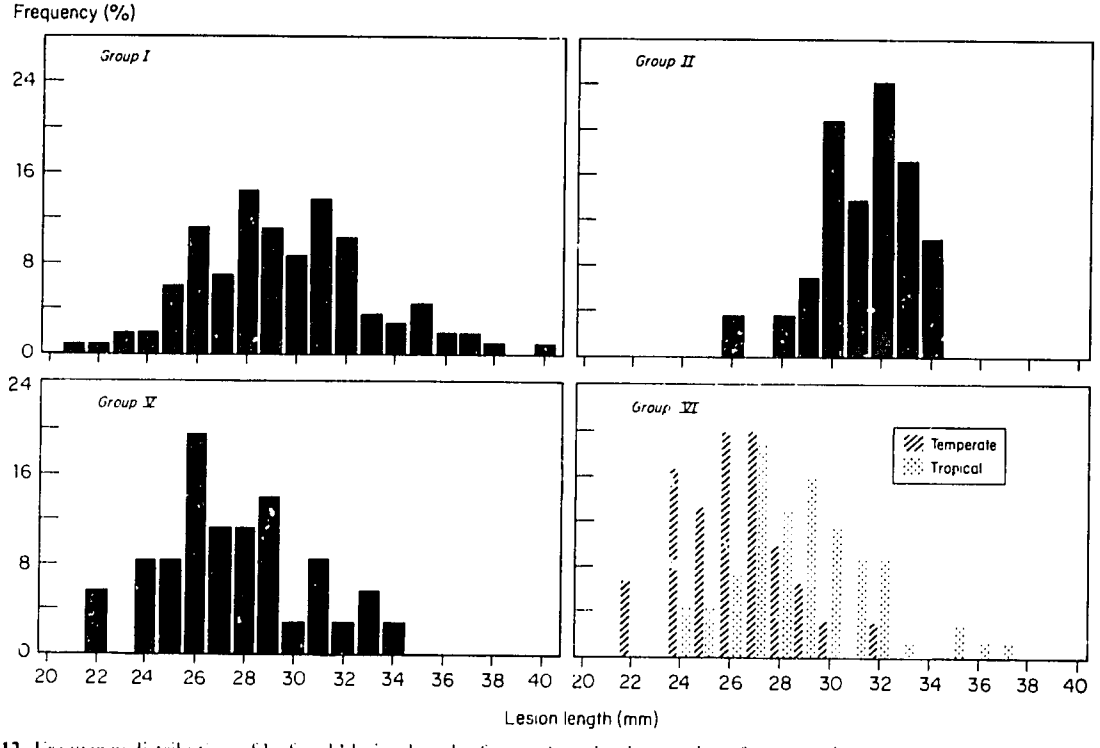
Screening for resistance. Establishment of the upland nursery for sheath blight (ShB) has greatly facilitated our capability to screen and evaluate rice for resistance to the disease. We also made use of the nursery to conduct recurrent selection for ShB resistance testing. In 1987 we completed 2 cycles of the materials and reduced the population from 3,600 plants to 2,400 in the second cycle by roguing S to HS plants.

The test materials were evaluated using scales based on the relative lesion height (RLH), or the

Table 18. Comparison of mean lesion length of germplasm bank accessions from various varietal groups.[a] IRRI, 1987.

Group[b]	Mean lesion length (mm)
I	29.0 c
II	30.8 d
III	27.4 abc
IV	27.3 ab
V	27.2 a
VI temperate	25.7 a
VI tropical	28.6 bc

[a]Average of 3 replications. [b]Varietal group classification based on isozyme analysis.



12. Frequency distribution of leaf scald lesion length of germplasm bank accessions from 4 varietal groups. IRRI, 1987.

ratio of the height of the uppermost lesion to plant height. Test entries with no infections are considered highly resistant (HR) or immune; those with less than 20% RLH are considered R; those with RLH ranging from 20 to 30% have moderate resistance. Any entry exhibiting more than 30% RLH is S: an entry can be MS (31-45% RLH), S (46-65%), or HS (greater than 65%).

Most of the 7,614 entries evaluated were rated MR to HS (Table 19).

A detached-leaf technique was used to assess ShB infection on different species of *Oryzae*. This technique is widely applied to evaluate the efficiency of antagonistic bacteria against ShB at IRRI. The method was compared with inoculation of plants grown in the greenhouse. Leaves were detached and inoculated with agar discs made of potato dextrose agar containing the mycelium of a 3-d-old culture of *Rhizoctonia solani*. The leaves were then placed under moist conditions and incubated at 27 °C. Lesion length was measured after 3 d. The intact plants grown in pots in the greenhouse were inoculated at 45 DAS with the same isolate cultured on rice grain-rice hull medium for 14 d. At 20 d after flowering, the lesion height was measured.

The results indicated that, although resistance or susceptibility of test entries could easily be identified using the two methods, some entries were resistant with one method but susceptible with another, and vice-versa (Table 20).

By the detached-leaf technique, many entries produced a wide variation in lesion length. The variation was less on 71 entries; the 0.0 to 3.0 cm for 26 entries was less than that for IR58, the S check (3.2 cm), while the 3.3 to 6.5 cm lesion length in 43 entries was longer than that for IR58 (Table 21). The technique will be further assessed for its efficiency as a means for varietal evaluation against ShB in the laboratory.

We also compared ShB development on rice cultivars grown under three cultivation conditions: upland—a dryland condition with sprinkler irrigation or rain as the source of water; lowland—the field was prepared wet by puddling, rice seedlings were transplanted, and irrigation was often provided; and lowland-upland—plants were initially maintained under lowland conditions but the

Table 19. Summary of screening of rice breeding materials and germplasm for sheath blight (ShB) resistance. IRRI, 1987.

Source	Entries (no.)	Entries (no.) with given reaction[a]					Entries (no.) for retesting[b]
		R	MR	MS	S	HS	
GEU elite lines							
DS	63	3	6	24	22	7	1
WS	63	0	1	1	13	11	37
Germplasm bank	220	0	3	29	95	56	37
IRTP nurseries							
IRRSWYN	38	0	0	2	11	25	0
IRON	177	0	8	22	13	13	121
IURYN	39	0	3	6	16	9	5
IRYN	78	0	1	0	34	43	0
IURON	81	2	6	25	27	18	3
IRRSWON	91	0	0	6	6	4	75
Wild rice	102	17	20	5	0	0	60
IR varieties	29	0	3	17	9	0	0
Upland replicated yield trials	600	48	203	71	8	2	268
IR lines and F_2s	33	2	14	8	0	1	8
Recurrent selections[c]							
1st cycle	3600	–	–	–	–	–	0
2d cycle	2400	–	–	–	–	–	0
Total	7614	72	268	216	254	189	615

[a]There were no highly resistant (0%) entries. R = resistant (0-20%), MR = moderately resistant (21-30%), MS = moderately susceptible (31-45%), S = susceptible (46-65%), HS = highly susceptible (>65%). [b]Entries that were inoculated but developed no infection. [c]Susceptible and highly susceptible entries were rogued. Seeds obtained from the first cycle were used for the second cycle.

Table 20. Reaction of wild rices to a single isolate of ShB under laboratory and greenhouse conditions. IRRI, 1987.

Species	Accession no.	Lesion length (cm) in laboratory	Relative lesion height (%) in greenhouse
O. sativa/O. rufipogon	100682 R	0.90	28.00
O. latifolia[a]	100966	1.40	55.88
O. latifolia	100890	2.23	30.00
O. nivara/O. sativa[a]	103790	2.50	48.42
O. latifolia	103808	2.73	38.00
O. sativa (IR50)[b]	–	3.17	33.00
O. glaberrima	102838	4.50	25.00
O. punctata	101409	4.50	34.66
O. latifolia	100168	4.67	30.42
O. officinalis	100179	4.73	34.66
O. eichingeri	101424	4.83	20.00
O. glaberrima[a]	102213	4.93	18.60
O. glaberrima	102214	5.00	34.20
O. punctata	103889	5.00	23.88
O. glaberrima[a]	102375	5.67	19.57
O. punctata	101417	6.50	28.00

[a]Varieties showing inconsistent reaction to ShB. [b]Laboratory test was conducted using detached-leaf technique; the greenhouse test was done by inoculating the test plants with rice grain-rice hull medium at 45 DAS.

Table 21. Reaction of selected wild rices to ShB, using detached-leaf technique in the laboratory. IRRI, 1987.

Species	Accession no.	Lesion length (cm)	SD
O. rufipogon/O. nivara	103313	0.00 a	0.00
O. sativa/O. nivara	100582	0.47 a	0.14
O. australiensis	100882	0.50 a	0.61
O. perennis	100687	0.70 ab	0.24
O. rufipogon	103321	0.83 ab	0.26
O. glaberrima	102429	0.83 ab	0.75
O. rufipogon	100588	0.87 ab	0.55
O. officinalis	100180	0.90 ab	0.14
O. nivara	102179	0.90 ab	0.60
O. sativa/O. rufipogon	100682 R[a]	0.90 ab	0.86
O. grandiglumis	101405	0.93 ab	0.00
O. latifolia	100914	1.23 abc	0.24
O. alta	100161	1.30 a-d	0.90
O. latifolia	100966	1.40 a-d	0.10
O. perennis	100597	1.50 a-e	0.35
O. barthii	101960	2.17 b-f	1.04
O. rufipogon	100904	2.17 b-f	1.04
O. nivara/O. rufipogon	101960	2.23 b-f	1.32
O. latifolia	100890	2.23 b-f	0.24
O. malampuzhaensis	100957	2.50 c-g	0.50
O. glaberrima	102557	2.50 c-g	0.85
O. nivara/O. sativa	103790	2.50 c-g	1.32

Continued on opposite page

Table 21 continued

Species	Accession no.	Lesion length (cm)	SD
O. officinalis	103285	2.73 c-h	0.84
O. latifolia	103808	2.73 c-h	0.75
O. barthii	101382	2.83 d-h	1.15
O. latifolia	100167	3.00 e-i	0.85
O. sativa (IR58)[b]	–	3.17 f-j	1.15
O. minuta	103874	3.17 f-j	1.25
O. perennis	103846	3.30 f-h	0.80
O. sativa/O. rufipogon	103793	3.33 f-l	0.56
O. brachyantha	101231	3.33 f-l	0.75
O. officinalis	101121	3.50 f-m	0.00
O. latifolia	100165	3.50 f-m	0.00
O. rufipogon	100924	3.50 f-m	0.50
O. rufipogon	100912	3.57 f-n	1.26
O. rufipogon	103817	3.67 f-o	0.26
O. glaberrima	102562	3.67 f-o	1.25
O. glaberrima	102705	3.93 g-p	0.60
O. alta	100967	4.00 g-q	0.00
O. nivara	103317	4.00 g-r	0.85
O. glaberrima	102443	4.17 h-r	0.75
O. glaberrima	102710	4.23 h-s	0.24
O. glaberrima	101855	4.50 i-t	1.32
O. glaberrima	102838	4.50 i-t	0.50
O. alta	100888	4.50 i-t	1.00
O. punctata	101409	4.50 i-t	1.08
O. nivara	103407	4.57 i-t	0.90
O. latifolia	100168	4.67 j-t	1.04
O. officinalis	100179	4.73 j-u	0.74
O. glaberrima	102213	4.93 l-w	1.20
O. punctata	103889	5.00 m-w	1.32
O. longiglumis	100974	5.00 m-w	0.50
O. glaberrima	102214	5.00 m-w	0.85
O. barthii	101378	5.00 m-w	1.00
O. nivara	100898	5.10 m-w	1.38
O. meridionalis	101145	5.17 h-w	1.08
O. glaberrima	102554	5.17 n-w	0.26
O. barthii	101223	5.23 a-w	1.12
O. nivara/O. rufipogon	103825	5.33 p-w	0.50
O. glaberrima	102211	5.57 q-w	0.51
O. rufipogon/O. nivara	101943	5.60 q-w	0.65
O. glaberrima	102375	5.67 r-w	0.26
O. brachyantha	101236	5.83 s-w	1.15
O. glaberrima	112641	6.00 t-w	0.50
O. glaberrima	102691	6.10 t-w	0.52
O. australiensis	100882	6.33 u-w	0.26
O. paraguayensis	101395	6.43 vw	0.10
O. punctata	101417	6.50 w	0.00

[a]R = red endosperm. [b]Susceptible check.

water was drained 5 d before inoculation (40 DAS); then the land was maintained under upland conditions until crop maturity. Six rice cultivars were tested, and the mean disease severity and incidence in each field condition were computed (Table 22).

The results indicated no significant difference in disease severity measured as RLH. However, ShB incidence based on the number of infected tillers divided by the total number of tillers was significantly different. ShB incidence in plants grown under lowland conditions was lower than in those grown under upland or lowland-upland conditions. Furthermore, ShB infection under both upland and lowland-upland conditions was more uniform as shown by lower standard deviation.

TUNGRO

Plant Pathology Department

Screening methods for testing resistance. *Scoring based on infection rate.* The mass screening method for testing resistance to rice tungro virus (RTV) was developed in 1964 and modified in 1972. In this screening method, we inoculate test seedlings in pots (29 seedlings/variety per pot) by releasing RTV-viruliferous green leafhoppers (GLH) in a cage with 16 pots, then scoring for infection rates 2 wk after inoculation (WAI). Varieties that have infection rates of 0-30% are defined as R, 31-60% as intermediate, and 61-100% as S. By this method, we have tested about 40,000 germplasm samples. Several varieties have had consistently low infection rates. These varieties were further evaluated and characterized as follows:

ARC11554, Pankhari 203, Gam Pai 30-12-15, Latisail, Sigadis, Kataribhog	:	Resistant to GLH, moderately tolerant of RTV
Habiganj DW8, Utri Merah (16680), Utri Rajapan	:	Resistant to RTV infection, moderately tolerant of RTV
Bahmau Putih	:	Tolerant of RTV

These tolerant varieties showed very mild or no clear symptoms and had less grain yield reduction when infected.

Scoring based on symptom severity. To develop an effective scoring method for selecting varieties either R to RTV infection or tolerant of RTV, we studied the correlation between symptom severity and grain yield reduction. Seedlings of nine varieties inoculated with RTV were transplanted in pots. At 1-2 WAI, plants infected with both viruses, rice tungro bacilliform virus (RTBV) alone,

Table 22. Incidence and severity of ShB of rice planted under upland, lowland, and lowland-upland conditions.[a] IRRI, 1987.

Cultivar	Upland		Lowland-upland		Lowland	
	Incidence	Severity	Incidence	Severity	Incidence	Severity
IR62	62.0 a	21.1 a	74.7 a	18.7 a	33.0 a	21.3 a
IR58	83.0 a	27.4 ab	91.7 ab	30.8 bc	58.3 bc	37.9 cd
IR36	87.3 a	34.9 c	100 b	33.7 c	70.7 c	38.8 d
IR60	87.3 a	31.6 bc	95.7 ab	29.7 bc	29.0 a	19.6 a
IR64	91.3 a	26.9 ab	75.0 a	25.1 b	46.7 ab	32.1 bc
IR20	95.7 a	29.0 bc	79.0 ab	30.9 c	45.7 ab	28.5 b
Mean	84.4	28.5	86.0	28.1	47.1	29.7

[a]Upland = dryland with sprinkler irrigation or rainwater. Lowland = flood irrigation with standing water. Lowland-upland = field was lowland and, 5 d before inoculation, was drained to upland conditions.

or rice tungro spherical virus (RTSV) alone, were identified. Plant height was measured and symptoms were recorded at 3 WAI. Grain yield was recorded.

Plant height and grain yield reductions were generally low in Balimau Putih, Palasithari, Sigadis, and Utri Rajapan, but were high in BW272-6B, FK135, and TN1 (Table 23). Doubly infected plants did not show leaf discoloration in Balimau Putih, but showed light green coloration in Utri Rajapan, mild yellowing in Sigadis and Palasithari, and severe yellow-orange coloration in other varieties. RTBV infected plants generally showed discoloration milder than that in doubly infected plants. RTSV-infected plants did not show leaf discoloration. Irrespective of variety, plants infected with RTBV + RTSV had higher height and yield reductions, followed by RTBV-infected plants and then by RTSV-infected plants. There were significant correlations between grain yield and plant height reduction among plants infected with RTBV + RTSV, RTBV alone, or RTSV alone in BW272-6B, FK135, and TN1, but not in Balimau Putih, Sigadis, and Utri Rajapan. Apparently, plants that showed severe symptoms had greater yield reduction. These results indicate that the level of tolerance can be scored on the basis of plant height reduction and occurrence of leaf discoloration at about 3 WAI.

Using those results, a new scoring method was developed and the mass screening method was modified as follows:

1. Seeds (30/sample) are soaked in water and 20 germinated seedlings are transplanted in a pot.
2. Viruliferous GLH are obtained by allowing feeding on RTV-infected plants for 3-4 d.
3. After 7-10 d of soaking, 16 pots are placed in a cage and exposed to viruliferous GLH at 8-10/seedling for 3 h. After viruliferous GLH are given sequential inoculation feeding on three sets of seedlings, they are made to feed overnight on RTV-infected plants and re-used the following day.
4. At 3 to 4 WAI, individual seedlings are scored as follows:
   1 = no symptoms
   3 = 1-10% plant height reduction with no distinct leaf discoloration
   5 = 11-30% plant height reduction with no distinct leaf discoloration
   7 = 31-50% plant height reduction with yellow or yellow-orange leaf discoloration
   9 = more than 50% plant height reduction with yellow or yellow-orange leaf discoloration.
5. Average score is calculated to indicate resistance or tolerance level.
6. All plants of entries that have average scores below 5 are indexed by enzyme-linked immunosorbent assay for presence of RTBV and RTSV.

By the modified mass screening method, more than 2,000 germplasm samples and lines were tested. Nine percent of germplasm tested scored 0-3. Tjempo Kijik and Utri Merah (Acc. No. 16682) had low scores. These varieties had high infection rates but exhibited very mild symptoms.

Reaction of GEU elite lines to infection. The reaction of 55 GEU elite lines to RTBV and RTSV infection was determined using the vector GLH

Table 23. Plant height reduction at 5 wk after infection, and grain yield reduction in seedlings of 7 varieties infected with tungro bacilliform virus (RTBV), tungro spherical virus (RTSV), or both at 5-7 d after soaking. IRRI, 1987.

Variety	Plants infected with	Reduction (%) in	
		Plant height	Grain yield
Balimau Putih	RTBV+RTSV	9.4	19.9
	RTBV	3.3	17.1
	RTSV	1.5	7.2
BW272-6B	RTBV+RTSV	62.6	94.2
	RTBV	59.4	81.9
	RTSV	16.3	14.5
FK135	RTBV+RTSV	72.0	99.0
	RTBV	68.2	98.0
	RTSV	2.9	19.5
Palasithari	RTBV+RTSV	36.9	33.5
	RTBV	34.6	20.6
	RTSV	4.5	10.1
Sigadis	RTBV+RTSV	16.9	30.7
	RTBV	13.5	23.9
	RTSV	11.2	9.1
Utri Rajapan	RTBV+RTSV	29.4	28.8
	RTBV	21.8	16.8
	RTSV	2.3	1.6
TN1	RTBV+RTSV	71.8	97.4
	RTBV	49.1	94.7
	RTSV	3.7	19.5

selected on cultivar IR64 or TN1. GLH adults that had fed on plants infected with RTBV + RTSV were individually given a 1-d inoculation access to 7-d-old seedlings in test tubes. Seedlings were indexed by latex serology 3 WAI. For each cultivar, 20 seedlings were tested.

When the TN1 colony was used for inoculation, 26 lines (47%) had less than 30% infection, and 6 lines (11%) higher than 60%. When the IR64 colony was used, 10 lines (18%) had less than 30% infection, and 30 lines (55%) higher than 60% (Table 24). The infection rate with RTBV + RTSV was higher when inoculation was by the IR64 colony; many lines were predominantly infected with RTBV alone when inoculation was by the TN1 colony. Several lines were infected with RTBV alone when infected with either colony. These results indicate that most lines tested have resistance to the vector GLH but not to the viruses.

Tungro transmission by green leafhopper colonies selected on green leafhopper-resistant cultivars. A GLH colony has been maintained on IR64 plants in a greenhouse at IRRI since 1985 (Annual report for 1986). After having been reared for 8-10 overlapping generations, 20-30 adult females were transferred and maintained on

Table 24. Transmission of RTV-associated viruses on 55 selected lines by RTV-viruliferous IR64 and TN1 colonies in test tubes[a] at 1 insect/seedling.[b] IRRI, 1987.

Line	IR64 colony				TN1 colony			
	GLH (no.) that transmitted[c]			Overall infection (%)	GLH (no.) that transmitted[c]			Overall infection (%)
	RTBV+RTSV	RTBV	RTSV		RTBV+RTSV	RTBV	RTSV	
IR5420-1-1-2-3	4	7	1	60	0	7	0	35
IR5931-113-1	10	5	1	80	6	3	1	50
IR6023-10-1-1	3	12	0	75	8	6	1	75
IR10147-113-5-1-1-5	7	8	1	80	1	6	1	40
IR1274-5-1-1-3	5	4	0	45	9	2	2	65
IR12979-24-1-8	1	7	2	50	7	3	0	50
IR13146-45-2-3	11	3	1	75	1	8	0	45
IR13754-5-2	4	3	2	45	1	3	0	20
IR13754-6-3	2	5	1	40	1	4	0	20
IR19319-5-3-3-2-1	9	8	0	85	2	5	0	35
IR19431-72-2	7	10	0	85	0	3	0	15
IR21567-9-2-2-2-1	5	12	0	85	1	5	0	30
IR21567-18-3	4	8	1	65	0	7	0	35
IR26894-37-2-1-3	2	14	0	80	3	4	0	35
IR26957-86-2	5	10	0	50	6	4	0	50
IR28222-9-2-2-2-2	0	7	0	35	0	3	0	15
IR28224-3-2-3-2	2	12	1	75	0	3	0	15

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Table 24 continued

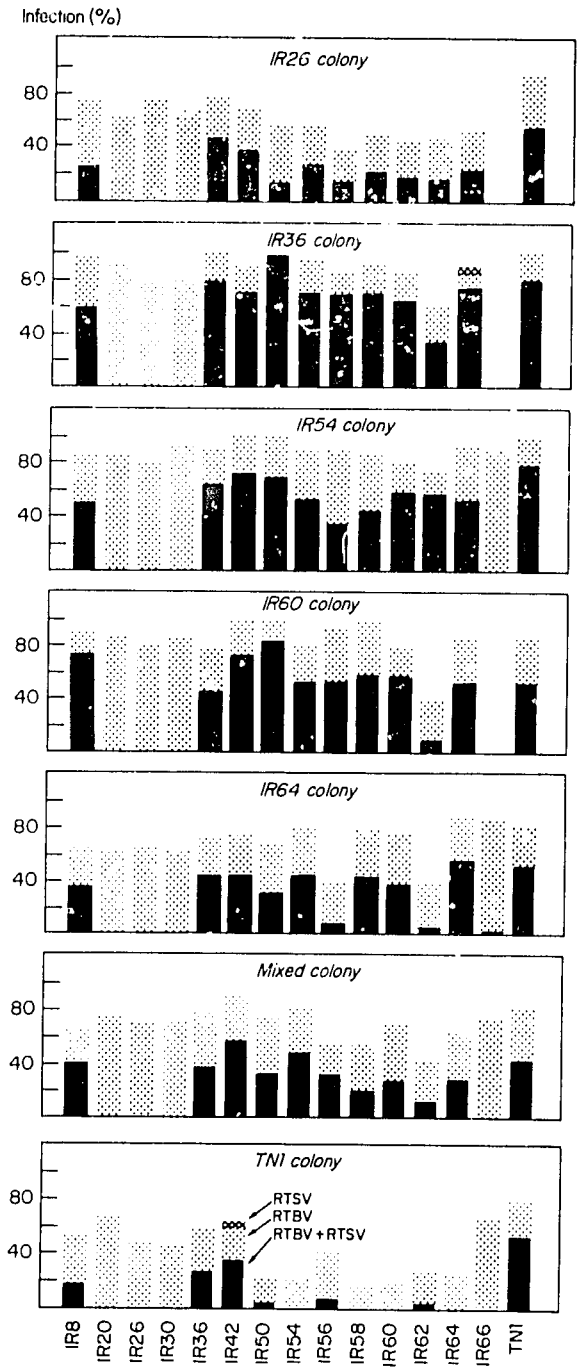
Line	IR64 colony				TN1 colony			
	GLH (no.) that transmitted[c]			Overall infection (%)	GLH (no.) that transmitted[c]			Overall infection (%)
	RTBV+RTSV	RTBV	RTSV		RTBV+RTSV	RTBV	RTSV	
IR28228-12-3-1-1-2	0	6	0	30	2	5	0	35
IR28228-119-2-3-1-1	3	2	0	25	3	1	0	20
IR28941-1-3-5-2	10	5	0	75	0	3	0	15
IR29429-B-3-B-1-4	2	13	0	75	1	14	0	75
IR29429-B-3-B-2-3	9	5	1	75	4	6	2	60
IR29723-88-2-3-3	0	4	0	20	0	8	0	40
IR29725-109-1-2-1	2	3	0	25	0	4	0	20
IR31802-48-2-2-2	4	11	0	75	1	5	0	30
IR31868-64-2-3-3-3	2	10	0	60	0	6	1	35
IR32429-47-3-2-2	7	11	0	90	2	6	0	40
IR32429-68-3-3-3	6	10	2	90	0	2	0	10
IR32429-122-3-1-2	4	8	0	60	0	3	0	15
IR32433-20-3-2-2	0	3	0	15	0	9	0	45
IR32809-26-3-3	0	7	0	35	0	5	0	25
IR33043-46-1-3	0	9	0	45	0	6	0	30
IR33059-26-2-2	0	6	0	30	3	1	0	20
IR33380-7-2-1-3	1	12	0	65	0	8	0	40
IR34686-179-1-2-1	1	8	0	45	1	6	0	35
IR35366-28-3-1-2-2	0	6	0	30	0	7	0	35
IR35366-62-1-2-2-3	0	9	0	45	2	4	0	30
IR35366-90-3-2-1-2	0	9	0	45	0	4	0	20
IR37721-9-2-1-3	0	6	0	30	0	5	0	25
IR37873-16-2-3-3-3-1	1	1	0	10	0	4	0	20
IR39323-182-2-3-3-2	6	5	1	60	3	10	0	65
IR39357-133-3-2-2-2	11	6	1	90	0	2	0	10
IR39768-31-1-2	5	7	0	60	4	11	0	75
IR40720-7-2-1-2	5	1	0	30	0	5	0	25
IR41985-77-3-3-3	2	8	0	50	1	8	0	45
IR41985-98-3-1-3-2	7	7	0	70	0	3	0	15
IR419815-111-3-2-2	6	6	0	60	4	5	0	45
IR41993-131-2-3-1	2	10	0	60	3	5	0	40
IR41996-12-2-2-3	4	6	1	55	1	5	0	30
IR41996-50-2-1-3	3	12	1	80	2	6	1	45
IR41996-163-2-1-2	4	9	0	65	1	5	0	30
IR42000-211-1-12-2-3	1	8	0	45	5	12	0	85
IR42015-83-3-2-2-2	5	10	0	75	1	6	0	35
IR42068-22-3-3-1-3	4	6	0	50	0	2	0	10
IR44595-70-2-2-3	4	5	0	45	1	2	1	20
TN1	17	15	0	80	20	16	0	90

[a]Leafhoppers were given 4 d acquisition access to plants infected with both RTBV and RTSV and 1 d inoculation access to 1-wk-old seedlings. [b]40 seedlings were tested. [c]The inoculated plants were tested 1 mo later by latex test.

seedlings of 2 varieties—IR26 and IR36—moderately resistant to GLH; 3 resistant varieties—IR54, IR60, and IR62; and a mixture of IR varieties. The mixture consisted of plants from equal proportions of seeds of IR26, IR36, IR54, IR56, IR64, and TN1. GLH colonies were successfully maintained on cultivars IR26, IR36, IR54, IR60, and the mixture. GLH colonies maintained on TN1 served as the controls. Adults of the ninth generation of the selected colonies were given a 3- to 4-d acquisition access to TN1 plants infected with RTBV + RTSV, and then individually given 1-d inoculation access to 1-wk-old seedlings of test varieties in test tubes. Inoculated plants were indexed by index serology 1 mo after inoculation.

On IR varieties. Irrespective of colony used, IR8, IR20, IR26, IR36, and IR42 had relatively higher infection rates. On IR50, IR54, IR56, IR58, IR60, IR62, and IR64, selected colonies transmitted RTBV + RTSV at higher rates, and the TN1 colony transmitted primarily RTBV alone (Fig. 13). Overall transmission rates on these varieties were higher when selected colonies were used, and lower when TN1 colony was used. Selected colonies did not transmit the viruses efficiently, especially on the corresponding varieties. Irrespective of the colony used for inoculation, IR20, IR26, and IR30 were infected with RTBV alone.

On non-IR varieties. Selected colonies also transmitted RTBV + RTSV at relatively higher rates than did TN1.



13. Transmission of rice tungro bacilliform (RTBV) and spherical (RTSV) viruses on seedlings of IR varieties by selected RTV-viruliferous green leafhopper colonies. IRRI, 1987.

RAGGED STUNT

Plant Pathology

Screening methods for testing resistance. *Scoring based on infection rate.* The mass screening method for testing resistance to ragged stunt virus (RSV) was developed in 1978. In this screening method, we inoculate test seedlings in pots (29 seedlings/variety per pot) by releasing RSV-viruliferous brown planthoppers (BPH) into a cage with 16 pots, then scoring for infection rates about 1 mo after inoculation. Varieties that have infection rates of 0-30% are defined as R, 31-60% as intermediate, and 61-100% as S. By this method, we tested about 20,000 varieties and lines. All germplasm that had low infection rates in the screening method was found to be R to the vector BPH. The low infection rates are likely to be due to their resistance to BPH.

Scoring based on symptom severity. We developed a new scoring method that can differentiate varieties with resistance to RSV infection or tolerance for RSV, and we have modified the mass screening methods as follows.

1. Seeds are soaked in water, and 20 germinated seedlings are transplanted in a pot.
2. At 7 to 10 d after soaking, 16 pots are placed in a cage and exposed to RSV-viruliferous BPH at 15-20 BPH/seedling for 1 d.
3. At 5 WAI, individual seedlings are scored as follows:

   1 = no symptoms

   3 = 0-10% plant height reduction, without abnormal leaves, leaves may have vein swelling on sheaths and may be shorter and darker green

5 = 0-10% plant height reduction with 1-2 abnormal leaves
7 = 10-30% plant height reduction with normal youngest leaves, 3-4 abnormal leaves
9 = more than 31% plant height reduction with abnormal leaves, including the youngest

4. Average score is calculated to indicate resistance or tolerance level of variety.
5. Three infected plants are transplanted in a concrete tub in a screenhouse and their fertility recorded.

In 1987, out of a total of 10,273 entries, 5,364 were tested under the new method. Varieties that showed higher fertility had average scores of 3-6 (Table 25).

Table 25. Average scores of varieties that showed higher fertility in the modified mass screening method for ragged stunt virus resistance. IRRI, 1987.

Accession no.	Variety	Average score	Origin
24383	Lai Lah 27-16-77	3	Thailand
24385	Lai Luang PW 60-12-874	4	Thailand
24542	Buntut Semut Putih	4	Indonesia
24561	Kapai	3	Indonesia
25329	Agai Kuning	4	Indonesia
25365	Cicih Jambu	4	Indonesia
25383	Del Tabanan	5	Indonesia
25415	Jeruyuk	5	Indonesia
25420	Keriahan	5	Indonesia
25427	Ketan Jaka	4	Indonesia
25439	Ketan Semut	5	Indonesia
25446	Kureng Kuning	4	Indonesia
25474	Padi Bayak	4	Indonesia
25488	Padi Embacang	4	Indonesia
25548	Padi Sudura	4	Indonesia
25562	Page Gersing	5	Indonesia
25595	Pulut Inhul	6	Indonesia
25625	Pulut Silupa	4	Indonesia
25679	Siansimun	6	Indonesia
25700	Sijarun Pare	5	Indonesia
25726	Simanuk	5	Indonesia
25730	Simeden	6	Indonesia
25735	Sinaek	4	Indonesia
43654	Sitopas	4	Indonesia

DISEASE RESISTANCE IN WILD RICES

Plant Pathology and Plant Breeding Departments

Screening wild germplasm for disease resistance. To identify useful sources of parental germplasm for disease resistance, we began a systematic screening of wild rices against major diseases. Preliminary screening results of selected wild rices against BB were obtained. Fifty-nine entries from 41 wild rice accessions were screened against 6 Philippine races of Xeo. The species tested were *O. longistaminata*, *O. nivara*, "*O. perennis*" with the AA genome, and *O. latifolia* with the CCDD genome. Plants were inoculated at 45-54 DAS, when most were at maximum tillering. Lesion areas were scored at 14 DAI (Table 26). Two entries, 104796-2 and 103821-1, were observed to have nonspecific resistance, i.e., R or MR to all six races. Nine *O. nivara* entries and one "*O. perennis*" entry showed resistance to four or more races. Specific resistance to only one or two races was observed in eight entries (e.g., 103893-2 and 102167-3). Generally, no variation in reaction was observed within accessions. But in *O. nivara* accession 102166, 102166-1 and 102166-3 were R to BB races, whereas 102166-2 was MS to races 1, 3, 4, 5, and 6.

The patterns of disease reaction in these wild rices resemble those observed among rice cultivars, suggesting that genes conditioning a differential reaction to races of the pathogen are present in these wild rices. Whether these genes are identical to those already present in the *O. sativa* gene pool remains to be tested.

Transfer of disease resistance from wild germplasm. Crosses were made between *Oryza sativa* and its wild relatives *O. minuta* (BBCC) and *O. latifolia* (CCDD) in an attempt to introgress useful agronomic traits to *O. sativa*. Backcrossing to the cultivated rice parent is now under way. The transfer of disease resistance was monitored by evaluating F_1 plants from these two crosses: *O. sativa* (IR31917-45-3-2)/ *O. minuta* (Acc. 101089, 101141), and *O. sativa* (IR36)/ *O. latifolia* (Acc. 100966).

Blast. The *O. minuta* parents were HR to Bl and the IR parent was S when exposed to natural inocula in the IRRI Bl nursery. Nodal cuttings (about 4-6 wk old) from F_1 plants and 18-d-old seedlings of the IR and *O. minuta* parents were tested with Bl fungus isolate PO-6-6 in the greenhouse. Again, the IR parent was fully S, whereas *O. minuta* was HR. The majority (49 of 51) of F_1 plants gave a hypersensitive reaction. Cuttings from three F_1 plants, however, showed a few intermediate S lesions.

Table 26. Adult plant reaction of *Oryza longistaminata*, *O. nivara*, "*O. perennis*", and *O. latifolia* to 6 Philippine races of *Xanthomonas campestris* pv. *oryzae*.[a] IRRI, 1987.

Species code[b]	Race 1		Race 2		Race 3		Race 4		Race 5		Race 6	
	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type
					O. longistaminata							
100930-1	–	–	10	MS	6	MR	78	HS	–	–	44	S
101199-2	67	HS	10	MS	12	MS	15	HS	22	MS	66	HS
103893-2	3	MR	19	MS	10	MS	10	MS	7	MR	17	MS
104100-1	8	MR	24	MS	22	MS	15	MS	9	MS	35	S
					O. nivara							
100898-1	–	–	13	MS	21	MS	59	HS	19	MS	19	MS
101193-1	18	MS	11	MS	14	MS	15	MS	16	MS	25	MS
101971-1	21	MS	26	MS	15	MS	27	MS	16	MS	32	MS
101973-1	22	MS	25	MS	19	MS	19	MS	23	MS	27	MS
101973-2	20	MS	18	MS	20	MS	24	MS	18	MS	30	MS
101973-3	20	MS	30	MS	19	MS	22	MS	16	MS	28	MS
101975-1	19	MS	23	MS	21	MS	24	MS	18	MS	36	S
101975-3	18	MS	23	MS	22	MS	28	MS	22	MS	28	MS
101994-1	40	S	24	MS	26	MS	36	S	26	MS	24	MS
102166-1	1	R	1	R	1	R	1	R	1	R	–	–
102166-2	22	MS	6	MR	11	MS	12	MS	13	MS	18	MS
102166-3	2	R	4	MR	3	MR	3	MR	2	R	14	MS
102167-1	25	MS	14	MS	13	MS	27	MS	23	MS	32	MS
102167-2	43	S	38	S	26	MS	47	S	65	HS	92	HS
102167-3	21	MS	8	MR	3	MR	20	MS	17	MS	29	MS
102169-1	2	R	2	R	2	R	10	MS	3	MR	26	MS
102169-3	3	MR	1	R	2	R	10	MS	2	R	28	MS
102179-1	9	MS	4	MR	6	MR	15	MS	6	MR	26	MS
103407-1	13	MS	27	MS	27	MS	24	MS	18	MS	36	S
103422-1	18	MS	17	MS	26	MS	24	MS	12	MS	30	MS
103422-3	–	–	–	–	42	S	60	HS	–	–	50	S
103821-1	4	MR	6	MR	8	MR	2	R	1	R	5	MR
103824-1	3	MR	7	MR	1	R	10	MS	1	R	35	S
103826-1	2	R	4	MR	3	MR	14	MR	–	–	28	MS
103826-2	1	R	2	R	2	R	14	MS	2	R	30	MS
103826-3	1	R	3	R	–	–	9	MS	1	R	32	MS
103834-1	22	MS	9	MS	20	MS	38	S	18	MS	38	S
103834-3	–	–	6	MR	15	MS	–	–	15	MS	19	MS
103835-1	27	MS	15	MS	20	MS	22	MS	–	–	30	MS
103835-3	17	MS	21	MS	12	MS	31	MS	15	MS	44	S
103839-2	21	MS	–	–	16	MS	38	S	18	MS	41	S
103840-2	–	–	12	MS	–	–	12	MS	–	–	26	MS
103840-3	17	MS	10	MS	12	MS	13	MS	10	MS	26	MS
103841-1	12	MS	4	MR	3	MR	30	MS	6	MR	1	R
103841-3	9	MS	3	MR	3	MR	20	MS	16	MS	1	R
104405-1	40	S	38	S	35	S	70	HS	57	HS	73	HS
104440-3	–	–	42	S	46	S	60	HS	–	–	72	HS
104443-1	75	HS	62	HS	40	S	70	HS	50	S	40	S
104473-1	15	MS	38	S	19	MS	30	MS	29	MS	39	S
102171-2	20	MS	5	MR	–	–	–	–	8	MR	–	–
102171-3	–	–	1	R	–	–	1	R	–	–	1	R
102176-1	–	–	20	MS	34	S	18	MS	–	–	38	S
102176-2	–	–	45	S	–	–	36	S	30	MS	56	HS
104687-1	52	HS	39	S	38	S	60	S	40	S	53	HS
104691-1	51	HS	44	S	44	S	43	S	42	S	61	HS
104691-2	59	HS	47	S	38	S	60	S	40	S	53	HS
104692-2	74	HS	41	S	42	S	46	S	34	S	65	HS
104696-1	43	S	37	S	38	S	48	S	34	S	55	HS
104697-1	40	S	43	S	40	S	44	S	31	MS	45	S

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Table 26 continued

Species code	Race 1		Race 2		Race 3		Race 4		Race 5		Race 6	
	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type
						"O. perennis"						
103848-1	38	S	37	S	34	S	27	MS	23	MS	52	HS
104766a-3	36	S	44	S	43	S	42	S	39	S	43	S
104756-2	10	R	1	R	1	R	1	R	3	MR	1	R
104642-2	44	S	1	R	2	R	49	S	40	S	66	HS
						O. latifolia						
100962-2	4	MR	14	MS	6	MR	23	MS	7	MR	28	MS
100964-1	9	MS	30	MS	27	MS	31	MS	14	MS	32	MS

[a]The representative isolates of races 1, 2, 3, 4, 5, and 6 were PXO 61, PXO 86, PXO 79, PXO 71, PXO 111, and PXO 99. Reaction type: R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, HS = highly susceptible. [b]First six digits represent the International Rice Germplasm Center accession number; final digit represents the plant from which seeds were obtained for testing.

Bacterial blight. An initial test of *O. minuta* and IR31917-45-3-2 against six Philippine races of Xco showed that *O. minuta* was R to all isolates, while the IR parent was R to race 1 (PXO 61), MR to race 5 (PXO 112), and S to races 2, 3, 4, and 6. This disease reaction pattern suggests that the *O. sativa* parent has resistance gene *Xa-4*.

Nodal cuttings of *O. sativa*/*O. minuta* F_1 hybrid plants were tested for reaction to BB (Table 27). Most F_1 plants showed resistance to all six races, indicating dominance for resistance factors from the *O. minuta* parent. However, a MS reaction to PXO 99 (race 6) was observed in one hybrid (WHC6-1), while a fully S reaction to PXO 71 (race 4) was observed in another hybrid (WHC7-3). Both hybrids were derived from an *O. minuta* plant (Acc. 101089) that was found to be polymorphic for the phosphoglucose isomerase isozymes. Tests are being made to confirm whether the factors conferring resistance to isolates PXO 71 and PXO 99 are heterozygous in the *O. minuta* parent.

The F_1 plants and the two parents in the cross *O. sativa* (IR64)/*O. latifolia* (Acc. 100966) were tested for their reaction to BB. The F_1 plants were tested at maximum tillering or at the flag leaf stage. The reactions of the F_1 plants were very similar to those of IR64 (Table 28), but some variations were observed. For example, WHD44-1 was MR to race 4 even though both parents were MS to that race.

PATHOGEN GENETICS

Plant Pathology Department

Experiments were done in collaboration with the University of Wisconsin at Madison and Kansas State University.

Blast fungus. Frequent shifts of virulence in the Bl fungus have been a constant problem in breeding durable resistance to the disease. Little is known about the genetics of virulence and the variability of the Bl fungus because of lack of systems amenable to genetic analysis. Recently, we succeeded in using the sexual stage of the fungus to determine the genetic control of virulence on rice. Random spore and tetrad analysis showed that two loci—Pos1 (pathogenicity on *O. sativa*) and Pos2—were involved in conditioning virulence to rice lines 51583 and Sha-tiao-tsao. From a cross between two field rice isolates, we identified three loci—Pos3, Pos4, and Pos5—controlling virulence on rice lines K59, 28558, and Kinandang Patong, respectively. Joint segregation analysis showed an excess of parental types with respect to virulence. This might reflect genetic linkage of virulence genes or segregation of other genetic factors epistatic to virulence. The virulence genes are being mapped by restriction fragment length polymorphism analysis.

Through genetic analysis, we have identified a buff pigment mutation that acts epistatically to virulence. The buff gene controls melanin synthesis

Table 27. Reactions of F_1 hybrids of *O. sativa* (IR31917-45-3-2)/*O. minuta* (Acc. 101089, 101141) and their parents to 6 Philippine races of *Xanthomonas campestris* pv. *oryzae* at maximum tillering.[a] IRRI, 1987.

Genotype code	Race 1		Race 2		Race 3		Race 4		Race 5		Race 6	
	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type
IR31917-45-3-2	11	MS	11	MS	19	MS	27	MS	6	R	22	MS
O. minuta (101089, 101141)	3	MR	2	MR	4	MR	1	R	1	R	1	R
F_1 hybrids[b]												
WHC1-2	1	R	–	–	–	–	–	–	–	–	–	–
WHC1-3	1	R	–	–	1	R	1	R	1	R	1	R
WHC1-4	1	R	–	–	–	–	1	R	1	R	–	–
WHC1-5	1	R	1	R	1	R	1	R	1	R	1	R
WHC3-1	1	R	1	R	1	R	1	R	1	R	1	R
WHC3-2	2	R	1	R	1	R	1	R	1	R	2	R
WHC3-3	1	R	1	R	1	R	1	R	1	R	1	R
WHC6-1	–	–	–	–	1	R	–	–	–	–	9	MS
WHC7-1	4	MR	–	–	–	–	–	–	–	–	6	MR
WHC7-3	4	MR	–	–	–	–	34	S	–	–	–	–
WHC8-1	–	–	–	–	–	–	[illegible]	R	1	R	–	–
WHC8-2	–	–	1	[illegible]	–	–	–	–	–	–	1	R
WHC8-3	1	R	1	R	1	R	1	R	1	R	1	R
WHC8-4	1	R	1	R	1	R	1	R	1	R	1	R

[a]The representative isolates of races 1, 2, 3, 4, 5, and 6 are PXO 61, PXO 86, PXO 79, PXO 71, PXO 111, and PXO 99. R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible. [b]The first number represents the cross number; the final digit represents the plant that was tested.

Table 28. Reactions of IR64, *Oryza latifolia* (Acc. 100966), and F_1 hybrids of IR64/*O. latifolia* to 6 Philippine races of *Xanthomonas campestris* pv. *oryzae*.[a] IRRI, 1987.

Genotype code	Race 1		Race 2		Race 3		Race 4		Race 5		Race 6	
	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type	Lesion area (%)	Reaction type
IR64	5	MR	45	S	44	S	15	MS	6	MR	43	S
O. latifolia (100966)	5	MR	4	MR	6	MR	12	MS	7	R	14	MS
F_1 hybrids[b]												
WHD44-1	3	MR	30	MS	–	–	6	MR	3	MR	38	S
WHD44-2	5	MR	22	MS	16	MS	11	MS	5	MR	48	S
WHD45-3	–	–	40	S	18	MS	–	–	–	–	57	MS
WHD45-4	3	MR	19	MS	15	MS	16	MS	16	MS	45	S
WHD46-1	–	–	42	S	20	MS	10	MS	4	MR	29	MS

[a]The representative isolates of races 1, 2, 3, 4, 5, and 6 are PXO 61, PXO 86, PXO 79, PXO 71, PXO 111, and PXO 99. R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible. [b]The first number represents the cross number; the final digit represents the plant that was tested.

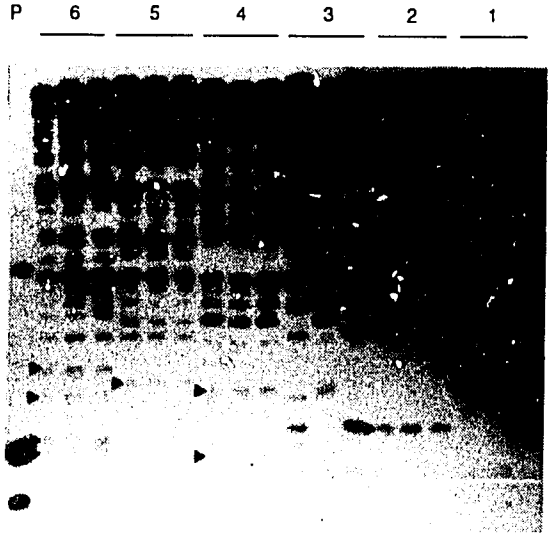
in the fungus, which is essential for successful penetration of host cells. Buff mutants cannot infect rice even though they have the correct combination of virulence genes. We are particularly interested in identifying plant components that may affect melanin synthesis in the fungus, as it might lead to durable Bl resistance.

Bacterial blight pathogen. A collection of antibiotic-resistant mutants from six Philippine races of Xco was obtained by spontaneous mutation or by nitrosoguanidine-induced mutagenesis. These genetically marked mutants were used as recipients in conjugal matings with *Escherichia coli*. Conjugal matings were achieved by using Xco strains that had been adapted to Czapek-Dox medium. The medium suppressed the growth of *E. coli*, thus allowing the selection of slow-growing Xco transconjugants via triparental mating with helper plasmids. The available genetic system now enables us to analyze the structure and function of genes involved in pathogenesis.

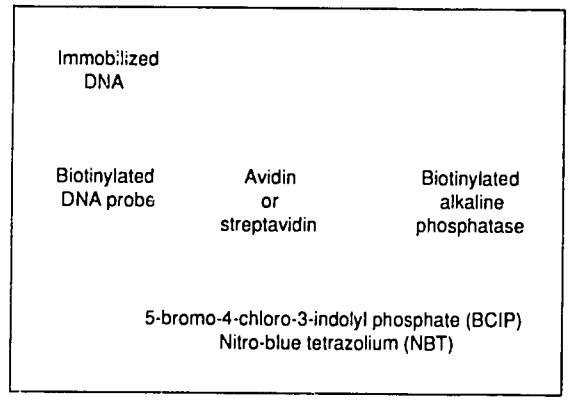
In addition to the development of a conjugal gene transfer system, we searched for lysogenic phages in Xco as a potential tool for genetic analysis. Supernatants from each tested isolate were obtained by centrifuging 24-h peptone broth cultures at 10,000 rev/min for 10 min. Ten microliters of chloroform-treated supernatant was spot-plated onto indicator strains to look for the presence of plaque-forming phages. Over 500 isolates from 6 Xco races were tested, but no lysogen was detected. Several isolates of race 4 consistently gave turbid plaques when infected with phages that were virulent to other races. Temperature and ultraviolet light induction are being used to determine whether these race 4 isolates could harbor lysogenic phages.

DNA probes for differentiation of pathogen strains. Genomic DNA libraries of the Bl fungus and BB pathogen have been constructed in plasmid cloning vectors. Such libraries provide a source of random DNA sequences that can be used as diagnostic probes in epidemiological studies.

From a cosmid library of Xco race 2, we identified a repeated DNA sequence that appeared to reveal race-specific polymorphisms when hybridized with digested genomic DNA of Xco races (Fig. 14). Also, in the Bl fungus, a repeated DNA sequence that hybridized with digested DNA of



14. Southern blot of EcoR I-digested *Xanthomonas campestris* pv. *oryzae* DNA probed with a ^{32}P-labeled repeated DNA sequence pJEL101, IRRI, 1987. Samples 1, 2, 3, 4, 5, and 6 refer to the 6 races in the Philippines. P refers to the plasmic pJEL101. Note bands (arrows) unique to races 1, 2, 4, 5, and 6.

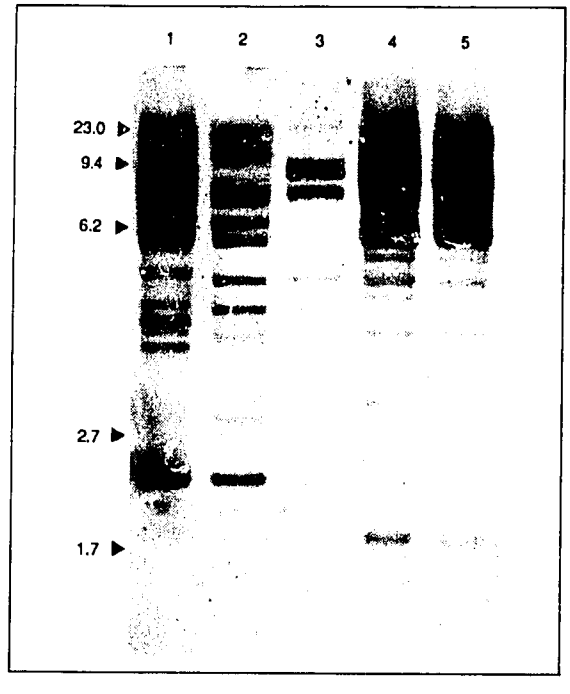


15. Nucleic acid hybridization with biotin-labeled probe. IRRI, 1987.

rice isolates but not with the DNA of two nonrice isolates was identified. These probes will be used to characterize field populations of the Bl fungus and Xco.

Biotin-labeled probes. Due to problems in obtaining a reliable supply of ^{32}P-radioactive nucleotides, we explored the use of a nonradioactive labeling technique with biotinylated nucleotides. This technique exploited the high affinity between biotin and avidin or streptavidin. Biotinylated DNA molecules could be coupled with biotinylated enzymes using avidin or streptavidin as an intermediate (Fig. 15). The DNA streptavidin- or avidin-enzyme complex will in turn give a color reaction with enzyme substrates.

Using standard nick-translation, DNA sequences from Xco were labeled with biotinylated deoxyribonucleotides and used to hybridize with genomic DNA digested by restriction endonucleases. Southern blot analysis showed that biotinylated DNA probes could detect DNA polymorphisms in various *X. campestris* pathovars (Fig. 16). The same biotin-labeled probe had been found to be sensitive enough to differentiate Xco from other pathovars of *X. campestris* in dot blot analysis. Other nonradioactive labeling procedures



16. Southern blot of EcoR I-digested DNA of *Xanthomonas campestris* pv. *oryzae* pathovars, IRRI, 1987. The blot was hybridized with a biotin-labeled cosmid clone from a genomic library of PXO 112. Lane 1 = *X. campestris* pv. *oryzicola*, 2 = *X. campestris* pv. *manihotis*, 3 = *X. campestris* pv. *campestris*. Lanes 4 and 5 are race 4 (PXO 71) and race 2 (PXO 86) of *X. campestris* pv. *oryzae*, respectively.

such as photobiotin labeling will be tested to develop a technique that will be simple and sensitive enough for routine blot hybridization analysis.

Genetic evaluation and utilization (GEU) program

Insect resistance

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SOURCES OF RESISTANCE

Entomology and Plant Breeding Departments and International Rice Testing Program

Evaluation of germplasm and other materials (*Entomology and Plant Breeding*). Screening of germplasm collections in 1987 identified accessions resistant to nine insect pests but none to whorl maggot *Hydrellia philippina* (Table 1). Of the 172,347 lines and other materials tested, 99% were evaluated for resistance to brown planthopper (BPH), green leafhopper (GLH), and yellow stem borer (YSB), indicating the current importance of these rice insect pests (Table 2, 3, 4).

Table 1. Screening of germplasm and breeding lines for resistance to insect pests. IRRI, Jan-Nov 1987.

Insect	Germplasm collections			Lines and other materials		
	Tested (no.)	Resistant		Tested (no.)	Resistant	
		no.	%		no.	%
Brown planthopper *Nilaparvata lugens*						
Biotype 1	4,426	517[a]	11.7	48,246	40,232	83.4
Biotype 2	0	–	–	17,746	11,372	64.1
Biotype 3	0	–	–	20,590	15,097	73.3
Whitebacked planthopper *Sogatella furcifera*	1,524	2	0.1	1,560	9	0.6
Green leafhopper *Nephotettix virescens*	1,623	53[a]	3.3	82,142	44,289	53.9
Yellow stem borer *Scirpophaga incertulas*	1,778	97[a]	5.4	1,661	257	15.5
Leaffolder *Cnaphalocrocis medinalis*	2,498	205[a]	8.2	126	0	0
Leaffolder *Marasmia patnalis*	2,253	1,123[a]	49.8	126	0	0
Whorl maggot *Hydrellia philippina*	2,991	0	0	126	0	0
Caseworm *Nymphula depunctalis*	2,617	5[a]	0.2	126	0	0
Hairy caterpillar *Rivula atimeta*	2,904	448[a]	15.4	126	0	0
Rice thrips *Stenchaetothrips biformis*	438	118	27	308	55	17.8
Total	23,052	2,568	11.1	172,883	111,311	64.4

[a]For retesting.

Table 2. Summary of breeding lines and varieties screened for resistance to brown planthopper (BPH) *Nilaparvata lugens*.[a] IRRI, 1987.

Test material[b]	Tested (no.)	Resistant	
		no.	%
Germplasm collection	1,521	248	16.3
Hybridization block (DS and WS)	654	392	59.9
Pedigree nurseries	86,582	66,701	77.0
Observational yield trial (DS and WS)	5,132	3,374	65.7
Replicated yield trial (DS and WS)	2,467	2,148	87.1
GEU elite lines (DS and WS)	378	272	72.0
IRTP materials	1,542	814	52.8
Wild rice lines (*O. officinalis*)	3,081	1,866	60.6
Tissue culture and F_1 hybrids	542	348	64.2
Chinese, Korean, and UPLB[c] materials	2,359	1,543	65.4
Total or average	104,249	77,406	74.25

[a]Materials tested for BPH biotypes 1, 2, and 3. [b]DS = dry season, WS = wet season. [c]University of the Philippines at Los Baños.

Table 3. Summary of breeding lines and varieties screened for resistance to green leafhopper *Nephotettix virescens*. IRRI, 1987.

Test material	Tested (no.)	Resistant	
		no.	%
Germplasm collection	1,623	53[a]	3.3
Hybridization block (DS)	218	66	30.3
Hybridization block (WS)	229	93	40.6
Pedigree nurseries[b]	78,443	41,943	53.5
Observational yield trial (DS)	490	297	60.6
Observational yield trial (WS)	1,304	1,089	83.5
Rainfed lowland yield trial	99	62	62.6
Replicated yield trial (DS)	384	242	63.0
Replicated yield trial (WS)	387	242	62.5
GEU elite lines (DS)	63	36	57.1
GEU elite lines (WS)	63	32	50.8
IRTP materials	436	168	38.5
F_1 hybrids	26	19	73.1
Wild rices	140	38	27.1
Other materials	14	6	42.9
Total or average	83,919	44,386	52.9

[a]To be retested. [b]Includes pedigree nurseries, Nov 1986 up to start of Nov 1987.

Table 4. Summary of breeding lines and varieties screened for resistance to yellow stem borer (YSB) *Scirpophaga incertulas*. IRRI, 1987.

Test material	Tested (no.)	Selected	
		no.	%
Germplasm collection	1778	97[a]	5.4
Stem borer composites	179	22	12.3
Replicated yield trial (DS)	383	10	2.6
Replicated yield trial (WS)	368	62	16.8
GEU elite lines (DS)	63	12	19.0
IRTP materials	441	104	23.6
UPLB materials	227	47	20.7
Total or average	3439	354	10.3

[a]For further testing.

IRTP insect resistance trials. (*International Rice Testing Program and Entomology*). Insect resistance information from 1986 International Rice Testing Program (IRTP) nurseries was analyzed in 1987. Table 5 shows entries that performed well across locations. Entries rated resistant to specific insects at certain locations are given in Table 6. Detailed results on IRTP trials are included in the IRTP section of this report.

Resistance of progenies of *Oryza sativa* and *O. officinalis* crosses (*Plant Breeding and Entomology*). We have derived 633 BC_2F_6 progenies from the crosses of 3 breeding lines of *O. sativa* with several *O. officinalis* accessions. In the 1987 wet season (WS), 633 BC_2F_6 pedigree lines were evaluated by the standard seedbox screening test (SSST) for BPH biotypes 1, 2, and 3, and the Mindanao BPH biotype. Of the 633 progenies screened, 329 showed resistance to biotype 1, 195 to biotype 2, and 263 to biotype 3. Only 102 progenies showed resistance to the virulent Mindanao BPH, and only 50 showed resistance to all biotypes tested. The pedigree lines IR54742-23-11-19-6 and IR54745-2-23-19-8 showed high resistance to all biotypes.

Resistance of GEU elite lines (*Entomology and Plant Breeding*). We evaluated 63 elite lines in WS for resistance to leafhoppers and planthoppers using SSST. Of the 24 lines resistant to GLH, to BPH biotypes 1, 2, and 3, and to Mindanao BPH, 7 were moderately resistant to whitebacked planthopper (WBPH) (Table 7). About 60% of the GEU elite materials during the dry season (DS) and WS were resistant to the 3 BPH biotypes.

Table 5. Best entries in 1986 IRTP insect nurseries. IRRI, 1987.

Nursery[a]	Trials (no.)	Entries rated resistant
IRBPHN	22	PTB33, IR27316-78-3-3, IR29725-109-1-2-1, IR28224-3-2-3-2, IR13427-45-3-1-2-2-2, IR29692-94-2-1-3, IR32822-2-2-3-2, RNR3070, Rathu Heenati (Acc. 11730)
IRWBPHN	3	Bahbolon, IR13475-7-3-2, IR13427-45-3-1-2-2-2, IR15529-253-3-2-2-2, Rathu Heenati (Acc. 11730), IR2035-117-3, IR15795-151-2-3-2-2, IR17307-11-2-3-2, IR28154-101-3-2, IR15527-21-2-3
IRSBN	2	
Vegetative phase		IR45, IR4619-57-1-1-2-1, W1263 (Acc. 11057)
Heading stage		IR15795-151-2-3-2-2, IR28150-84-3-3-2, IR4619-57-1-1-2-1, Ratna

[a]IRBPHN = International Rice Brown Planthopper Nursery, IRWBPHN = International Rice Whitebacked Planthopper Nursery, IRSBN = International Rice Stem Borer Nursery.

Resistance of Korean lines (*Entomology and Plant Breeding*). We screened 108 Korean lines at IRRI against BPH and WBPH pests using SSST and identified lines resistant to BPH biotypes 1 (96%), 2 (50%), and 3 (68%) (Table 8). Only 6% of the Korean lines were moderately resistant to BPH.

Using the modified seedbox screening test, we screened 46 Korean lines identified susceptible in SSST and found 13 lines resistant. Among the 13, HR6615-49-6-3, SR11027-B-B-145-2, and YR3583-28-3-7-1-1 exhibited antibiosis to BPH biotype 2, as indicated by lower growth indices.

Resistance of F_1 rice hybrids (*Entomology and Plant Breeding*). We screened 26 F_1 hybrids and their parents. Among them, 81% resisted *Nephotettix virescens* and *Nilaparvata lugens*, while 50% were resistant or moderately resistant to *Sogatella furcifera*. In growth index studies, the F_1 hybrids of IR54752A crossed with IR28723-143-3-2-1R, IR27315-145-1-3-2R, IR54R, and IR13419-113-1R exhibited antibiosis to *N. lugens* biotype 2.

Table 7. Resistance of selected wet season GEU elite lines and IR varieties to leafhoppers and planthoppers. IRRI, 1987.

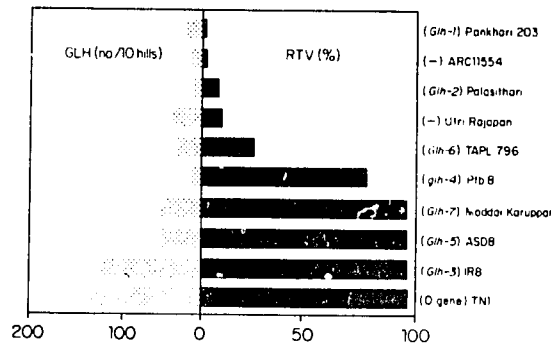
Variety or line	Reaction[a] to					
	BPH biotypes				GLH	WBPH[b]
	1	2	3	Mindanao		
IR8	S	S	S	S	S	S
IR36	R	R	S	S	S	S
IR64	R	R	R	S	R	S
IR66	R	R	R	S	R	S
IR19319-1-2-1-1-2	R	MR	R	MR	R	MR
IR28224-3-2-3-2	R	R	MR	MR	R	S
IR28228-12-3-1-1-2	R	R	R	MR	MR	S
IR29723-88-2-3-3	R	R	R	R	R	S
IR32429-47-3-2-2	R	R	R	MR	R	S
IR32429-122-3-1-2	R	R	R	R	R	S
IR32453-20-3-2-2	R	R	R	R	R	S
IR33043-46-1-3	R	R	R	R	R	MR
IR33059-26-2-2	R	R	R	R	R	MR
IR34686-179-1-2-1	R	R	R	MR	R	MR
IR35366-28-3-1-2-2	R	R	R	R	R	MR
IR35366-62-1-2-2-3	R	R	R	R	R	MR
IR35366-90-3-2-1-2	R	R	R	MR	R	S
IR37873-16-2-3-3-3-1	R	R	R	R	R	S
IR40720-72-1-2	R	R	R	R	MR	S
IR41985-77-3-3-3	R	R	R	R	R	S
IR41996-12-2-2-3	R	R	R	MR	MR	S
IR41996-118-2-1-3	R	R	R	R	MR	S
IR41996-163-2-1-2	R	R	R	R	R	MR
IR42028-50-2-1-3-2-2	R	R	R	MR	MR	S
IR42029-38-1-3-3-2	R	R	R	MR	R	S
IR42068-22-3-3-1-3	R	R	R	MR	R	S
IR44530-4i-1-2-1	R	R	R	R	R	S
IR44595-70-2-2-3	R	R	R	MR	R	S
TN1	S	S	S	S	S	S

[a]R = resistant, MR = moderately resistant, S = susceptible.
[b]Whitebacked planthopper. Based on modified seedbox screening technique.

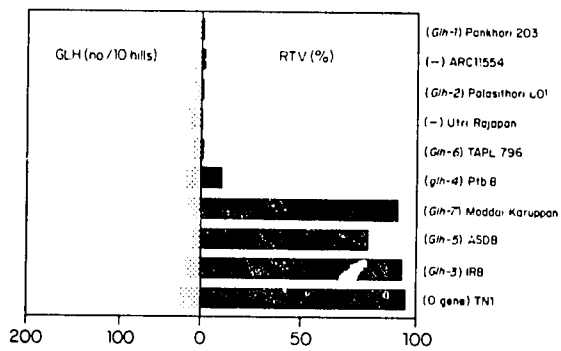
Table 8. Level of resistance of 108 Korean lines to *N. lugens* biotypes 1, 2, and 3, and to *S. furcifera*. IRRI, Jan-Mar 1987.

Pest	Biotype	Lines (%) with damage score[a] of			
		1 & 3	5	7	9
N. lugens	1	84	12	4	0
	2	15	35	44	6
	3	49	19	26	6
S. furcifera		0	6	40	54

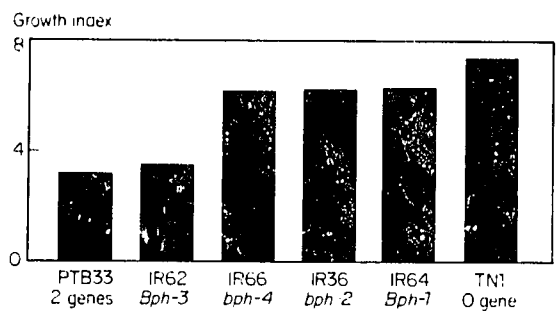
[a]Based on 0-9 damage scale in the standard seedbox screening test: 0 = highly resistant, 9 = highly susceptible.



1. Green leafhopper (GLH) count at 30 d after transplanting (DT) and tungro (RTV) (%) at 60 DT on differential hosts in Midsayap, North Cotabato, Philippines, 1987 WS.



2. GLH count at 30 DT and RTV (%) at 60 DT on differential hosts. IRRI, 1987 WS.



3. Brown planthopper (BPH) reactions on selected varieties irrespective of location. IRRI, 1987 WS.

(*Bph-1*), and IR66 (*bph-4*) were becoming susceptible (Fig. 3). PTB33 (two resistance genes) and IR62 (*Bph-3*) were still resistant at all six Philippine locations.

Screening for whitebacked planthopper resistance—effect of temperature (*Entomology*). We determined whether differences in temperature

Table 7. Resistance of selected wet season GEU elite lines and IR varieties to leafhoppers and planthoppers. IRRI, 1987.

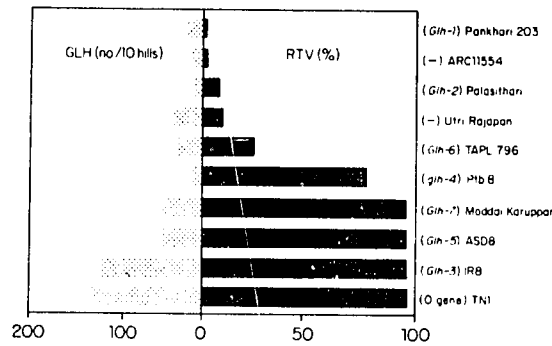
Variety or line	Reaction[a] to					
	BPH biotypes				GLH	WBPH[b]
	1	2	3	Mindanao		
IR8	S	S	S	S	S	S
IR36	R	R	S	S	S	S
IR64	R	R	R	S	R	S
IR66	R	R	R	S	R	S
IR19319-1-2-1-1-2	R	MR	R	MR	R	MR
IR28224-3-2-3-2	R	R	MR	MR	R	S
IR28228-12-3-1-1-2	R	R	R	MR	MR	S
IR29723-88-2-3-3	R	R	R	R	R	S
IR32429-47-3-2-2	R	R	R	MR	R	S
IR32429-122-3-1-2	R	R	R	R	R	S
IR32453-20-3-2-2	R	R	R	R	R	S
IR33043-46-1-3	R	R	R	R	R	MR
IR33059-26-2-2	R	R	R	R	R	MR
IR34686-179-1-2-1	R	R	R	MR	R	MR
IR35366-28-3-1-2-2	R	R	R	R	R	MR
IR35366-62-1-2-2-3	R	R	R	R	R	MR
IR35366-90-3-2-1-2	R	R	R	MR	R	S
IR37873-16-2-3-3-3-1	R	R	R	R	R	S
IR40720-72-1-2	R	R	R	R	MR	S
IR41985-77-3-3-3	R	R	R	R	R	S
IR41996-12-2-2-3	R	R	R	MR	MR	S
IR41996-118-2-1-3	R	R	R	R	MR	S
IR41996-163-2-1-2	R	R	R	R	R	MR
IR42028-50-2-1-3-2-2	R	R	R	MR	MR	S
IR42029-38-1-3-3-2	R	R	R	MR	R	S
IR42068-22-3-3-1-3	R	R	R	MR	R	S
IR44530-41-1-2-1	R	R	R	R	R	S
IR44595-70-2-2-3	R	R	R	MR	R	S
TN1	S	S	S	S	S	S

[a]R = resistant, MR = moderately resistant, S = susceptible.
[b]Whitebacked planthopper. Based on modified seedbox screening technique.

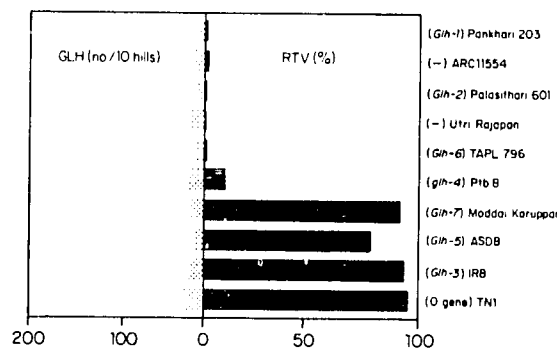
Table 8. Level of resistance of 108 Korean lines to *N. lugens* biotypes 1, 2, and 3, and to *S. furcifera*. IRRI, Jan-Mar 1987.

Pest	Biotype	Lines (%) with damage score[a] of			
		1 & 3	5	7	9
N. lugens	1	84	12	4	0
	2	15	35	44	6
	3	49	19	26	6
S. furcifera		0	6	40	54

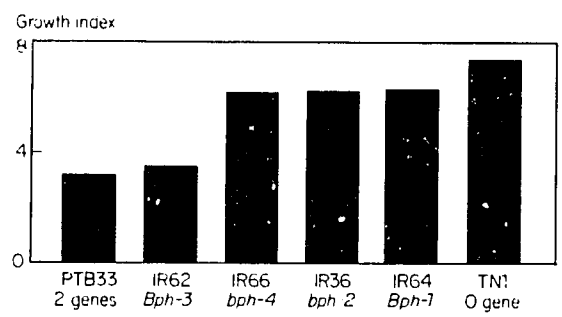
[a]Based on 0-9 damage scale in the standard seedbox screening test: 0 = highly resistant, 9 = highly susceptible.



1. Green leafhopper (GLH) count at 30 d after transplanting (DT) and tungro (RTV) (%) at 60 DT on differential hosts in Midsayap, North Cotabato, Philippines, 1987 WS.



2. GLH count at 30 DT and RTV (%) at 60 DT on differential hosts. IRRI, 1987 WS.



3. Brown planthopper (BPH) reactions on selected varieties irrespective of location. IRRI, 1987 WS.

(*Bph-1*), and IR66 (*bph-4*) were becoming susceptible (Fig. 3). PTB33 (two resistance genes) and IR62 (*Bph-3*) were still resistant at all six Philippine locations.

Screening for whitebacked planthopper resistance—effect of temperature (*Entomology*). We determined whether differences in temperature

would affect WBPH infestation and damage to test varieties. Regardless of temperature, TN1 and Podiwi A8 were susceptible to WBPH. The resistant check IR2035-117-3 and the moderately resistant IR60 and IR65 remained unaffected, but mean damage ratings of other test varieties differed significantly at different temperature regimes (Table 9). The optimum temperatures for screening resistance to WBPH were 20/30 °C or 25/35 °C.

Efficiency of green leafhopper nymphs in tungro transmission (*Entomology*). Screening for RTV resistance uses GLH adults, but nymphs are used in screening for resistance to GLH. We tested whether GLH nymphs could be used in screening for RTV resistance. We allowed 2d- to 3d-instar nymphs to feed on RTV-infected TN1 plants for 15, 24, and 72 h. We then infested 7-d-old TN1 seedlings at 1, 3, or 6 nymphs per seedling for 2 h.

At infestation by 1 nymph/seedling, nearly 70% of seedlings became infected when exposed to nymphs having had acquisition feeding periods as short as 15 h. In another test, 7-d-old TN1 seedlings were infested for 1, 2, or 6 h with GLH nymphs that had fed overnight on source plants. A 1-h inoculation feeding period was enough for RTV transmission. We also successively infested 4 healthy TN1 seedlings at 2-h intervals with single viruliferous nymphs: 71% of infective nymphs transmitted RTV to the first seedling, 78% to the second and third, and 58% to the fourth.

Table 9. Effect of temperature on *S. furcifera* damage rating of selected varieties.[a] IRRI, 1987.

Variety or line	Damage rating at indicated night/day temperature				Mean
	15/20 °C	15/25 °C	20/30 °C	25/35 °C	
IR48	4.17	5.50	6.33	5.67	5.42
IR52	3.67	5.83	5.00	5.00	4.88
IR60	4.67	5.00	5.50	5.50	5.17
IR62	3.67	4.83	5.00	4.83	4.58
IR65	4.67	5.00	5.67	5.83	5.29
SR11027-50-2-2	4.00	5.17	5.83	6.00	5.25
HR6615-9-3-2	3.67	5.83	5.83	6.00	5.33
YR6408 Acp 75	3.33	5.[illegible]7	5.67	5.83	5.00
Gayabyeo	3.67	5.17	4.50	7.00	5.08
Milyang 82	3.83	6.00	6.50	7.00	5.83
Podiwi A8	4.83	6.50	7.00	6.50	6.21
N22	3.83	2.50	5.33	2.83	3.62
TN1	5.00	7.17	7.17	7.50	6.71
IR2035-117-3	3.00	1.50	3.17	2.00	2.42
Total means[b]	4.00 c	5.08 b	5.16 a	5.54 a	–

[a]Av of 12 replications. [b]Means followed by a common letter are not significantly different at the 5% level by DMRT.

Table 10. *N. lugens* biotype 2 reaction on selected rice varieties.[a] IRRI, 1987.

Variety	Adult recovery (%)	Development period (d)	Longevity of female (d)	Viable eggs (no./female)	Population (no./cage)	Damage rating[b]
TN1	92.5 c	12.5 c	18.2 d	279 b	486 d	9.0 c
IR26	85.0 c	12.8 c	16.6 d	242 b	445 d	9.0 c
Utri Rajapan	88.5 c	12.9 c	18.2 d	270 b	444 d	3.0 b
Kencana	83.8 c	13.3 bc	5.9 bc	60 a	227 c	2.3 ab
Triveni	82.5 c	14.1 b	5.1 abc	86 a	131 b	2.3 ab
ASD7	36.2 bc	14.1 b	1.8 a	0 a	16 a	2.3 ab
IR56	15.0 a	15.8 a	2.1 ab	0 a	2 a	1.0 a

[a]Av of 8 replications. [b]Plants were infested with 400 nymphs/45-d-old plant.

NATURE OF RESISTANCE

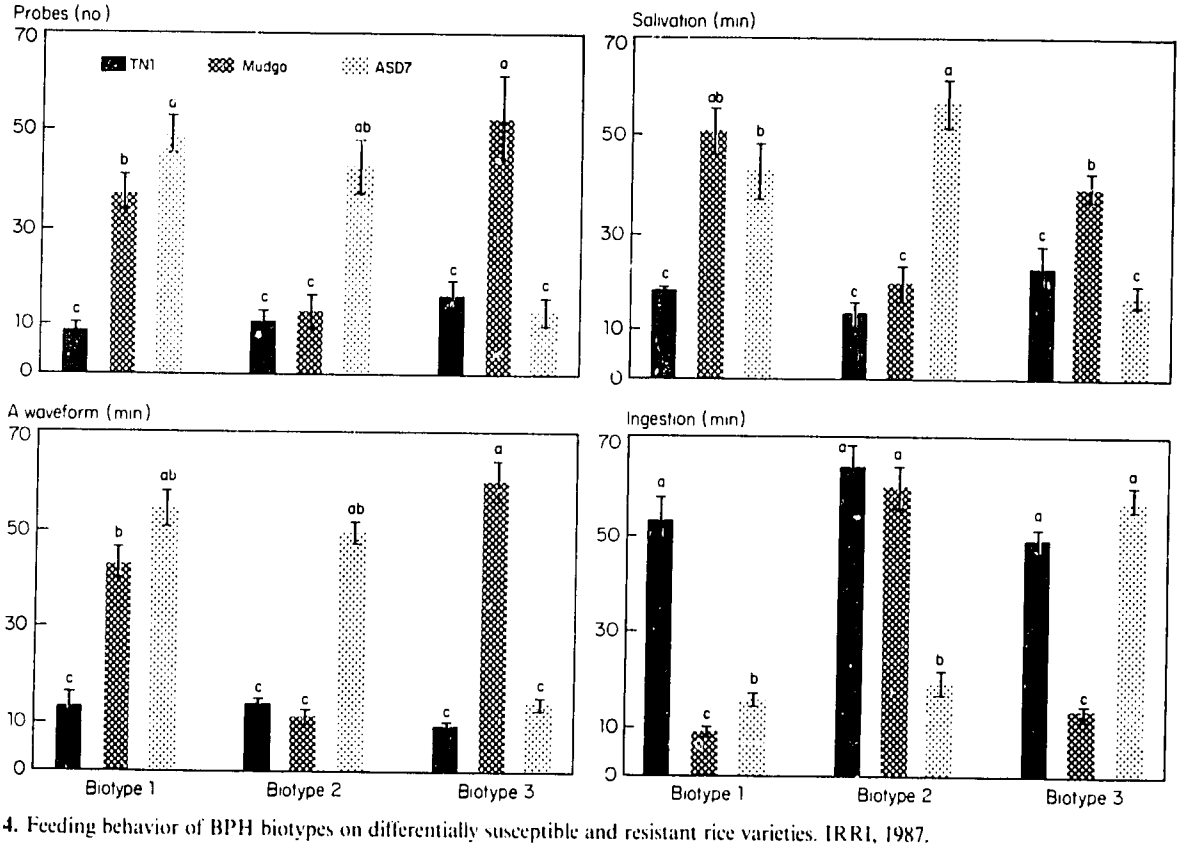
Entomology Department

Tolerance for brown planthopper. Responses of BPH biotype 2 on Utri Rajapan, Kencana, and Triveni, considered tolerant, were compared with those on susceptible TN1 and IR26, and on resistant ASD7 and IR56. Nymphal growth and development, female longevity and fecundity, and increase in population of BPH biotype 2 on tolerant Utri Rajapan were not significantly different from those on susceptible TN1 and IR26 (Table 10). Utri Rajapan was significantly less damaged than TN1 or IR26 when infested with 400 BPH nymphs/45-d-old plant.

Feeding behavior of brown planthopper biotypes on resistant and susceptible rice varieties. The feeding activity of *N. lugens* biotypes 1, 2, and 3 was monitored on TN1 (no resistance gene), Mudgo (*Bph-1* gene), and ASD7 (*bph-2* gene) rices. Electronically recorded waveforms corresponding to planthopper probing, salivation, and ingestion on the leaf sheaths of susceptible and resistant rice plants differed significantly. All three biotypes probed readily and fed longer on their respective susceptible varieties than on resistant varieties (Fig. 4). The quantity of food ingested and assimilated was also significantly higher on susceptible than on resistant plants.

Effect of mineral, salinity, and temperature stresses on rice plants and on the whitebacked planthopper population. We conducted phytotron studies to determine the effect of N, K, salinity, and temperature stresses on rice growth and on WBPH population increase. Rice plants were grown in culture solutions for separate N, K, and salinity tests, and 35-d-old plants were infested with 5 pairs of WBPH adults.

Increasing the N level increased plant height and tiller number and significantly reduced root length (Table 11). WBPH population also increased with increase in N level, but differences in insect



4. Feeding behavior of BPH biotypes on differentially susceptible and resistant rice varieties. IRRI, 1987.

Table 11. Effect of nitrogen and potassium stresses on rice plants in culture solutions and on *S. furcifera* population.[a] IRRI, 1987.

Concn. (ppm)	TN1 Height (cm)	TN1 Tillers (no.)	TN1 Root length (cm)	IR2035-117-3 Height (cm)	IR2035-117-3 Tillers (no.)	IR2035-117-3 Root length (cm)	Nymphs and adults (no.) TN1	Nymphs and adults (no.) IR2035-117-3	Nymphs and adults (no.) Difference[b]
					Nitrogen				
5	39.1 c	3.8 c	30.1 a	47.8 c	4.1 c	50.8 a	311.8 a	5.8 a	306.0**
40	64.9 b	10.1 b	30.0 a	73.8 b	10.1 b	47.8 b	1618.8 b	21.3 b	1597.5**
200	71.9 a	14.1 a	14.5 b	79.3 a	13.3 a	20.2 c	2183.8 c	57.5 c	2126.3**
					Potassium				
3	63.6 b	11.2 b	34.7 b	57.1 c	13.3 c	41.8 b	665.0 b	50.0 c	615.0**
40	71.8 a	12.4 a	38.6 a	76.0 b	13.7 b	48.8 a	551.0 ab	33.0 b	518.0**
200	71.8 a	12.6 a	38.2 a	78.5 a	14.6 a	48.5 a	446.0 a	22.0 a	424.0**

[a]In a column under each parameter, means followed by a common letter are not significantly different at the 5% level by DMRT. Rice plants were measured after 40 d of N stress and 50 d of K stress. Five pairs of WBPH were released, and counting was done about 45 d after release for N and 30 d for K. [b]** = significant at the 1% level by LSD.

populations on susceptible TN1 and resistant IR2035-117-3 remained significant.

Plant height, tiller number, and root length were low in plants grown in K-deficient culture solution. Increase in K significantly reduced WBPH population.

Salinity stress reduced plant height, root length, and weight of rice plants (Table 12). WBPH populations on salinity-stressed TN1 and IR2035-117-3 were significantly higher than on control plants. However, WBPH populations on tolerant varieties Nona Bokra and Pokkali did not increase significantly when salts were added.

WBPH population was significantly higher on TN1 grown at 29/21 °C (day/night temp) than at higher (36/28 °C) or lower (24/16 °C) temperatures (Table 13). On resistant IR2035-117-3, insect populations were significantly higher at both higher and lower temperatures than at 29/21 °C. Thus, both lower and higher temperature stresses reduced resistance.

Response of striped stem borer on selected wild rices. Freshly cut, 18-cm-long stalks of 5 wild rice accessions in glass jars were separately infested with 50 first-instar larvae per jar, 2 jars per accession. Rexoro was the susceptible check, and

Table 12. Effect of salinity stress on rice plant growth and increase in *S. furcifera* population.[a] IRRI, 1987.

Parameter	Treatment[b]	Varieties: TN1	IR2035-117-3	Nona Bokra	Pokkali
Plant height (cm)	Salinity	71.2 c	62.9 d	105.0 b	119.9 a
	Control	74.3 d	81.7 c	116.4 b	128.6 a
	% ±	- 4.2**	-23.0**	- 9.8**	- 6.8**
Tillers (no.)	Salinity	5.2 ab	5.6 a	4.8 b	3.0 c
	Control	5.4 b	6.4 a	4.8 c	3.0 d
	% ±	- 3.7 ns	-12.5**	0.0 ns	0.0 ns
Root length (cm)	Salinity	15.5 d	31.1 a	29.0 b	21.5 c
	Control	24.3 d	38.6 b	41.8 a	30.2 c
	% ±	-36.2**	-19.4**	-30.6**	-28.8**
Fresh weight of shoot (g)	Salinity	100.3 c	68.9 d	163.7 a	150.2 b
	Control	145.1 c	92.5 d	224.2 a	213.8 b
	% ±	-30.9**	-25.5**	-27.0**	-29.7*
Nymphs or adults (no.)	Salinity	546.3 a	51.5 c	315.5 b	31.0 b
	Control	433.5 a	28.0 c	255.0 b	252.8 b
	% ±	+26.0*	+45.6**	+23.7 ns	+22.6 ns

[a]In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. ns = not significant, * = significant at the 5% level, ** = significant at the 1% level by LSD. [b]Level of salts was EC 12 dS/m (6800 ppm) except for IR2035-117-3 (EC 10 dS/m or 5000 ppm).

TKM6 the resistant check. Jars were covered with black cloth held tightly with rubber bands and kept at room temperature to allow larvae to grow. Rice stalks were dissected at 4-d intervals, and the collected larvae were weighed and transferred to fresh rice stalks until pupation. On all wild rices, larvae were underweight and failed to pupate. Larval survival was 37% on TKM6 and 63% on Rexoro.

Stem borer neonate sensitivity to handling. We investigated whether neonate handling has any growth-inhibiting effect on pink stem borer *Sesamia inferens* reared on an artificial diet. When neonate larvae were transferred with a camel hair brush to a Southwestern corn borer diet, pupae reared from them weighed less than those reared without disturbance from the blackhead egg stage.

Effect of plant age on susceptibility to yellow stem borer. We measured survival of YSB larvae and degree of damage on IR64 plants of varying ages infested with newly emerged larvae at 15 larvae/20 tillers per pot. Few larvae survived and emerged on younger rice plants (Table 14). Survival increased with plant age up to 34 and 40 d after sowing (DAS), but thereafter declined progressively. Consequently, fewer deadhearts were observed in younger plants than in plants at 34, 40, and 46 DAS; deadheart count declined sharply at 52 DAS. Larvae were heaviest on plants at 40 DAS; they weighed less on plants at 34, 46, and 52 DAS.

Table 13. Effect of temperature stress and varietal resistance on population increase of *S. furcifera*. IRRI, 1987.

Day/night temp (°C)	Nymphs and adults (no.)		
	TN1	IR2035-117-3	Difference[a]
16/17	427.8 b	67.8 a	360.0**
29/21	585.8 a	34.8 b	551.0**
35/27	594.3 a	75.3 a	519.0**
24/16	441.5 b	72.3 a	369.2**
29/21	519.5 a	39.5 b	480.0**
36/28	24.8 c	21.3 b	3.5 ns

[a]** = significant at the 1% level by LSD, ns = not significant.

Performance of *Marasmia patnalis* on selected rice varieties. We measured *M. patnalis* feeding response, fecundity, hatchability, and growth index on 10 rice varieties including resistant TKM6 and susceptible IR36 checks. On most test varieties, *M. patnalis* fed less, laid fewer eggs, and developed more poorly than on susceptible IR36 (Table 15). Hatchability was also significantly less on Kamalbhog and ASD7 than on IR36.

Yield loss due to leaffolders. We conducted field trials to determine leaffolder (LF) damage to IR36 rice plants at 45, 55, and 65 DAS and at different infestation levels, using adults (1986 WS) or eggs at the blackhead stage (1987 DS). Results showed that IR36 yield decreased as infestation level increased. As insect density increased, a larger leaf surface area was scraped by larvae.

Settling and feeding preference, and growth of rice leaffolder on selected wild rices. We evaluated four wild rices—*O. australiensis*, *O. nivara*, *O. punctata*, and *O. perennis*—for their resistance to rice LF *Cnaphalocrocis medinalis*. In a choice test, fewer larvae settled and fed on *O. australiensis*, *O. perennis*, and *O. nivara* than on susceptible IR36 (Table 16, Fig. 5). None of the wild rices except *O. australiensis* was more preferred than resistant

Table 14. Survival and development of YSB *S. incertulas* larvae and damage at different days after infestation (DAI) on IR64 plants of different ages.[a] IRRI, 1987.

Plant age (DAS)	Larval wt (mg/larva) 18 DAI	Survival (%)		Adults that emerged (no.)	Deadhearts (%)	
		18 DAI	25 DAI		18 DAI	25 DAI
10	0 a	0 a	1 a	0 a	10 a	9 a
16	7.8 b	2 ab	2 ab	0 a	22 b	12 b
22	8.9 b	2 ab	4 ab	0 a	25 b	14 b
28	12.8 c	4 b	5 b	5 b	27 b	16 bc
34	34.1 de	68 d	55 d	33 c	69 c	66 de
40	41.2 e	68 d	52 d	63 d	69 c	71 e
46	33.3 de	37 c	49 d	48 c	57 c	56 d
52	29.8 d	28 c	28 c	41 c	27 b	26 c

[a]Av of 4 replications.

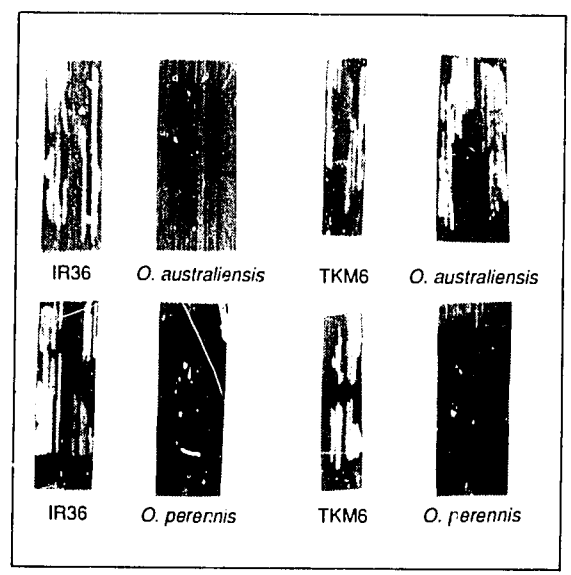
Table 15. Performance of leaffolder *M. patnalis* on selected rice varieties. IRRI, 1987.

Variety	Accession no.	Dry wt (mg) of excreta/10 larvae per 24 h	Fecundity (no. of eggs/ female)	Hatchability (%)	Growth index
Vazhaipoo Samba	59339	0.44 h	214 b	80 ab	3.03 ab
Choorapaudy	49529	0.36 l	186 b	78 ab	2.63 b
GE824	5909	0.42 i	192 b	78 ab	2.81 b
PTB33	19375	0.39 k	211 b	83 ab	2.97 b
Darukasail	45493	0.65 c	200 h	87 ab	3.27 ab
Kamalbhog	43020	0.53 d	211 b	74 b	2.61 b
Kapur Kanti	46048	0.47 g	178 b	85 ab	2.59 b
W1263	11057	0.50 f	156 b	78 ab	2.54 b
Muthumanikam	15327	0.52 e	232 b	81 ab	3.05 ab
ASD7	6303	0.67 b	202 b	73 b	3.25 ab
TKM6	237	0.40 j	173 b	80 ab	3.33 ab
IR36	30416	0.72 a	343 a	89 a	3.85 a

Table 16. Settling responses of LF *C. medinalis* larvae on leaf cuts of susceptible IR36 and wild rices in a choice test. IRRI, 1987.

Plant	Larvae that settled (%)	Difference[a]
IR36	87.5	75.0**
Oryza australiensis	12.5	
IR36	65.3	30.6**
O. nivara	34.7	
IR36	70.8	41.6**
O. perennis	29.2	
IR36	51.4	2.8 ns
O. punctata	48.6	
IR36	83.3	66.6**
TKM6	16.7	
TKM6	41.6	−16.8**
O. australiensis	58.4	
TKM6	61.6	22.2 ns
O. nivara	38.9	
TKM6	51.4	2.8 ns
O. perennis	48.6	
TKM6	45.8	−8.4 ns
O. punctata	54.2	

[a]** = significant at the 1% level by the chi-square test, ns = not significant.



5. Feeding by *C. medinalis* larvae on leaf cuts of susceptible IR36 and resistant TKM6 plants vs *Oryza australiensis* and *O. perennis* in 2-choice test. IRRI, 1987.

TKM6 plants. First-instar larvae caged on *O. perennis* showed significantly lower weight at 15 d after infestation than on other rice varieties and wild rices (Table 17).

Spinning and feeding behavior of rice leaffolder on selected susceptible and resistant rice plants. Electronically recorded waveforms for the spinning and feeding behavior of LF *C. medinalis* were distinctly different on leaf blades of susceptible and resistant plants. On susceptible IR36, the insect readily folded the leaf blade and fed steadily (Table 18). In contrast, the insect was restless on resistant TKM6 plants and consequently fed for reduced periods.

Effect of nitrogen level on leaffolder incidence and damage to susceptible and resistant rice varieties. In a field trial at Lian, Batangas, N at 0, 30, 60, 90, and 120 kg/ha was applied to susceptible IR36, moderately resistant IR5865-26-1, and resistant TKM6 to study LF incidence on rice. At 65 and 75 d after transplanting (DT), LF damage

Table 17. Weights of 5th instar *C. medinalis* larvae reared on susceptible IR36, resistant TKM6, and selected wild rices.[a] IRRI, 1987.

Plant	Weight (mg)/larva
Oryza australiensis	16.6 b
O. nivara	14.9 c
O. perennis	8.2 e
O. punctata	13.9 cd
TKM6 (resistant check)	12.7 d
IR36 (susceptible check)	18.8 a

[a]Av of 10 replications, 10 larvae/replication.

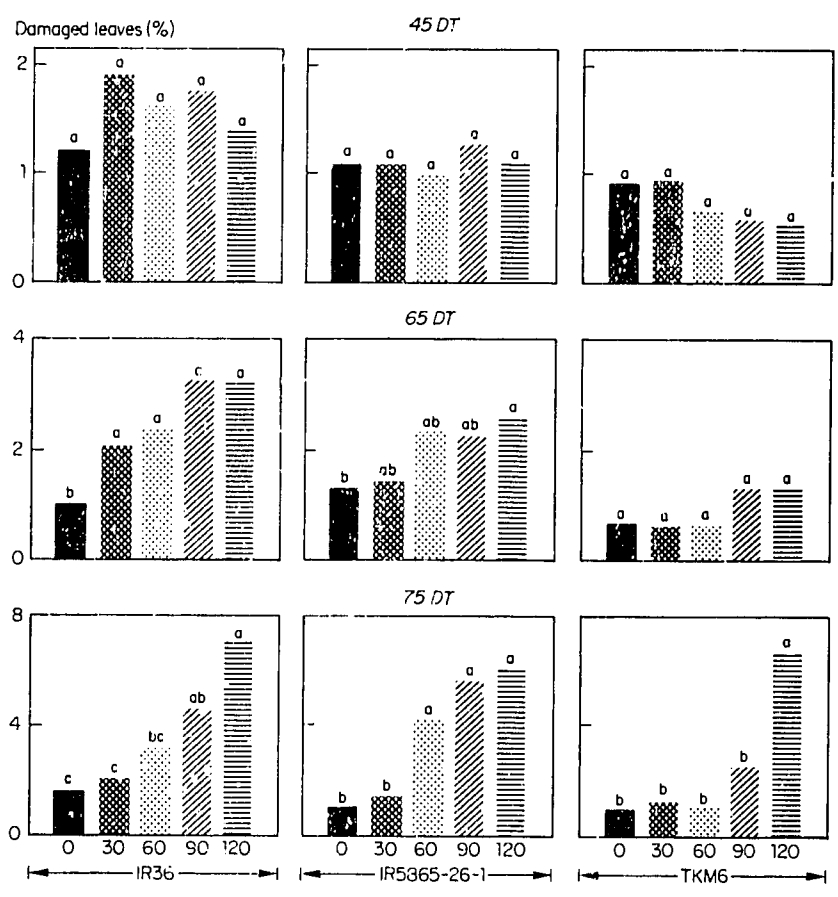
Table 18. Means of electronically recorded events during 60-min feeding by *C. medinalis* larvae on susceptible and resistant rice varieties.[a] IRRI, 1987.

Variety	Duration (min)			
	Spinning	Feeding	Moving	Resting
TKM6 (resistant)	25.3	10.8	19.8	4.1
IR36 (susceptible)	16.7	27.1	13.3	1.9
Difference[b]	8.6**	−16.3**	6.5**	2.2 ns

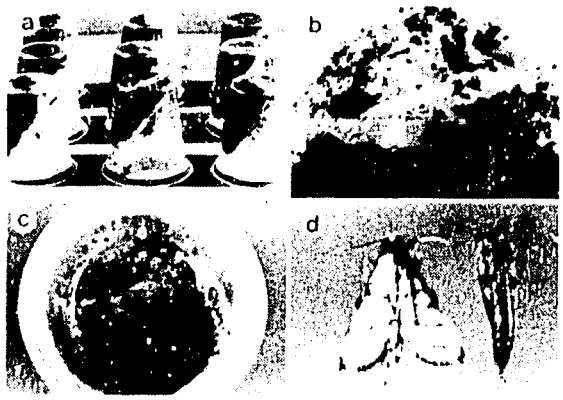
[a]Av of 15 replications. Each replication had a fresh plant and a fresh larva. [b]** = significant at the 1% level by LSD, ns = not significant.

on IR36 and IR5865-26-1 increased significantly as N application increased. Damage to TKM6 plants increased significantly only at 120 kg N/ha at 75 DT (Fig. 6).

Artificial diet for rice leaffolder. To ensure a regular supply of LF, we reared *C. medinalis* on an artificial diet comprising agar, ground wheat germ, soy protein, ground pinto beans, sorbic acid, methyl paraben, aureomycin, ascorbic acid, torula yeast, casein, formaldehyde, and vaderzant vitamin mix (Fig. 7). The development period (14-21 d, av 16.2 d) was comparable to that on susceptible IR36



6. Damage caused by rice leaffolders to susceptible IR36, moderately resistant IR5865-26-1, and resistant TKM6 rice plants at 45, 65, and 75 DT, with application of 0, 30, 60, 90, or 120 kg N/ha. IRRI, 1987.



7. Artificial diet for rearing *C. medinalis*, IRRI, 1987. a) inverted plastic cup with the diet, b) a leaffolder (LF) larva feeding on the diet, c) a pupated LF in the cup, and d) a LF adult and pupa reared on the diet.

plants (17 d). Pupal weight, longevity, and fecundity were similar for LF on the diet and for those on IR36.

Protein profiles in leaffolder larvae feeding on resistant and susceptible rice varieties. We determined the basis for the low survival and reproduction of LF *M. patnalis* on resistant TKM6 rice. Total protein variability between 3d-instar larvae reared on resistant TKM6 and susceptible IR22 rice plants was analyzed using disc gel electrophoresis. Of 34 protein bands detected, 24 were present in TKM6-fed larvae and 28 bands in IR22-reared larvae. Six protein bands, mostly cathodal, were distinct only in larvae feeding on TKM6, while nine protein bands, mostly anodal, were distinct in larvae feeding on IR22. The high frequency of bands #32 and #33 in larvae reared on susceptible IR22 and their total absence in larvae reared on resistant TKM6 indicated the insect's inability to grow normally on the resistant variety.

CHEMICAL BASES OF RESISTANCE

Entomology, Cereal Chemistry, and Plant Breeding Departments

Biochemical basis of host selection by brown planthopper (*Entomology*). We studied the host selection behavior of BPH on TN1 rice plants and on *Leersia hexandra* grass. The odor of TN1 plant volatiles, extracted by steam distillation, attracted rice-infesting BPH adults, whereas that of *L. hexandra* attracted grass-infesting BPH. TN1 extract was more toxic to 1st-instar nymphs and newly emerged females of grass-infesting BPH than was *L. hexandra* extract (Table 19). Similarly, *L. hexandra* extract was more toxic to rice-infesting BPH individuals. Females of rice-infesting BPH ate less on TN1 plants treated with *L. hexandra* extract. Intake and assimilation of food by grass-infesting BPH was also reduced when *L. hexandra* plants were treated with TN1 extract.

Gas chromatography of steam distillates from TN1 rice versus *L. hexandra* plants indicated differences. TN1 plants were richer in sugars, proteins, and amino acids than were *L. hexandra* plants. Thus, rice-infesting BPH individuals adapted to feed on high concentrations of sugars and amino acids do not prefer nutritionally poor *L. hexandra* grass. Similarly, grass-infesting BPH individuals do not prefer nutritionally rich TN1 rice plants.

Phloem sap and susceptibility to brown planthopper (*Cereal Chemistry and Entomology*). Because BPH is a phloem feeder, we collected phloem sap from rice plants by cutting the bases of panicles in 80% ethanol or water diffusate from stem segments of 45-d-old plants. Bleeding sap from panicle bases had 50% more free sugars in susceptible IR8 plants than in resistant IR26.

Table 19. Toxicity of steam distillate extracts of TN1 rice plants and *L. hexandra* grass to newly emerged females of rice- and grass-infesting *N. lugens*.[a] IRRI, 1987.

Treatment	Dosage (µg/female)	Mortality[b] (%)
	Rice-infesting BPH	
TN1 extract	1	6 de
	5	7 de
	10	12 cd
L. hexandra extract	1	20 bc
	5	37 ab
	10	49 a
Acetone (control)	0	3 e
	Grass-infesting BPH	
TN1 extract	1	17 c
	5	23 bc
	10	50 a
L. hexandra extract	1	4 d
	5	4 d
	10	30 b
Acetone (control)	0	4 d

[a]Av of 10 replications, 10 females/replication. [b]Under each parameter, means followed by a common letter are not significantly different at the 5% level by DMRT.

Results with diffusates from 45-d-old plant stem segments were similar, and showed 50% more free amino acids in IR8.

Plant volatiles, steam distillates, and fractions from varieties resistant to stem borer and leaffolder (*Cereal Chemistry and Entomology*). Because of the labile nature of some plant volatiles, we developed a technique for collecting rice plant volatiles directly. Plant tissue (about 50 g) kept in a glass container was subjected to low pressure (10^{-3} mm Hg), the vacuum valve was closed, and the connecting collection chamber was kept at -70 °C for 24 h. The collected volatiles were saturated with sodium chloride, extracted thrice with 2 ml of methyl chloride, dried for 4 h with anhydrous sodium sulfate, and concentrated to 0.25 ml. The gas chromatography (GC) profiles of volatiles from susceptible Rexoro and resistant TKM6 plants showed qualitative differences. Preliminary GC-MS (mass spectrometry) analysis by chemists at Louisiana State University suggested that the volatiles were a mixture of naturally occurring monoterpenes.

After collecting volatiles, the residual plant material was dried at 40-45 °C, then ground and extracted with organic solvents of increasing polarity for bioassays. Incorporation of 10% dried plant powder into diets of *C. medinalis* 1st-instar larvae resulted in normal growth for susceptible IR36, delayed larval development for resistant TKM6, and higher mortality for resistant wild rices *O. punctata, O. perennis*, and *O. nivara*. Survival was 72% for the control diet, 65% for IR36 and TKM6, 52% for *O. nivara*, 31% for *O. punctata*, and 26% for *O. perennis*. Thus, dried powder is a suitable starting material for isolating factors biocidal to LF.

Cooperative GC-MS studies with chemists at the Laboratory of Chemical Evolution, University of Maryland, USA, identified volatile compounds other than pentadecanal in the steam distillate of TKM6 rice plants. They were citral, tetradecanol, hexadecanol, oleyl alcohol, 1-octadecanol, and ethyl arachidonate. Most were less biocidal to striped stem borer and BPH nymphs than was pentadecanol.

Calli as media for screening yellow stem borer resistance (*Cereal Chemistry, Plant Breeding, and Entomology*). To demonstrate the chemical basis of YSB resistance, we reared YSB larvae on calli of cultivated and wild rices on MS-3 and LS media. First-instar YSB larvae failed to survive on *O. ridleyi* callus, developed to 3d instars on resistant Chianan 2 callus, and to 5th instars on susceptible Rexoro callus in 20 d at 28 °C and 12:12 photoperiod. Crude protein content (dry weight) of callus was usually higher than that of rice. Amino acid patterns were similar, but aspartic acid was lower in callus protein.

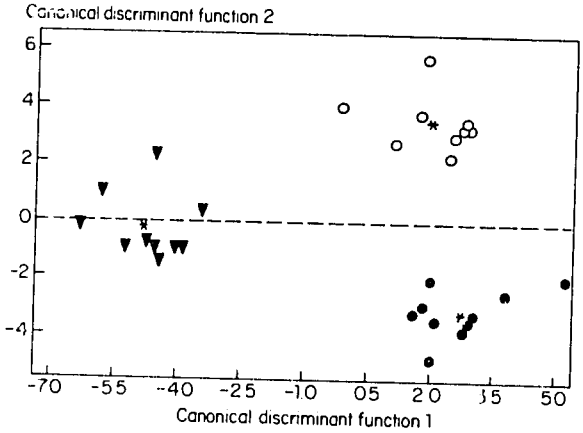
INSECT BIOTYPES

Entomology Department

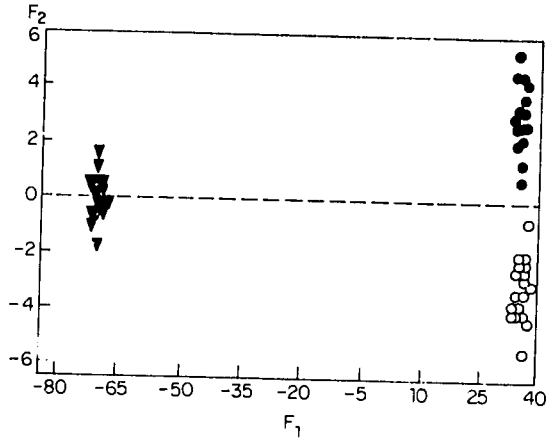
Technique to purify biotype 1 population of brown planthopper. Since BPH biotype 1 is maintained on TN1 rice plants, which are susceptible to all three biotypes, the purity of biotype 1 is always questioned. We developed a technique to obtain a homogeneous population of biotype 1 from single male-female pairs selected based on their low food intake on rice varieties Mudgo and ASD7 with *Bph-1* and *bph-2* resistance genes, respectively. The purity of this biotype 1 population was demonstrated in three generations based on differences in nymphal growth and development, and adult longevity and fecundity on resistant Mudgo and ASD7 and on susceptible TN1.

Genetic differentiation among *Nilaparvata lugens* biotypes. Using horizontal starch electrophoresis, we determined protein variation in *N. lugens* biotypes. Biotypes 1 and 2 differed genetically at five loci: adenyl kinase (AK), malic dehydrogenase (MDH), phosphoglucose isomerase (PGI), alkaline phosphatase (ALKP), and isocitric dehydrogenase (IDH). Biotypes 1 and 3 varied at four loci: MDH, PGI, ALKP, and IDH; biotype 1 and *Leersia*-infesting biotype at four loci: AK, MDH, PGI, and IDH: biotypes 2 and 3 at two loci: AK and MDH; biotype 2 and *Leersia*-infesting biotype at five loci: AK, MDH, PGI, ALKP, and IDH; and biotype 3 and *Leersia*-infesting biotype at five loci: AK, MDH, PGI, ALKP, and IDH.

Morphometrics of whitebacked planthopper populations from China, Korea, and the Philippines. We examined differences in WBPH populations, comparing morphometrics of sensory appendages (antennae, rostrum, and legs) of WBPH from China, Korea, and the Philippines. Scattered-plot diagrams based on computed discriminant



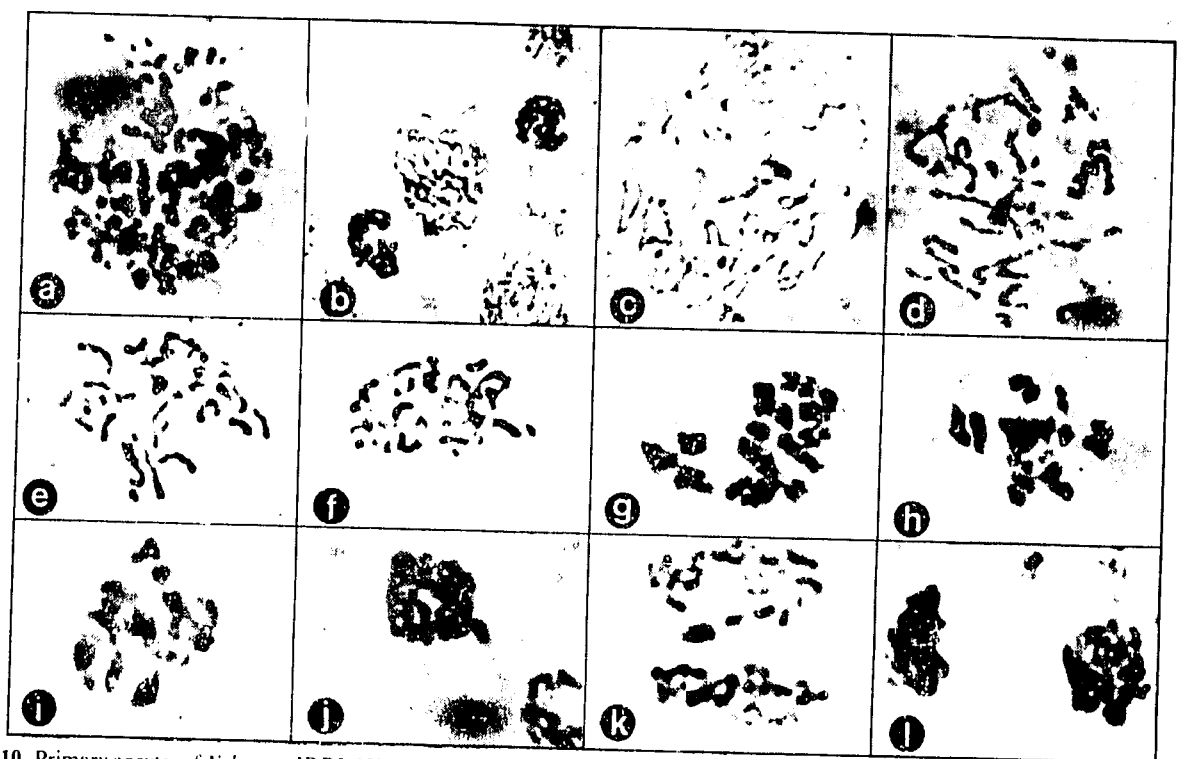
8. Scatter-plot diagram based on computed discriminant scores of 20 selected antennal, rostral, and leg characters of brachypterous females of *S. furcifera* collected from China (o), Korea (▼), and the Philippines (●). IRRI, 1987. * = mean.



9. Graph of discriminant function 1 (F1) vs discriminant function 2 (F2) of the pooled morphometrics of leg, antennal, rostral, genital, and abdominal characters of *N. virescens* females collected from the Philippines (●), Bangladesh (o), and Coimbatore, India (▼). IRRI, 1987.

scores of 20 selected and combined characters reveal distinct segregation of the 3 populations (Fig. 8).

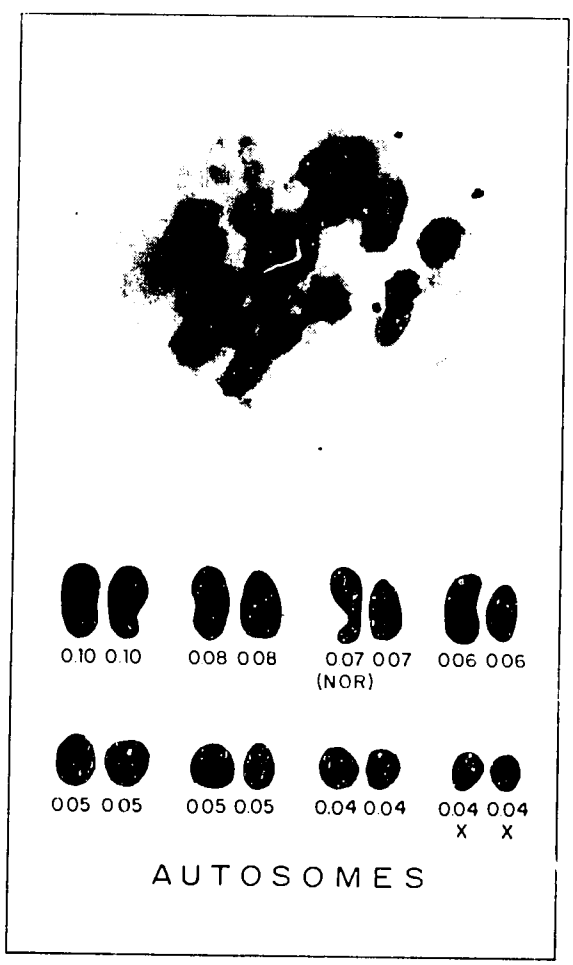
Morphometric differentiation among green leafhopper populations from Bangladesh, India, and the Philippines. Discriminant analysis of the pooled morphometrics of abdominal and sensory appendages (antennae, rostrum, and legs) showed that the three allopatric populations of *N. virescens* distinctly segregated from one another (Fig. 9).



10. Primary oocytes of *N. lugens*, IRRI, 1987. a) leptotene, b) zygotene, c) and d) pachytene, e) and f) diplotene, g) diakinesis, h) and i) premetaphase I, j) metaphase I, k) anaphase I, l) telophase I. Magnification, 1000X (oil immersion).

The leg characters were most discriminating. The Indian *N. virescens* population was completely different from the Philippine and Bangladesh populations.

Allozyme differentiation in two rice leaffolder species. Allozyme differentiation (14 loci) between *C. medinalis* and *M. patnalis* was investigated using horizontal starch gel electrophoresis. The species differed remarkably in esterase locus in the larval and pupal stages and also in isocitric dehydrogenase (IDH) locus. *M. patnalis* was differentiated for IDH-2^{94}, while *C. medinalis* was differentiated for IDH-2^{100}. The species differed further in the acid phosphatase locus. *M. patnalis* showed slower migrating isozymes, while *C. medinalis* had faster-moving isozymes.



11. Photomicrograph (top) and karyogram (bottom) of the premetaphase brain chromosomes of female *N. virescens*, IRRI, 1987. NOR = nucleolar organizing region.

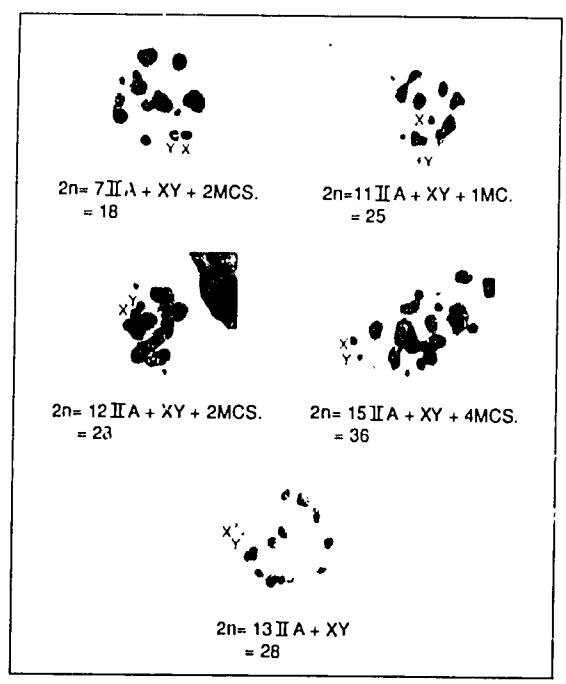
CYTOLOGY OF INSECT PESTS

Entomology Department

Oogenetic cells and chromosomes of brown planthopper. We studied genetic mitosis in the oogenetic cells of rice-infesting BPH females. Fifth-instar nymphs were ideal for studying genetic mitosis, while newly emerged females were suitable materials for first meiotic division (Fig. 10). The diploid (2n) chromosome number was 30, comprising 14 pairs of somatic homologous autosomes and a pair of sex chromosomes (XX).

Karyotype of brain chromosomes of green leafhopper. Using the standard lacto-aceto-orcein staining technique, we studied the brain chromosomes in ganglial cells of 4th-instar *N. virescens* nymphs. The premetaphase chromosome counts established the normal diploid complement at 2n = 16 (14 autosomes and XX sex chromosomes) (Fig. 11).

Meiotic cells and chromosomes of rice leaffolder. Examination of primary spermatocytes at diakinesis showed that LF *M. patnalis* possesses 16 to 34 diploid chromosomes (Fig. 12). The most common diploid complement was 2n = 28 (13 IIA + XY).



12. Photomicrographs of diakinetic chromosomes of male *M. patnalis*, IRRI, 1987. Magnification, 1000X (oil immersion).

Genetic evaluation and utilization (GEU) program

Drought tolerance

International Rice Testing Program, International Rice Germplasm Center, Rice Farming Systems Program, and Agronomy and Plant Breeding Departments

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SCREENING AND FIELD TESTING

International Rice Testing Program, International Rice Germplasm Center, and Agronomy and Plant Breeding Departments

Drought-tolerant materials identified in IRTP trials (*International Rice Testing Program*). The rice varieties and breeding lines listed in Table 1 exhibited good drought tolerance or recovery in the 1986 International Rice Testing Program (IRTP) nurseries.

1987 dry season field drought screening (*Agronomy*). In the 1987 dry season (DS), 6,600 accessions, varieties, and advanced generation lines from the International Rice Germplasm Center (IRGC), IRTP, IRRI rice breeders, and University of the Philippines at Los Baños rice breeders were screened for drought and recovery ability in the field (Table 2).

Soil moisture tension exceeded 32 kPa at 15-cm depth by day 6, and at 20-cm depth by day 9 after cessation of irrigation (Fig. 1). Drought reaction was scored when soil moisture tensions (SMTs) were within 100-200, 400-500, and 800-1000 kPa at 15-cm depth. SMT at 20-cm depth reached 300 kPa only after 40 d of imposed drought.

One hundred thirty-six entries (13 IRGC accessions, 105 breeding lines, and 18 IRTP rices) had high levels of tolerance for imposed drought (Table 2). They exhibited at most 40% leaf desiccation resulting from soil moisture deficit, and 90% or higher stand recovery at 13 d after rewatering. Of the 136 outstanding selections, 66 showed no effects of drought stress at 100-200 kPa SMT, while the rest had slight leaf tip drying. At 400-500 kPa SMT, cross IR47686 had 7 lines that did not show any effects of soil moisture deficit, and 5 lines had slight leaf tip drying. At 800-1000 kPa SMT, 8 lines of the same cross showed only slight leaf tip drying.

Table 1. Material identified for drought tolerance or recovery in 1986 IRTP trials. IRRI, 1987.

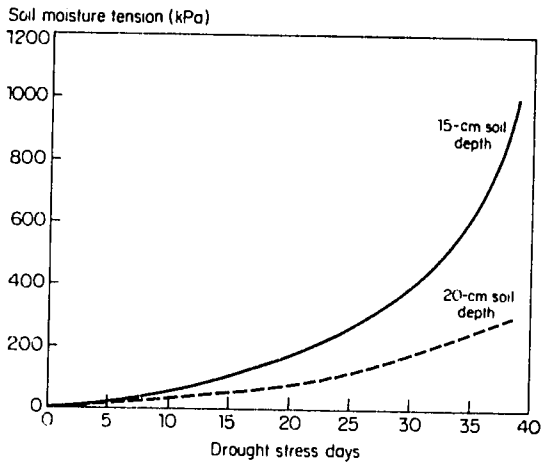
Nursery[a]	Entries
IURYN-E (3 sites)	IR10198-66-2, IR19793-25-2-2, IR25588-7-3-1, IR9761-19-1, RAU4004-105
IURYN-M (4 sites)	ADT31, B2992b-Tb-73-4-2-3-3-3-2, C894-7, IR27078-11-2, IR43
IURON[b] (6 sites)	IRAT112, IAC164, NDR116, NDR117, IR9761-40-3-2, KU82, NDR111, Palghar 31-1-3, IAC233/79, IR18599-68-1, IR2307-247-2-2-3, IR25890-82-5-3, IR25898-57-2-3, KMP34, NDR118, NDR80, UPR231-28-1-2
IRRSWYN-E (2 sites)	IR21178-39-P1, IR21567-9-2-2-3-1-3, IR5629-64-3, IR18272-27-3-1, IR21015-80-3-3-1-2, IR26933-16-2-3
IRRSWYN-M (4 sites)	IR13610-72-2-2E-P2, KDML65-GU-45-45, Mahsuri
IRRSWON (2 sites)	IR13149-43-2-P1, IR13610-72-2-2E-P2, IR21064-48-2-1E-P1, KKN7205-39-3-SKN-1-1-1, RP1064-14-2-2

[a]IURYN-E and -M = International Upland Rice Yield Nursery - Early Maturing and - Medium Maturing. IURON = International Upland Rice Observational Nursery, IRRSWYN-E and -M = International Rainfed Rice Shallow Water Yield Nursery-Early and -Medium, IRRSWON = International Rainfed Rice Shallow Water Observational Nursery. [b]Entries were given good ratings for both drought tolerance and drought recovery.

Table 2. Entries and outstanding selections in field drought screening. IRRI, 1987 DS.

Source of entry	Entries (no.)	Selections (no.)
International Rice Germplasm Center	887	13
Breeding programs		
Upland	200	0
Adverse environments	99	19
Rainfed lowland	1675	35
Deepwater	1855	43
Irrigated lowland	795	2
Others		
Elite lines	128	0
Hybridization block	188	4
Agronomy selections	84	2
International Rice Testing Program[a]		
IRYN-VE, -E, and -M	68	1
IRON	174	4
IURYN-E and -M	32	0
IURON	102	1
IRRSWYN-E and -M	32	0
IRRSWON	127	7
IRDWON	78	4
IFRON	21	0
ITPRON	45	1
University of the Philippines at Los Baños	10	0
Total	6600	136

[a]IRYN VE, -E, and -M = International Rice Yield Nursery - Very Early, -Early, and - Medium; IRON = International Rice Observational Nursery; IRDWON = International Rice Deep Water Observational Nursery; IFRON = International Floating Rice Observational Nursery; ITPRON = International Tide-Prone Rice Observational Nursery.



1. Development of soil moisture deficit during field drought screening, IRRI, 1987 DS. Day 0 = 16 Mar.

The outstanding IRGC accessions consisted of three each from Burkina Faso, India, and Sri Lanka, and two each from Burma and Sierra Leone (Table 3). Of the 18 IRTP entries that exhibited better drought reactions than the drought-tolerant check Salumpikit, 5 were from India, 2 from Thailand, and 1 each from Indonesia and Sri Lanka; 9 were IRRI-developed lines. Three out of seven lines of cross IR31432 entered in the 1986 IRTP International Rainfed Rice Shallow Water Observational Nursery (IRRSWON) were highly tolerant of drought (Table 4). Table 5 shows the drought reaction of the tolerant and susceptible checks.

Rainfed rice breeding programs produced a large number of promising lines for drought tolerance (Table 6). Cross IR47686, bred for adverse environments, yielded 16 drought-tolerant lines. Among the 19 rainfed lowland rice crosses, IR49718 produced the most drought-tolerant lines (8) while 18 other crosses yielded 28 lines. Deepwater cross IR38692 produced 9 drought-tolerant lines, while 23 other crosses produced 34 outstanding selections.

Crosses IR47686 and IR47691, bred for adverse environments, had Moroberekan as a possible drought gene(s) donor (Table 6). Sixteen of 19 rainfed lowland crosses had Nam Sagui 19 as the possible progenitor with drought tolerance. Among the deepwater crosses, seven involved RD19 as the direct parent or ancestor, and five have Nam Sagui 19 genes. Moroberekan, Nam Sagui 19, and RD19 were identified as drought tolerant in earlier drought tests.

Cross IR21015, a Nam Sagui 19 derivative, had drought-tolerant lines entered in tests for various rice environments. IR21015-72-3-3-3-1 was entered in the IRTP 1986 International Rice Observational Nursery (irrigated lowland) (Table 4). IR21015-80-3-3-1-2 was entered in the IRTP 1986 IRRSWON. Glutinous variety IR65, also known as the drought-tolerant line IR21015-196-3-1-3, has been recom-

Table 3. Outstanding International Rice Germplasm Center accessions in field drought screening, IRRI, 1987 DS.

Designation	Accession number	Origin	Drought score[a] at soil moisture tension of			Recovery score[b]
			100-200 kPa	400-500 kPa	800-1000 kPa	
Am Zi	67797	Burma	0	2	3	1
Ex Daude	69523	Burkina Faso	0	2	3	1
Ex Dan	69520	Burkina Faso	0	2	4	1
Mahogoda Al	67641	Sri Lanka	0	3	4	1
Dikwee	67620	Sri Lanka	1	3	4	1
Moe Sate Sate	67773	Burma	1	3	4	1
Ex Faramana	69529	Burkina Faso	0	4	4	1
Manki	67515	India	1	4	4	1
Podi Wee	67648	Sri Lanka	1	4	4	1
Ramrajaya	67751	India	1	4	4	1
Rewa-4	67754	India	1	4	4	1
Ex Gofor-Pujehon	69540	Sierra Leone	1	4	4	1
Pa Therei	69768	Sierra Leone	1	4	4	1

[a]0-9 scale, where 0 = no visible effects of soil moisture deficit, 9 = all plants fully desiccated. [b]1-9 scale, where 1 = 90-100% plants recovered, 9 = 0-13% plants recovered.

Table 4. Outstanding 1986 IRTP materials in field drought screening. IRRI, 1987 DS.

Designation	Source	Origin	Drought score[a] at soil moisture tension of			Recovery score[b]
			100-200 kPa	400-500 kPa	800-1000 kPa	
IR35353-94-2-1-3	IRYN-M #15	IRRI	1	3	3	1
BW288-1-3	IRON #35	Sri Lanka	1	4	4	1
B5323B-PN-5-MS-60	IRON #117	Indonesia	1	3	4	1
IR21015-72-3-3-3-1	IRON #41	IRRI	1	4	4	1
IR36	IRON #60	IRRI	0	3	4	1
RR20-5	IURON #75	India	1	4	4	1
IR21178-43-1-2-2-2	IRDWON #39	IRRI	0	3	4	1
SPR7292-0-0-0-0-1	IRDWON #74	Thailand	1	3	4	1
TCA181-1	IRDWON #77	India	0	2	4	1
TCA8	IRDWON #78	India	0	2	3	1
IR21015-80-3-3-1-2	IRRSWON #10	IRRI	1	4	4	1
IR31432-1-2	IRRSWON #90	IRRI	0	3	4	1
IR31432-15-2	IRRSWON #91	IRRI	0	2	4	1
IR31432-8-6	IRRSWON #95	IRRI	0	3	4	1
IR33383-23-3-3-3	IRRSWON #99	IRRI	1	3	4	1
MTU7029	IRRSWON #113	India	1	4	4	1
RAU4057-35-20	IRRSWON #28	India	1	4	4	1
BKN6986-66-2	ITPRON #5	Thailand	1	4	4	1

[a]0-9 scale, where 0 = no visible effects of soil moisture deficit, 9 = all plants fully desiccated. [b]1-9 scale, where 1 = 90-100% plants recovered, 9 = 0-19% plants recovered.

Table 5. Drought reaction of drought-tolerant and susceptible checks and other outstanding breeding lines in field drought screening. IRRI, 1987 DS.

Designation	Source	Drought score[a] at soil moisture tension of			Recovery score[b]
		100-200 kPa	400-500 kPa	800-1000 kPa	
Pinidut	HB86W #1087	0	3	4	1
TCA177	HB87D #1378	0	3	4	1
IR27078-3-6	HB87D #1444	1	3	4	1
IR32021-B-1-B-5-2	HB86W #1075	0	4	4	1
IR21015-196-3-1-3	Agronomy Department selection	1	2	4	1
IR20 (susceptible check)	n = 145	3.1 ± 0.04	7.1 ± 0.05	7.6 ± 0.06	5.7 ± 0.10
IRAT9 (susceptible check)	n = 146	3.8 ± 0.07	8.1 ± 0.05	8.6 ± 0.04	8.0 ± 0.10
IR442-2-58 (tolerant check)	n = 150	1.8 ± 0.06	5.6 ± 0.06	6.1 ± 0.05	2.3 ± 0.10
Salumpikit (tolerant check)	n = 146	1.5 ± 0.05	5.0 ± 0.06	5.8 ± 0.06	2.2 ± 0.08

[a]0-9 scale, where 0 = no visible effects of soil moisture deficit, 9 = all plants fully desiccated. [b]1-9 scale, where 1 = 90-100% plants recovered, 9 = 0-19% plants recovered.

mended for irrigated lowland environments but is also promising under upland conditions.

Careful selection of parents leads to development of drought-tolerant upland rices (*Plant Breeding*). In 1983, at the beginning of the IRRI-Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières collaborative project for breeding rices for unfavorable upland environments, a cross was made between IRAT104 and Palawan, two group VI (japonica) entries as identified by isozyme analysis. These parents were chosen because IRAT104 is among the most drought-resistant varieties from Africa, whereas Palawan is well adapted to Philippine soils and pests, and is preferred by consumers. One line from this cross, IR47686-6-2-B, was the top performer in the 1986 drought tolerance screening trial, and sister lines IR47686-6-2-1-1 and IR47686-6-2-2-1 were among the top entries in 1987 (Table 7). These lines demonstrate that drought tolerance can be improved through traditional breeding methods if parents are carefully selected. These derivatives of

Table 6. Crosses that produced outstanding breeding lines in field drought screening. IRRI, 1987 DS.

Cross	Drought tolerant lines (no.)	Source of tolerance[a]
Breeding for adverse environments (19 lines)		
IR47686	16	Moroberekan
IR47691	1	Moroberekan
B3622F-TB-14-2	1	–
Aus 196	1	–
Rainfed lowland rice breeding lines (35 lines)		
IR9782	1	Nam Sagui 19
IR33353	1	Nam Sagui 19
IR33355	1	Nam Sagui 19
IR42221	3	Nam Sagui 19
IR42243	2	Nam Sagui 19
IR42346	1	Nam Sagui 19
IR42563	1	Nam Sagui 19
IR43038	1	Nam Sagui 19 and Khao Dawk Mali 105
IR43048	1	Nam Sagui 19
IR43582	1	Nam Sagui 19
IR45375	1	Nam Sagui 19
IR48151	1	Nam Sagui 19
IR48799	2	Nam Sagui 19
IR49643	1	–
IR49644	1	Khao Dawk Mali 105
IR49687	4	Nam Sagui 19
IR49694	1	Nam Sagui 19
IR49702	3	–
IR49718	8	Nam Sagui 19
Deepwater rice breeding (43 lines)		
IR8234	1	Nam Sagui 19
IR38685	1	64-117
IR38692	9	64-117
IR38784	3	RD19
IR39498	1	Leb Mue Nahng 111
IR39527	2	RD19
IR39680	1	Nam Sagui 19 and Khao Dawk Mali 105
IR40554	1	8KN7022-6-4
IR41010	1	64-117
IR41125	1	Leb Mue Nahng 111
IR41134	3	DWCT156-1-B-B
IR41222	1	FR43B*
IR41371	2	RD19
IR41427	1	Nam Sagui 19
IR41430	2	Nam Sagui 19
IR41533	1	DWCT156-1-2-0-0*
IR42511	1	Nam Sagui 19 and BKN7022-6-4
IR42569	2	RD19
IR42583	1	RD19
IR42584	2	RD19
IR42590	1	BKN7022-6-4
IR42606	1	FR43B*
IR43707	2	DWCT156-1-B-B
IR43756	1	RD19
Irrigated lowland rice breeding (2 lines)		
IR21015	1	Nam Sagui 19
IR28120	1	–

[a]– = unknown parent, * = possible source of tolerance.

Table 7. Drought tolerance and recovery[a] of derivatives from IRAT104/Palawan cross, parents, and resistant check. IRRI, 1986 and 1987 DS.

	Drought tolerance score[b]			Recovery
	100-200 kPa	400-500 kPa	800-1000 kPa	
1986				
IR47686-6-2-B	0.5	1.5	4	1
IR47686-13-2-B	0	1.5	4	3
IR47686-9-8-B	0	1.5	4	3
IR47686-5-12-B	0	2	4	3
IR47686-6-10-B	0.5	2	4	3
Resistant check				
Salumpikit	1.1	3.1	5.6	2.3
1987				
IR47686-6-2-1-1	0	0	1	1
IR47686-6-2-2-1	0	0	1	1
IR47686-4-4-8-1	0	0.5	1	1
IR47686-4-5-B-1	0	0	1	1
IR47686-6-1-1	0	0	1	1
IR47686-6-1-2	0	0	1	1
IR47686-6-4-1-1	0	0	1	1
IR47686-9-4-B	0	0.5	1	1
IR47686-1-4-1-1	0	0.5	2	1
IR47686-17-1-1-1	0	0.5	2	1
Parents				
IRAT104 (E)	0	2	3	3
Palawan (A)	1.5	6	7	5
Resistant check				
Salumpikit	1.0	4.5	5.7	3

[a]Both tolerance and recovery used a modified SES scale where 0 = best and 9 = worst recovery. Av values. [b]Av of several replications.

IRAT104/Palawan should also be considered as drought tolerance donors in future crosses.

Field screening for drought resistance (*International Rice Germplasm Center*). Screening of germplasm bank (GB) accessions, and breeding lines from both the upland and lowland nurseries was continued. A total of 6,305 entries were tested (Table 8). Of 3,778 GB accessions scored during the vegetative phase, 25% were found to have high levels (score = 1-3) of field resistance to drought. Among the 814 upland breeding lines, 41.2% were found to have drought scores of 1-3. Most of these lines were preselected for deep and thick roots in the early generations. Among entries in the rainfed lowland nurseries, 8.8% of the 1,665 tested were found to have high levels of field resistance. Among the GEU elite lines, IR6023-10-1-1 (an upland breeding line) and IR28224-3-2-3-2 (a lowland breeding line) showed a score of 3, while

Table 8. Field screening for drought resistance under upland conditions. IRRI, 1987 DS.

Group	Entries (no.)	Plants (no.) showing a drought score[a] of								
		1	2	3	4	5	6	7	8	9
					Vegetative phase					
Germplasm bank (GB) accessions	3778	63	19	866	178	1920	546	181	0	5
Upland breeding lines	814	53	0	282	0	432	0	47	0	0
Rainfed lowland nurseries	1665	20	0	126	6	854	162	497	0	0
GEU elite lines	48	0	0	2	0	42	0	4	0	0
					Reproductive phase					
GB accessions	1176	2	1	107	0	200	0	492	0	374
Advanced upland breeding lines	65	1	0	1	0	13	0	35	0	15

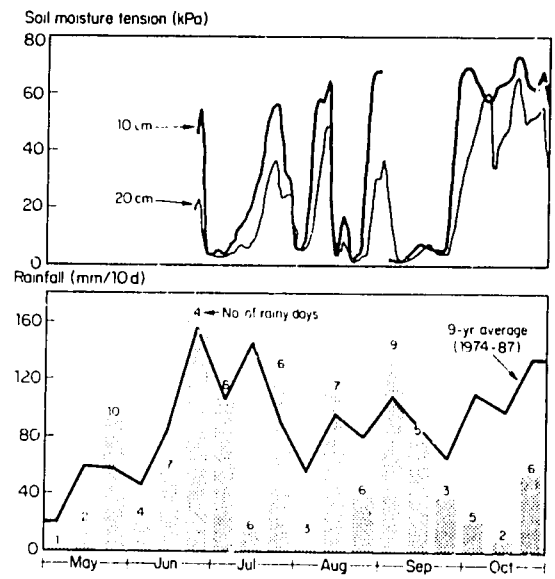
[a]Drought resistance scores: 1 = resistant, 9 = susceptible.

most other entries showed an intermediate to moderately susceptible reaction.

Drought reactions during the reproductive phase were scored after the second stress period was imposed. Plant age was from 110 to 130 d after sowing (DAS). Only 1,176 GB accessions reached the grain filling stage by the cutoff date of 135 DAS. Of these, 9.4% showed drought scores of 1-3 (Table 8). Lu Tao 2 from China and Mak Hing from Laos had 95% grain filling. From the upland breeding nurseries, IR36269-B-B-B-1 and IR38547-B-B-B-15 were outstanding. The sources of resistance of these lines are Black Gora and E425.

Heavy rains in mid-May following the scoring for reproductive phase resistance enabled us to evaluate recovery ability after heading. The rainfed lowland breeding lines and some of the upland breeding lines showed excellent recovery ability. The early-maturing lines in the GB accessions, however, showed very poor recovery ability compared with the late-maturing accessions.

Upland rice yield trial (*Agronomy*). The 1987 WS was characterized by low rainfall and consequent brief to prolonged soil moisture deficits at IRRI, in farmers' fields in Santo Tomas and Cuenca, Batangas; and at the Bureau of Plant Industry (BPI) experiment station in Ilagan, Isabela, all in the Philippines. Rainfall was below the average over 9-13 yr during most of the wet season (WS) (Figs. 2-5). At IRRI, SMT at 10- and 20-cm depths went beyond 30 kPa in 5 instances. The longest of these was in late September to late October, when only 50 mm of precipitation over 37 d (23 Sep - 29 Oct) occurred (Fig. 2). In Santo

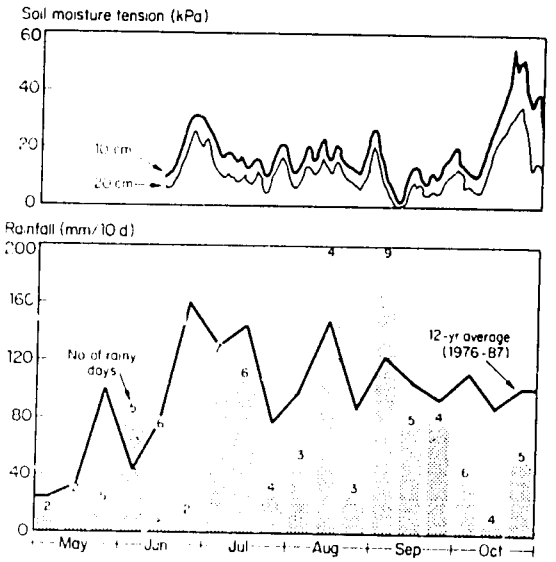


2. Rainfall distribution and soil moisture tension during upland rice yield trials at the IRRI dryland site. 1987 WS.

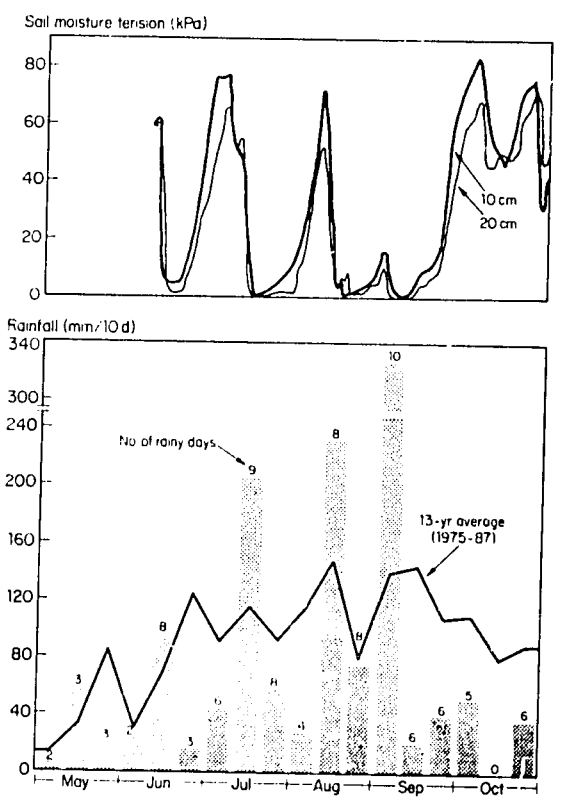
Tomas, SMT passed 30 kPa in October only, resulting from 26 low-rainfall days (Fig. 3). The trend in Cuenca was similar to that at IRRI (Fig. 4). In Ilagan, dry spells every month ranged from 13 to 25 d (Fig. 5). Rainfall was high during some periods because of tropical depressions and typhoons near the experimental sites.

The BPI La Granja experiment station in Negros Occidental had fairly adequate rainfall except in early October, when the WS crop was at the late maturation stage (Fig. 6).

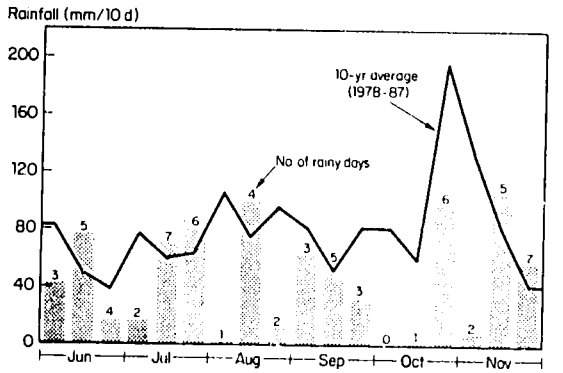
Grain yield. Despite the dry spells, the early seeded (June) crops in two Batangas farmers' fields



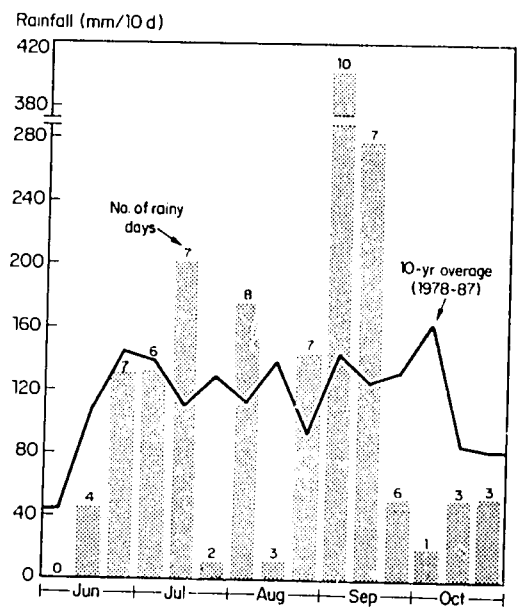
3. Rainfall distribution and soil moisture tension during upland rice yield trials in a farmer's field. Santo Tomas, Batangas, Philippines, 1987 WS.



4. Rainfall distribution and soil moisture tension during upland rice yield trials in a farmer's field. Cuenca, Batangas, Philippines, 1987 WS.



5. Rainfall distribution during upland rice yield trials. Ilagan Experiment Station, Isabela, Philippines, 1987 WS.



6. Rainfall distribution during upland rice yield trials. La Granja Experiment Station, Negros Occidental, Philippines, 1987 WS.

produced fairly high grain yields (Table 9). UPLRi-7 yielded highest at 5.0 t/ha in Cuenca. IR13754-12-3 produced 4.6 t/ha in Santo Tomas. In the June seeding, UPLRi-7 was consistently among the highest yielders at IRRI and in Santo Tomas, Cuenca, and La Granja in two groups where it was entered (IRTP's 1987 International Upland Rice Yield Nursery-Early [IURYN-E] and Upland Rice Yield Trial [URYT] special groups). None of the IURYN-E entries equaled UPLRi-7's yield performance. In the URYT, Philippine

Table 9. Grain yield of selected entries in early seeded upland rice trials at 4 Philippine sites, 1987 WS.

Designation	Origin	Grain yield[a] (t/ha)				
		IRRI (4 Jun)	Santo Tomas (11 Jun)	Cuenca (29 May)	La Granja (10 Jun)	Mean
International Upland Rice Yield Nursery-Early Maturing (IURYN-E)						
UPLRi-7 (local check)	Philippines	2.8 a	3.5 a	5.0 a	3.5 a	3.7
RPCB-2B-849 (IET1444)	India	1.7 b	3.5 a	3.6 bc	4.1 a	3.3
BG367-4	Sri Lanka	1.5 b	3.6 a	4.0 bc	3.6 a	3.2
Kinandang Patong (local check)	Philippines	1.3 b	1.6 b	3.1 c	2.8 a	2.2
Group mean (21 entries)		1.1	2.3	3.5	3.6	
CV (%)		22	22	12	25	
International Upland Rice Yield Nursery-Medium Maturing (IURYN-M)						
IR26957-86-2	IRRI	3.2 a	2.7 a	3.5 a	3.0 a	3.1
IR43 (check)	IRRI	2.9 ab	3.0 a	3.6 a	2.7 a	3.1
B3016B-TB-260-3-2-1-1-3	Indonesia	2.6 bc	3.0 a	3.8 a	3.7 a	3.3
B3622F-TB-14-2	Indonesia	2.6 bc	3.2 a	3.2 a	3.9 a	3.2
BR319-1	Bangladesh	2.2 cd	3.3 a	4.0 a	3.1 a	3.2
B3622E-TB-5-4-4	Indonesia	2.0 d	3.2 a	4.0 a	3.3 a	3.1
Group mean (21 entries)		1.8	2.6	2.8	2.4	
CV (%)		14	21	18	32	
Upland Rice Yield Trial (special group)						
UPLRi-7 (check)	Philippines	2.2 ab	3.6 ab	4.5 a	3.4 a	3.4
IR9560-2-6-3-1	IRRI	2.8 a	3.6 ab	3.9 ab	2.4 a	3.2
BPIRi-6	Philippines	2.3 ab	3.3 bc	4.0 ab	3.0 a	3.2
IR29429-B-3-B-2-3	IRRI	2.4 ab	3.2 bc	4.1 ab	2.6 a	3.1
IR13754-12-3	IRRI	2.4 ab	4.6 a	3.4 b	2.6 a	3.2
IR11397-1-8-1	IRRI	2.8 a	3.8 ab	3.3 b	2.5 a	3.1
IR26957-86-2	IRRI	2.0 b	4.0 ab	3.3 b	2.8 a	3.0
IR43	IRRI	2.3 ab	3.1 bc	3.4 b	3.0 a	3.0
Kinandang Patong (check)	Philippines	1.1 c	2.3 c	3.2 b	2.4 a	2.2
Group mean (36 entries)		1.9	3.2	3.4	2.4	
CV (%)		18	20	13	32	

[a]In a column and within each group, means followed by a common letter are not significantly different at the 5% level by DMRT. Seeding dates are in parentheses.

variety BPIRi-6 and lines IR9560-2-6-3-1 and IR29429-B-3-B-2-3 gave grain yields statistically similar to those of UPLRi-7 at all four sites.

IR43 and IR26957-86-2 were consistently the highest yielders in IRTP's International Upland Rice Yield Nursery-Medium maturing group (IURYN-M) at four sites (Table 9). UPLRi-7 was superior to these two rices in Cuenca when grouped together in the URYT.

The recurrent dry spells in Ilagan adversely affected rice during the vegetative and reproductive phases, resulting in mostly empty spikelets.

La Granja and Cuenca had higher average grain yield for IURYN-E than the two other sites, while Cuenca produced the highest average yield for IURYN-M and URYT among the four sites (Table 9).

Other agronomic characteristics. The better yielding rices had a growth duration of 110-128 d (81-98 d to heading from emergence) (Table 10). These were of intermediate stature, except the semidwarfs IR43 and IR9560-2-6-3-1. However, the latter two, together with IURYN-E's RPCB-2B-849 (IET1444) from India, gave the highest panicle number.

After at least 3 wk of dry spell at IRRI and in Isabela (4 wk in Isabela but punctuated by a 52-mm rain at the end of the second week), the vegetative phase drought reactions were recorded on 15 Oct and 17 Sep. Scores as poor as 8 at IRRI

Table 10. Grain yield and other agronomic characteristics of selected entries in early seeded upland rice trials at 4 Philippine sites and drought reaction at 2 sites, 1987 WS.

Designation	Mean grain yield (t/ha)	Heading (DE)[a]	Plant height (cm)	Panicles (no./m²)	Drought reaction[b] at IRRI 15 Oct[c]	Drought reaction[b] at Ilagan 17 Sep[c]	Important diseases[d]
IURYN-Early Maturing							
UPLRi-7	3.7	81	102	209	2	1	ShR
RPCB-2B-849 (IET1444)	3.3	77	84	280	3	2	BB, LSc, ShR
BG367-4	3.2	78	88	238	3	3	BB, ShR
Kinandang Patong	2.2	94	131	141	3	1	BLS, LSm, ShR
IURYN-Medium Maturing							
IR26957-86-2	3.1	98	115	238	3	1	ShR
IR43	3.1	96	77	254	4	1	ShR
B3016B-TB-260-3-2-1-1-3	3.3	82	113	207	3	1	BB, ShR
B3622F-TB-14-2	3.2	84	131	174	2	0	BB, LSc, LSm, ShR
BR319-1	3.2	83	99	226	4	1	BB, LSc, ShR
B3622E-TB-5-4-4	3.1	82	132	205	3	0	LSm, ShR
Upland Rice Yield Trial (special group)							
UPLRi-7	3.4	82	102	200	1	2	ShR
IR9560-2-6-3-1	3.2	96	79	253	2	3	BB, LSc, LSm, ShR
BPIRi-6	3.2	92	98	228	3	2	NBl
IR29429-B-3-B-2-3	3.1	88	110	228	1	1	ShB
IR13754-12-3	3.2	96	109	241	3	1	BLS
IR11397-1-8-1	3.1	94	116	205	3	3	NBl, ShR
IR26957-86-2	3.0	100	115	231	3	1	—
IR43	3.0	95	78	246	3	3	ShR
Kinandang Patong	2.2	87	132	150	4	3	BB, LSm, ShR
Salumpikit (drought-tolerant check)	2.2	88	136	199	2	3	BB, ShR
IRAT9 (drought-susceptible check)	1.9	82	80	225	7	3	LSc, ShR

[a]DE = days after emergence. [b]0-9 scale, where 0 = no visible effects of soil moisture deficit, 9 = all plants dead. [c]Drought scoring date. [d]BB = bacterial blight, BLS = bacterial leaf streak, LSc = leaf scald, LSm = leaf smut, NBl = neck blast, ShB = sheath blight, ShR = sheath rot.

and 7 in Isabela were recorded. The selected entries were among those with the least leaf desiccation at both sites (Table 10).

Sheath rot (ShR) was most prevalent at IRRI and in Batangas. Bacterial blight and neck blast were observed in many entries. URYT line IR26957-86-2 had only slight lesions from ShR infection in Santo Tomas.

Effect of drought stress. The late September-October dry spell caught most of the late-seeded (July) yield trial entries during the spikelet-filling stage. Many entries in Batangas and most entries at IRRI failed to yield. Drought stress markedly reduced grain yield (Table 11). Early-maturing entries produced better grain yields than did the longer duration ones, which had not yet headed when the dry spell began. Growth duration was not affected (Table 11), indicating that the earlier, shorter duration dry spells did not inhibit panicle initiation (PI). However, plant height and panicle number were markedly reduced. The vegetative phase drought-tolerant Salumpikit and IR442-2-58 performed similarly, as did the less tolerant rices when drought occurred during the reproductive phase.

The better yielding June-seeded rices (Table 9) that showed relatively more stable drought reaction were B3016B-TB-260-3-2-1-1-3 and B3622F-TB-14-2 from IURYN-M, and IR29429-B-3-B-2-3 and Philippine varieties BPIRi-6 and UPLRi-7 from URYT.

Lowland rices under upland conditions. IRTP's International Rice Yield Nursery-Very Early (IRYN-VE) for lowland rice comprised the other special group of upland rice yield trials in Cuenca. Six IRYN-VE entries performed similarly (by Duncan's multiple range test), as did checks UPLRi-7 and Kinandang Patong (Table 12). Using

Table 11. Performance of selected upland rices at 2 sites in relation to seeding date (D). Batangas, Philippines, 1987 WS.

Designation	Grain yield[a] (t/ha)				Av heading (DE)		Av plant height (cm)		Av panicles (no./m²)	
	Santo Tomas		Cuenca							
	D1 (11 Jun)	D2 (10 Jul)	D1 (23 May)	D2 (2 Jul)	D1	D2	D1	D2	D1	D2
	IURYN-Early Maturing									
CR222-MW10	2.7	1.9	3.6	1.0	74	76	80	68	237	212
CR289-1208	2.5	1.7	2.6	1.7	54	54	64	61	243	216
NDR-97	3.2	1.7	3.4	1.4	65	68	80	71	307	218
RAU4028-2	2.7	1.6	3.3	1.7	54	59	73	64	264	225
UPLRi-7	3.5	1.6	5.0	1.5	80	80	112	89	216	180
	IURYN-Medium Maturing									
B3016B-TB-260-3-2-1-1-3	3.0	0.8	3.8	1.0	80	80	117	96	208	166
B3622E-TB-5-4-4	3.2	1.1	4.0	1.4	80	82	142	120	204	162
B3622F-TB-14-2	3.2	0.9	3.3	1.5	82	82	140	120	188	162
RP1674-4038-78-4	2.4	1.6	2.0	1.1	67	67	81	82	257	238
IR43	3.0	0.2	3.6	0.4	94	93	80	62	248	210
	Upland Rice Yield Trial (special group)									
IR21015-196-3-1-3	3.4	1.2	3.9	1.8	87	86	88	72	284	222
IR29429-B-B-B-2-3	3.2	1.3	4.1	1.3	86	85	118	98	232	178
BPIRi-6	3.3	1.2	4.0	1.9	89	86	108	86	224	163
UPLRi-7	3.6	0.8	4.5	1.8	78	79	110	102	197	192
Salumpikit (drought-tolerant check)	1.4	0.4	2.7	1.6	88	79	142	126	202	181
IR442-2-58 (drought-tolerant check)	3.1	1.3	4.0	0.9	90	90	95	75	240	214
IRAT9 (drought-sensitive check)	1.6	0.6	2.7	0.7	78	79	85	70	222	183

[a]Seeding dates are in parentheses.

Table 12. Performance of very early lowland rices (IRYN-VE) under upland conditions. Cuenca, Batangas, Philippines, 1987 WS.

Designation	Grain yield[a] (t/ha)	Heading (DE)	Plant height (cm)	Panicles (no./m²)	Important diseases
IR32429-47-3-2-2	3.96*	75	75	317	LSm
UPLRi-7 (check)	3.95*	86	106	198	–
IR29692-117-1-2-2	3.84	72	90	289	–
IR31787-16-1-2-3-2	3.64	74	71	286	–
IR25898-60-2-3	3.58	72	83	347	BB, LSm
IR29725-40-3-2-3	3.51	76	73	364	BB
IR39422-75-3-3-3-2	3.39	70	63	311	BB, LSm
Kinandang Patong (local check)	3.27	89	151	148	
Mean (26 entries)	3.05				
CV (%)	11.8				

[a]* = significantly higher than that of Kinandang Patong at P = 0.05 by the F-test. All 8 rices did not significantly differ by DMRT.

the *F*-test, IR32429-47-3-2-2 and UPLRi-7 were better yielding than tall traditional Kinandang Patong at P = 0.05. Under upland conditions, short stature is a disadvantage, since it imparts low competitive ability with weeds. Therefore the semidwarf IR32429-47-3-2-2 is still inferior to the intermediate-statured UPLRi-7, but its 10-d shorter growth duration is a desirable trait in areas with a short WS, like Cuenca.

Drought screening under limited rooting depth (*Agronomy*). Drought screening was conducted in drums in the IRRI greenhouse twice during 1987 under limited rooting depth. Seeds of 2 test entries and check Leb Mue Nahng 111 were planted in

each of 2 sets (replications) of 52 drums filled with 45-cm-deep soil. These were irrigated to field capacity until 30 d after seedling emergence before drought stress was imposed. Each entry was scored for drought reaction using the *Standard evaluation system for rice* (SES) 0-9 scale when Leb Mue Nahng 111 in the drum had attained a score of 9 (i.e., was fully desiccated).

The first seeding (4 Apr) consisted of 63 GEU 1987 DS elite lines and 41 IRTP 1987 International Upland Rice Observational Nursery (IURON) entries. The second (29 Aug) consisted of 33 GEU 1987 WS elite lines and 71 IRTP 1987 International Rice Deepwater Observational Nursery (IRDWON) entries. To fully desiccate, Leb Mue Nahng 111 took 21-52 d in the first seeding and 36-49 d in the second (Table 13). Soil moisture content at this point varied considerably, probably because of differences in root and other characteristics that caused varying evapotranspiration rates.

Five entries in the first seeding were outstanding: 1987 IURON entries IR43 from IRRI and Chakula from Bangladesh, and three elite lines. For the August-seeded test, no test entry was outstanding. Only IRDWON material Tilakkachari from India was relatively better than Leb Mue Nahng 111 (Table 13).

Differences in drought stress duration in the drums, before Leb Mue Nahng 111 dried up, and the final soil moisture content should be investigated.

Table 13. Outstanding rices in drought screening under limited rooting depth in the greenhouse.[a] IRRI, 1987.

Designation	Seed source	Stress days (no.)		Soil moisture content (%) at soil depth of 10 cm		Soil moisture content (%) at soil depth of 20 cm		Drought score[b]		Recovery score[c]	
		R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2
				4 Apr seeding							
IR43	IURON 1987	21	–	6.4	5.0	12.2	9.3	5	6	1	1
IR28222-9-2-2-2-2	Elite 1987 DS	33	–	6.5	5.4	10.7	11.2	6	6	1	1
IR41996-163-2-1-2	Elite 1987 DS	39	35	7.0	6.6	12.0	10.6	5	7	1	1
IR42000-211-1-2-2-3	Elite 1987 DS	41	32	7.2	5.0	13.9	9.4	6	5	1	1
Chakula	IURON 1987	33	–	6.9	6.5	11.0	9.4	7	7	1	1
Leb Mue Nahng 111 (check)		21 to 52		6.45±0.14	6.08±10.10	10.91±0.15	10.28±0.15	9	9	9	9
				29 Aug seeding							
Tilakkachari	IRDWON 1987	41	49	10.1	–	12.4	–	8	8	7	5
Leb Mue Nahng 111 (check)		36 to 49		10.14±0.10	10.71± 0.12	12.96±0.13	13.09±0.15	9	9	9	9

[a] – = no data. R_1 and R_2 = replications 1 and 2. [b] SES 0-9 scale, where 0 = no visible effect of drought stress, 9 = all plants apparently dead. [c] SES 1-9 scale, where 1 = 90% or higher recovery stand, and 9 = 0-19% recovery stand.

SCREENING METHODS

Agronomy Department

Pot screening for drought resistance. Field screening of rices for drought resistance requires facilities that may not be available to researchers in developing countries. The objective of this study, therefore, was to test a method for screening pot-grown rices. In September 1987, 3 replications of 18 rice genotypes were dibbled in 5-liter pots containing Maahas clay soil in the greenhouse at IRRI. Pots were irrigated daily until 30 DAS, when irrigation was stopped. The water deficit was allowed to develop until 40 DAS, when plants of the susceptible check variety (IR20) were apparently dead. At 40 DAS all pots were re-

Table 14. Selected growth parameters measured at 40 DAS and SES drought resistance (DRT) scores of best and worst genotypes, as measured in greenhouse pot trial. IRRI, 1987 WS.

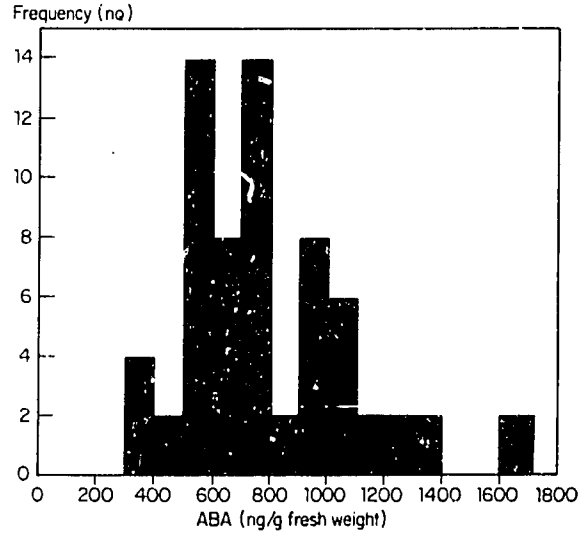
Genotype	Root length (cm)	Root dry weight (g)	Shoot length (cm)	Shoot dry weight (g)	Leaf area (cm^2)	Leaf water potential (MPa)	DRT at 0.5 MPa	DRT at 1 MPa
ARC7098	10.8	0.03	47.7	0.11	13.6	3.12	7.0	9.0
IR20	11.5	0.02	41.7	0.09	21.4	3.16	7.0	9.0
IR47686-1-4B	20.0	0.14	44.7	0.52	38.6	1.31	1.0	3.0
Salumpikit	18.7	0.13	53.3	0.47	37.5	1.30	1.0	3.7
Mean	15.8	0.08	48.9	0.29	27.24	2.10	5.3	6.4
SE	0.72	0.004	1.22	0.03	4.10	0.04	0.3	0.7
LSD classes	4	7	8	8	7	9	4	7

irrigated, and recovery from stress was evaluated at 45 DAS. Varieties differed significantly in maximum root length, root dry weight, shoot length, shoot dry weight, leaf area, leaf water potential, and SES score (Table 14). Generally, Salumpikit (the resistant check) and IR47686-1-4B showed the greatest drought resistance, whereas IR20 and ARC7098 showed the least. If resolution of genotypes into the greatest number of significantly different classes can be taken as an indicator of parameter effectiveness in assessing drought resistance, then the most discriminating parameter in this study was leaf water potential. SES scores of susceptible and resistant checks from this pot screening were significantly correlated to SES scores from field drought tolerance trial results in the IRRI databank ($r = 0.95$, $P < 0.01$). Therefore, it appears that pot screening for vegetative phase drought resistance is a viable alternative to field screening where irrigation and field facilities are not adequate for field trials.

Abscisic acid and drought resistance in upland rice. Abscisic acid (ABA) is accumulated in the leaves of many crops during drought. Because ABA causes stomatal closure, ability to accumulate it may confer drought resistance or improve plant water use efficiency (WUE). To survey wild and cultivated rice varieties for ABA accumulation in response to drought and to determine whether selection for the capacity to accumulate ABA affects WUE or yield, experiments were conducted in controlled-environment cabinets at the Plant Breeding Institute, Cambridge, United Kingdom, and in the greenhouse and field at IRRI.

Drought-induced ABA accumulation. Sixty rice genotypes and nine *Oryza* species were grown in controlled-environment cabinets. Within 1 d of the appearance of its ligule, leaf 6 on the main stem was excised at the lamina base, allowed to lose 10% of its initial fresh weight, incubated in the dark at 28 °C for 2 h, and then assayed for ABA by radioimmunoassay. A 5-fold difference in drought-induced ABA accumulation among the 60 genotypes and a 2-fold difference among the 9 wild species were found (Fig. 7). This wide range of ABA accumulation among genotypes suggests a good possibility to increase or decrease ABA levels of rice cultivars through breeding and selection.

Selection for high and low capacity to accumulate ABA. Lines with high and low capacity to accumulate ABA identified in the survey were



7. Frequency distribution of drought-induced abscisic acid accumulation in detached leaves of 60 rice genotypes and 9 *Oryza* species. IRRI, 1987.

Table 15. Drought-induced abscisic acid (ABA) accumulation as measured by the detached leaf test. IRRI, 1987.[a]

Generation	ABA accumulation (ng/g)					
	IR20/IR36		High:low ratio	IR20/63-83		High:low ratio
	Low	High		Low	High	
F_4	525±25 (12)	855±20 (24)	1.57	392±30 (11)	973±81 (19)	2.08
F_6	572±40 (7)	1157±30 (29)	2.02	460±24 (11)	973±81 (19)	2.11

[a]Numbers in parentheses are number of lines tested.

crossed, and F_1 plants were raised at IRRI by the International Rice Germplasm Center. F_2 seed was grown in controlled-environment cabinets, and plants of highest and lowest ABA were retained for continued selection and analysis. There was a strong correlation between ABA accumulation in the F_3 and F_4, indicating that lines were approaching heterozygosity. Seed from the F_5 was raised in the field at IRRI without selection to provide F_6 seed for subsequent experiments. Drought-induced ABA accumulation for the F_4 (last generation with selection) and F_6 is presented in Table 15. Differences between average ABA levels in the F_4 and F_6 were probably due not to genetic differences, but to differences in the environments in which the plants were raised.

Water use efficiency in controlled-environment cabinets. High- and low-ABA F_6 plants were grown in pots. Before drought treatment, plants of each genotype were sorted according to transpiration rate, with similar plants divided into 3 groups: group 1 was harvested at the beginning of the drought treatment; group 2 was fully irrigated; and group 3 was not irrigated for 7-10 d until the same level of stress was reached in all genotypes. Average WUE was 9% greater for low-ABA lines than for high-ABA lines (Table 16). For all lines, there was a negative correlation between initial dry weight and leaf water potential (LWP) at the end of the drought treatment ($r = -0.68$, $P < 0.001$) and between initial dry weight and stomatal conductance ($r = 0.69$, $P < 0.001$), and a positive correlation between LWP and stomatal conductance ($r = 0.66$, $P<0.01$). WUE and LWP were significantly related for low-ABA lines ($r = 0.64$, $P<0.05$) but not for high-ABA lines ($r = 0.03$).

Greenhouse trial. Two high- and two low-ABA lines from IR20/IR36, and three high- and three

Table 16. Water use efficiency (WUE), leaf water potential (LWP), and stomatal conductance (g_s) of high- and low-ABA lines in the F_6 from crosses IR20/IR36 and IR20/63-83 in controlled-environment cabinets. IRRI, 1987.

Cross	High ABA				Low ABA			
	Initial dry weight (g)	WUE[a]	LWP (MPa)	g_s (cm/s)	Initial dry weight (g)	WUE	LWP (MPa)	g_s (cm/s)
IR20/IR36	5.39	0.529	−1.83	0.189	4.54	0.529	−1.78	0.192
	2.86	0.429	−1.93	0.200	2.94	0.473	−1.59	0.257
	3.21	0.462	−1.76	0.198	3.66	0.490	−1.69	0.207
IR20/63-83	1.13	0.436	−1.39	0.554	2.34	0.554	−1.41	0.397
	1.30	0.487	−1.19	0.378	2.39	0.596	−1.30	0.277
	3.36	0.519	−1.68	0.227	3.84	0.339	−1.86	0.222
	1.67	0.437	−1.29	0.265	3.64	0.482	−1.63	0.209
	4.51	0.411	−1.73	0.228	4.96	0.561	−1.68	0.263
	5.98	0.497	−1.78	0.255	4.98	0.494	−1.87	0.170
	3.62	0.404	−2.08	0.185	4.73	0.450	−1.63	0.137

[a]WUE in g/100 ml water transpired.

low-ABA lines from IR20/63-83 together with their parents were grown in pots in the IRRI greenhouse. Stressed plants were not irrigated for 8 d at maximum tillering. Stress led to a 6% reduction in total dry weight, a 24% reduction in yield, and a 2.5-fold increase in leaf ABA content compared with the unstressed treatment. Lines from IR20/63-83 had greater dry weight and appeared to become stressed more quickly than those from IR20/IR36. There were no significant differences in WUE or grain yield between the high- and low-ABA lines (Table 17). Differences in plant size may have masked differences between high- and low-ABA lines. At the end of the stress treatment, negative correlations were observed between LWP and ABA ($r = -0.77$, $P<0.01$) and between ABA and stomatal conductance ($r = -0.79$, $P<0.01$).

Field trial. During 1987 DS, 7 high- and 6 low-ABA lines from IR20/IR36 and 10 high- and 6 low-ABA lines from IR20/63-83 were planted under upland conditions at IRRI. A split-split-plot design was used with stress as the main plot, cross as the sub-main plot, and line as the subplot treatment. Stress treatments were 1) fully irrigated and 2) unirrigated for 12 d at maximum tillering. At the end of the stress period, LWPs of stressed plants were only 300-400 kPa lower than those of unstressed plants, indicating that stress levels were relatively mild. Still, stress reduced dry weights and grain yields by 7% and increased stomatal resistance 6-fold as compared with the unstressed treatments. Stress treatment did not affect ABA level; nor were there apparent differences between high- and low-ABA lines (Table 18). Thus, under field conditions, LWP, stomatal conductance, and

Table 17. Plant growth, leaf water potential (LWP), and stomatal conductance (g_s) in response to drought for high- and low-ABA lines in the F_6. IRRI greenhouse, 1987.

Genotype[a]	Height (cm)	Initial dry weight (g)	LWP (MPa)	g_s (cm/s)	ABA (ng/g fresh weight)	Water use efficiency (g/100 ml)	Yield (g)
			IR20/IR36				
High (2)	87.9	66.92	-1.13	0.227	285	0.346	87.83
Low (2)	81.7	55.48	-1.17	0.631	232	0.343	97.91
			IR20/63-83				
High (3)	143.2	81.78	-1.96	0.234	323	0.281	51.30
Low (3)	122.4	82.36	-2.50	0.256	388	0.301	51.99
			Parents				
IR20	107.0	66.40	-1.69	0.331	256	0.377	50.80
IR36	79.9	50.27	-1.02	1.098	167	0.229	84.67
63-83	113.5	74.96	-2.50	0.141	375	0.589	63.96

[a]Numbers in parentheses are number of lines tested.

Table 18. Growth and water relations parameters at end of drought stress period for high- and low-ABA lines in the F_6 grown under upland field conditions. IRRI, 1987 DS.

Genotype[a]	LWP (MPa)	g_s (cm/s)	ABA (ng/g fresh weight)	Dry weight (g)	Grain yield (g)	Grains (no.)	200-grain weight (g)
			IR20/IR36				
High (7)	-1.50	0.41	174	302	129.9	1133	4.14
Low (6)	-1.52	0.36	181	262	124.4	970	4.02
			IR20/63-83				
High (10)	-1.49	0.37	186	336	97.9	1157	5.11
Low (6)	-1.58	0.33	201	293	96.5	978	4.96

[a]Numbers in parentheses are number of lines tested.

growth all appeared more sensitive to water deficit than did leaf ABA level.

Water retention of excised rice leaves. Water retention by excised leaves has been shown to be an efficient indicator of drought resistance in sorghum and wheat. Therefore, a preliminary greenhouse experiment was conducted to study the water retention characteristics of excised leaves for six rice varieties, and to test the method as a possible technique to screen for drought resistance in rice. Three water levels were imposed: 1) continuously flooded, 2) no water applied 25-35 DAS, and 3) no water applied 35-45 DAS. At day 5 and 10 of each stress period, 3 fully expanded penultimate leaves were excised and weighed. Leaves were soaked in water for 2 h to fully hydrate them before water retention measurement. They were then spread and allowed to dry in a controlled-temperature room. The leaves were weighed after 1, 3, 5, and 7 h and again after 24 h of oven drying at 80 °C.

Varietal differences in leaf water content at 0, 1, 3, and 5 h were more pronounced in well-watered plants than in stressed plants (Table 19, 20). Generally, varietal separation was greatest at 1-3 h and least after 5 h. Under well-watered conditions, Kinandang Patong, a drought-resistant variety, almost always had higher leaf water content than IR20, a drought-susceptible variety. Although data are preliminary, they suggest that the method can be used to rank well-watered plants. The technique needs further study to determine 1) the relationship between water retention and drought resistance, 2) effects of plant age and leaf position, 3) drying time for greatest varietal differentiation, and 4) heritability of the trait.

Rolling of excised rice leaves. The first visible response of rice plants to water deficit is leaf rolling. We hypothesized that leaf rolling characteristics may indicate drought resistance and may be used to evaluate the drought resistance of rices without imposing stress. Initial studies quantified the degree of leaf rolling in excised leaves of rice by measuring changes in leaf area. Ten genotypes were grown in pots containing well-watered soil in a greenhouse. At 45 DAS, 3 penultimate, fully expanded leaves from each variety were excised and immediately placed inside an ice chest to minimize physical and physiological changes. Leaves were floated in water for 2 h to achieve full

Table 19. Water content of excised rice leaves at 30 and 35 DAS after different drying times.[a] IRRI, 1987.

Variety	Water content (%) at 30 DAS after drying for					Water content (%) at 35 DAS after drying for				
	0 h	1 h	3 h	5 h	7 h	0 h	1 h	3 h	5 h	7 h
				Control (well-watered)						
DZ151	92.12 ab	48.89 ab	17.48 ab	17.08 a	16.97 a	75.04 b	58.85 ab	10.51 a	3.11	2.79
OS4	82.07 bc	33.74 b	6.68 b	6.21 ab	5.96 ab	80.72 a	38.70 c	4.09 b	2.21	2.01
Kinandang Patong	88.66 ab	58.49 a	21.12 a	10.91 ab	10.74 ab	78.93 ab	51.25 abc	3.97 b	2.42	2.15
Salumpikit	89.45 ab	38.78 ab	11.63 ab	7.31 ab	10.04 ab	78.20 ab	47.69 abc	4.50 b	3.52	2.19
UPLRi-7	93.61 a	39.98 ab	17.63 ab	16.94 a	16.84 a	77.14 ab	40.99 bc	5.98 ab	2.49	2.17
IR20	77.19 c	22.99 b	2.97 b	1.59 b	1.19 b	78.33 ab	61.12 a	6.49 ab	1.72	1.42
				No water applied 25-35 DAS						
DZ151	87.58	21.54	10.05	9.93	9.82	79.03 abc	49.57 b	8.00	3.29 abc	3.10 ab
OS4	78.06	25.99	1.18	0.79	0.53	80.48 a	48.88 b	9.21	3.93 ab	3.66 a
Kinandang Patong	83.78	29.47	7.79	7.54	7.44	79.33 abc	5.63 ab	8.25	1.88 bc	1.18 bc
Salumpikit	85.88	37.69	10.02	6.89	6.76	77.56 c	51.93 b	9.29	1.55 c	0.77 c
UPLRi-7	84.79	23.45	8.09	7.52	7.44	79.69 ab	50.30 b	6.84	5.00 a	4.70 a
IR20	77.93	22.31	2.35	1.46	1.24	78.63 bc	67.85 a	11.35	3.30 abc	2.88 ab

[a] In a column and within a treatment, means followed by a common letter are not significantly different at the 5% level by DMRT.

Table 20. Water content of excised rice leaves at 40 and 45 DAS after different drying times.[a] IRRI, 1987.

Variety	Water content (%) at 40 DAS after drying for					Water content (%) at 45 DAS after drying for				
	0 h	1 h	3 h	5 h	7 h	0 h	1 h	3 h	5 h	7 h
				Control (well-watered)						
DZ151	78.64 a	50.37 b	13.59 bc	2.81 b	2.53	79.54 ab	23.89 c	6.85 c	1.90	1.77
OS4	79.33 a	53.87 b	16.66 abc	2.38 b	1.95	79.39 ab	41.98 ab	20.18 ab	5.10	2.02
Kinandang Patong	79.17 a	62.88 a	25.22 a	5.14 a	2.32	80.33 a	40.60 ab	23.56 a	4.72	3.61
Salumpikit	78.74 a	56.14 bc	12.62 bc	2.64 b	2.27	78.48 ab	36.75 ab	18.76 ab	5.85	4.16
UPLRi-7	74.34 b	51.57 c	7.55 c	2.98 b	2.66	77.87 b	35.17 b	12.88 bc	2.81	2.03
IR20	78.51 a	52.37 ab	20.86 ab	2.82 b	2.37	78.99 ab	47.05 a	9.08 c	2.81	2.39
				No water applied 35-45 DAS						
DZ151	78.46 ab	52.03 ab	15.66 cd	5.25	2.17	78.38	37.87	21.73	4.03	2.43
OS4	79.80 ab	51.62 ab	10.94 cd	2.70	2.76	77.94	38.89	19.22	2.40	1.88
Kinandang Patong	78.95 ab	57.81 ab	17.79 bc	3.17	2.18	79.63	40.98	18.83	2.89	2.05
Salumpikit	81.73 a	60.85 ab	26.10 ab	2.18	1.82	77.46	36.62	18.34	3.47	2.34
UPLRi-7	75.70 b	48.84 b	5.74 d	2.62	2.34	76.02	39.01	18.06	3.81	1.94
IR20	80.75 ab	62.55 a	33.83 a	3.52	2.32	77.22	44.15	12.40	2.86	2.72

[a] In a column and within a treatment, means followed by a common letter are not significantly different at the 5% level by DMRT.

hydration, after which they were placed in a growth cabinet at 30 °C, 48-50% relative humidity (RH), and radiation of 113 W/m^2. The area of individual leaves was measured at 5-min intervals with an automatic area meter. Although there were significant genotypic differences in initial leaf area, it was not related to either the rate or final level of leaf rolling (Table 21). Genotypes were separated into the most DMRT classes at 20 min. Research to relate leaf rolling characteristics to drought resistance is continuing.

Drought resistance of rainfed lowland rice as affected by crop establishment method. Very few varieties or lines have been evaluated for their performance under direct seeded, rainfed lowland conditions. Because direct seeding and transplanting have different effects on root development, they might also have different effects on drought resistance. Therefore, a field experiment was conducted at the Maligaya Rice Research and Training Center during 1987 DS to compare direct seeded and transplanted rice responses to water deficit under simulated rainfed lowland conditions. A split-split-plot design with 3 replications was used where main plots were 2 water regimes: 1) continuously flooded (control), and 2) stressed, in which irrigation was stopped at 45 DAS and water deficit was allowed to develop until the SES drought score of the most sensitive genotype was 7-8. Subplot and main plot treatments were 2 crop establishment methods: 1) transplanting of 20-d-old seedlings with a hill spacing of 20 × 25 cm and 2-3 seedlings/hill, and 2) direct seeding using a mechanical drum seeder with 20 cm between rows. Both crop establishment methods had the same seeding date, 24 Feb 1987. Subplots were 24 varieties or lines selected from rainfed lowland yield nurseries tested in drought-prone areas.

Fertilizer inputs consisted of a basal incorporation of 60 kg N/ha as urea 1 d before seeding or transplanting, and a topdressing of 40 kg N/ha at 30 DAS, about 5 d before PI.

Mean yields of control treatments under transplanted and direct seeded conditions were similar, but in general the rices were more susceptible to yield reduction by stress when transplanted than when direct seeded (Table 22).

Although many rices were similar under transplanted and direct seeded conditions, IR11418-15-

Table 21. Leaf rolling characteristics for excised leaves of 10 rice varieties. IRRI, 1987.

Genotype	Initial leaf area (cm^2)	Percentage of initial leaf area after		Time (s) to reach given percentage of initial leaf area	
		20 min	40 min	75%	50%
Azucena	137 a	41 fg	33 c	420	814
AUS196	101 b	49 d	41 ab	671	1177
IAC47	98 b	52 c	40 bc	537	1500
BR319-1	77 c	46 e	34 e	288	814
IR6023-10-1-1-9	69 cd	62 a	38 d	600	1920
B35-2	64 cd	42 f	29 f	268	833
IR43	58 de	61 a	42 a	771	1800
IR45	48 ef	57 b	38 cd	810	1636
IR12979-24-3-4	44 f	57 b	39 cd	755	1725
Tres Meses	37 f	39 g	27 g	197	750

Table 22. Grain yield of 24 rainfed lowland rice genotypes under 2 establishment methods and 2 water regimes.[a] Maligaya Rice Research and Training Center, Nueva Ecija, Philippines, 1987 DS.

Variety	Grain yield (t/ha)				
	Transplanted		Direct seeded		Mean
	Control	Stressed	Control	Stressed	
IR21567-18-3	6.3 A a	4.8 A b	4.9 A-C b	5.2 AB b	5.3 A
IR19431-72-2	4.3 B bc	3.4 B c	5.0 A-C ab	5.8 A a	4.6 B
IR13146-13-3-3	3.9 B-D b	1.8 EF c	5.2 AB a	5.0 AB a	4.0 BC
IR29723-143-3-2-1	3.3 B-F bc	2.3 C-F c	4.4 A-D ab	5.1 AB a	3.8 CD
IR42342-40-3-3-2-3	4.1 BC	2.4 B-F	3.8 B-F	4.2 A-C	3.6 C-E
IR41054-81-2-3-2	4.1 BC	3.1 B-D	3.9 B-F	3.1 C-G	3.6 C-E
IR19319-1-2-2-2-2	3.6 B-E a	2.5 B-E b	3.7 C-F a	3.9 B-D a	3.4 C-E
IR21188-15-2-2-3-3-3-1-1	2.9 D-F bc	1.5 EF c	4.4 A-D ab	4.9 AB a	3.4 C-E
IR42241-76-2-2-2	2.9 D-F	2.4 B-F	4.3 A-D	3.8 B-E	3.3 D-E
IR43518-62-2-2-1-3	2.6 E-G	3.4 B	3.8 B-F	2.9 C-G	3.2 D-F
IR30168-63-1-5-2	2.3 F-H bc	1.6 EF c	5.4 A a	3.2 C-F b	3.1 E-G
IR33355-39-1-1-3	3.7 B-E	2.3 C-F	3.1 D-G	2.9 C-G	3.0 E-H
IR11418-15-2	3.9 B-D	3.3 BC	1.5 H	2.2 E-H	2.6 F-I
IR64 (check)	3.0 C-F	1.4 F	2.1 GH	3.6 B-E	2.5 G-J
IR52	3.1 C-F a	1.5 EF b	3.1 D-G a	1.9 F-H b	2.4 H-J
IR5931-110-1	2.9 D-F	2.1 D-F	2.6 E-H	1.7 F-H	2.3 IJ
IR12979-24-1	2.9 D-F	1.4 F	2.2 G-H	2.4 D-H	2.2 IJ
IR26894-37-2-1-3	3.4 B-F a	2.3 C-F b	1.5 H b	1.7 F-H b	2.2 IJ
IR13146-45-2-3	3.0 C-F a	1.7 EF b	2.4 F-H ab	1.7 F-H b	2.2 IJ
IR9782-111-2-1-2	1.4 H c	2.4 B-F a	1.9 GH b	1.7 F-H bc	1.9 JK
IR28252-10-1-2-1	3.1 C-F a	1.6 EF b	1.6 H b	1.0 HI b	1.9 JK
IR29725-109-1-2-1	1.7 GH	1.5 EF	1.4 HI	1.5 G-I	1.5 JK
IR58 (check)	1.5 GH	1.5 EF	1.4 HI	1.8 F-HI	
IR40860-31-6-3-1	0 I	0 G	0 I	0 I	0 L
Mean	3.1 a	2.2 b	3.1 a	3.0 a	2.8

[a]Treatment means followed by the same uppercase letter in a column and by the same lowercase letter in a row are not significantly different at the 5% level by analysis of variance.

2, IR26894-37-2-1-3, and IR28252-10-1-2-1 appeared to perform better under transplanted than direct seeded conditions, whereas IR13146-3-3, IR29723-143-3-2-1, IR21188-15-2-2-3-3-3-1-1, IR42241-76-2-2-2, and IR30168-63-1-5-2 performed better under direct seeding than transplanting. Because some varieties perform differently under direct seeded and transplanted

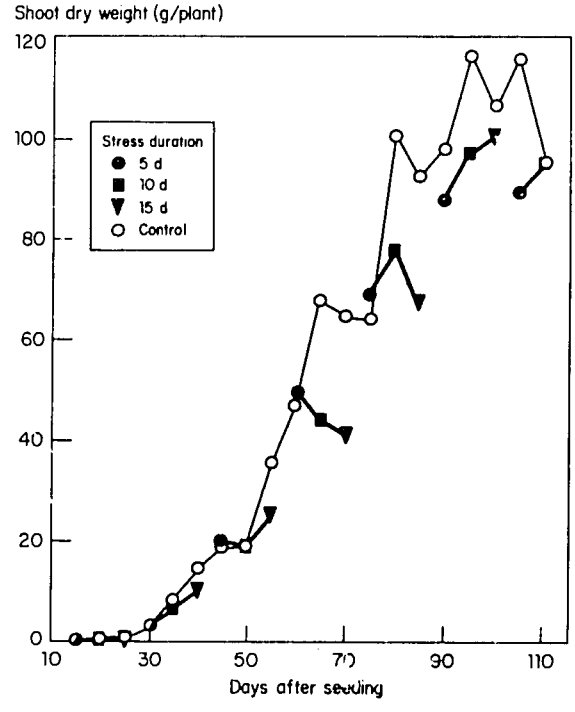
conditions, parallel testing under different crop establishment methods is probably justified.

DROUGHT STRESS INDEX FOR RICE

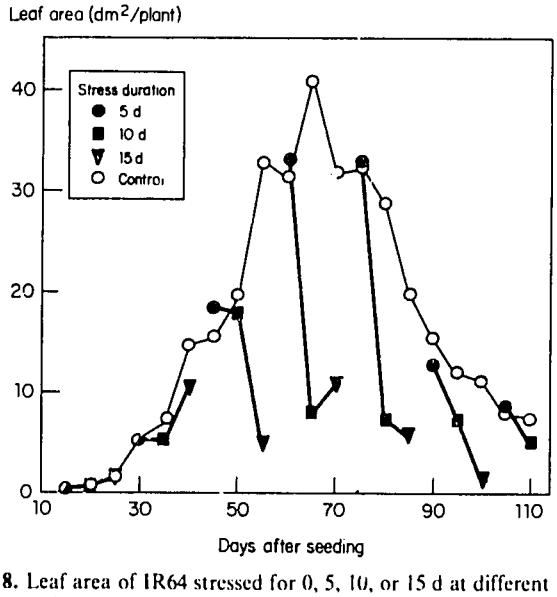
Agronomy Department

Results of drought resistance screening trials from different locations are difficult to compare because severity and timing of drought stress are frequently observed but not controlled. To develop a drought stress index to assess the level of drought stress, a series of experiments was planned. The first experiment determined the effects of water stress of various durations at different developmental stages on the growth and yield of rice. IR64 was grown in a greenhouse during 1987 WS (July-November) in polyvinyl chloride (PVC) pots (20 cm inside diameter, 55 cm height) under aerobic conditions. N, P, and K were applied at 60-30-30 kg/ha at 9 DAS. Water was withheld for 5, 10, or 15 d from stress treatment pots beginning at 10, 25, 40, 55, 70, 85, and 100 DAS. Treatments were replicated 6 times, with 1 plant in 1 pot per replication. At the end of each stress period, 2 of the 6 pots were sampled to determine leaf area, plant biomass, and developmental stage. Corresponding control plants were also harvested.

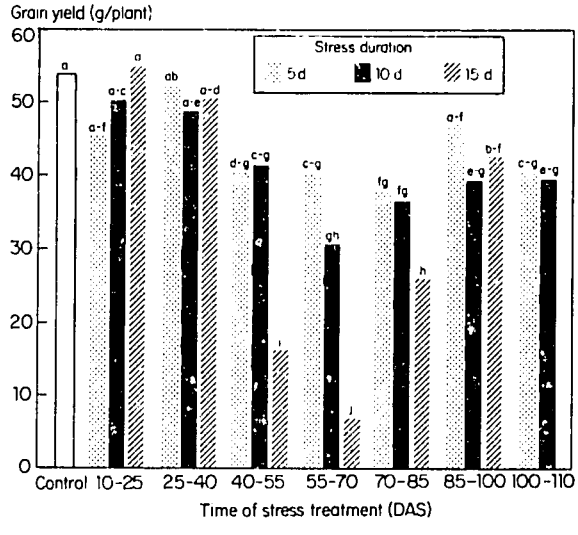
The effects of water deficit on leaf area increased with length of stress period and age of the plants (Fig. 8). Leaf area was reduced mostly by leaf



9. Shoot dry weight of IR64 stressed for 0, 5, 10, or 15 d at different growth stages. IRRI, 1987 WS.



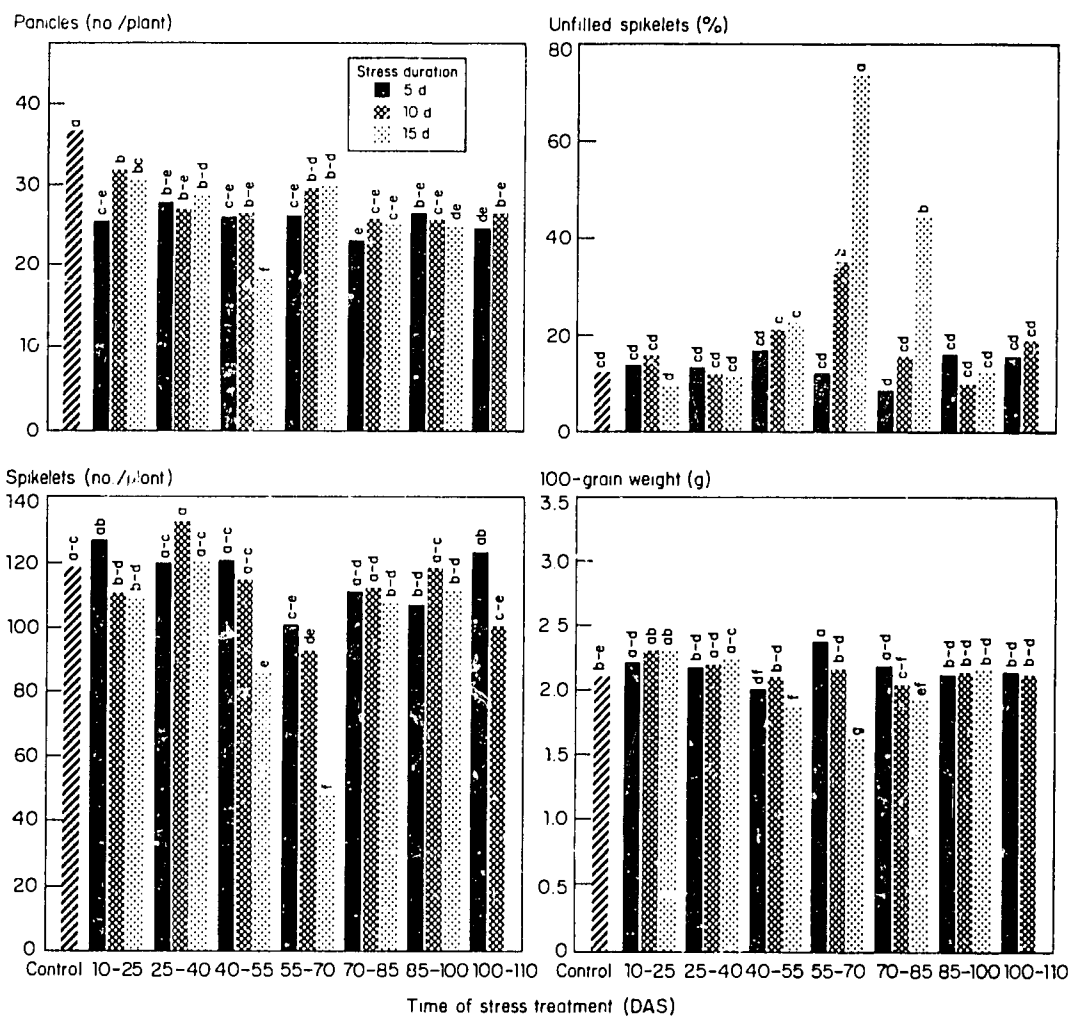
8. Leaf area of IR64 stressed for 0, 5, 10, or 15 d at different growth stages. IRRI, 1987 WS.



10. Grain yield of IR64 stressed for 0, 5, 10, or 15 d at different growth stages, IRRI, 1987 WS. Bars with the same letter are not significantly different at the 5% level by DMRT. DAS = days after seeding.

rolling, not by abscission. Shoot dry weights of plants stressed for 10 or 15 d were less than those of the control plants by 20-40% (Fig. 9). Water stress before 40 DAS had no significant effect on grain yield (Fig. 10). Stress periods of 5 and 10 d during the reproductive phase (45-80 DAS) caused 25-40% yield reductions. At PI (55 DAS), flowering (70 DAS), and early grain filling (85 DAS), the 15-d stress period reduced yields by 70, 88, and 52%, respectively. Yield component analysis (Fig. 11) showed the following: 1) Stress at PI reduced panicle number most, but all stresses—regardless of crop stage or duration—significantly reduced panicle number. 2) Stress at flowering caused the greatest reduction in filled spikelets per plant and the greatest increase in unfilled spikelets. At flowering, the 15-d stress reduced grain weight, but the 5-d stress increased grain weight, presumably because the 5-d stress affected the sink more than the source, whereas the 15-d stress affected both source and sink. 3) During early grain filling, the 15-d stress increased the proportion of unfilled spikelets.

These results will be used to develop a dynamic model of drought stress that integrates severity and crop stage of stress into a single index related to grain yield.



11. Grain yield components of IR64 stressed for 0, 5, 10, or 15 d at different growth stages, IRRI, 1987 WS. Bars with the same letter are not significantly different at the 5% level by DMRT.

FLOWERING STAGE DROUGHT RESISTANCE

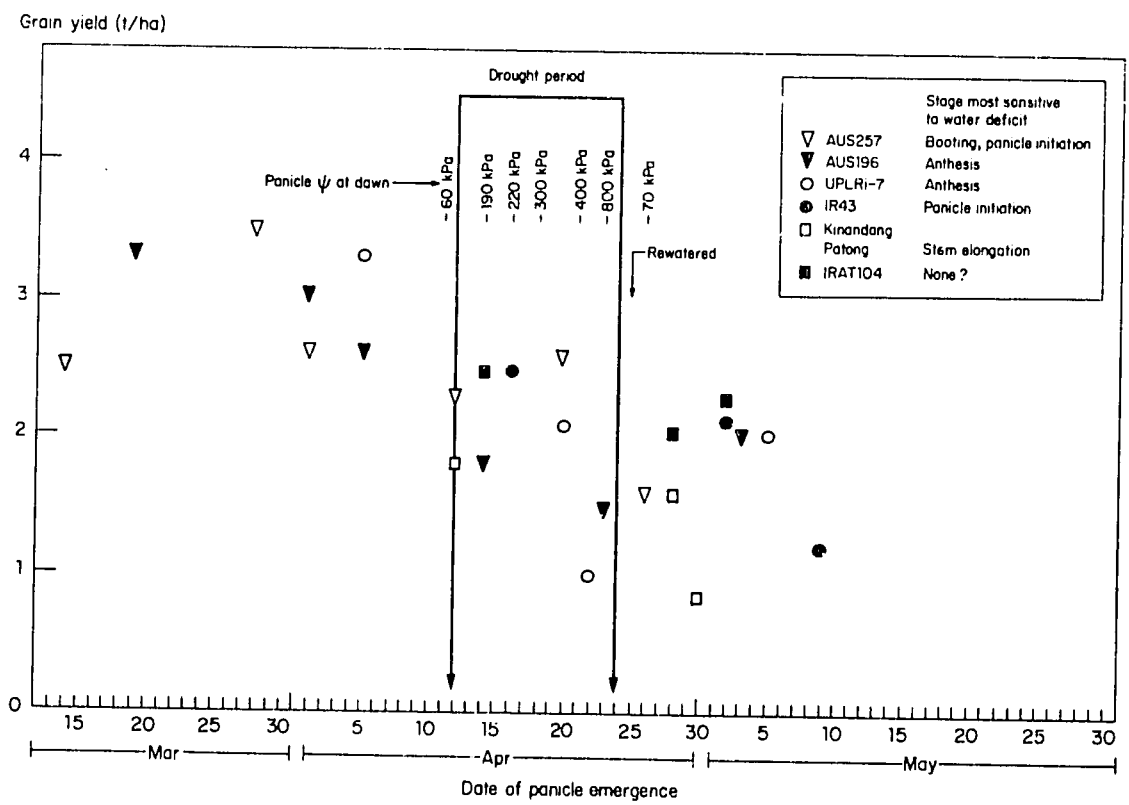
Agronomy Department and Rice Farming Systems Program

Grain growth and yield of rice under water deficit at different growth stages (*Agronomy*). Rice yields are most susceptible to reduction by drought that occurs at flowering. To understand the mechanisms of reproductive phase drought resistance, a field experiment on the IRRI upland farm investigated the effects of water deficit at different growth stages on grain growth characteristics and yield. Six cultivars representing three rice types were studied: AUS257 and AUS196 (aus type), Kinandang Patong and IRAT104 (japonica type), and IR43 and UPLRi-7 (indica type). All cultivars were seeded on 6 dates at 7- to 14-d intervals to generate plots of different growth stages during a single drought period.

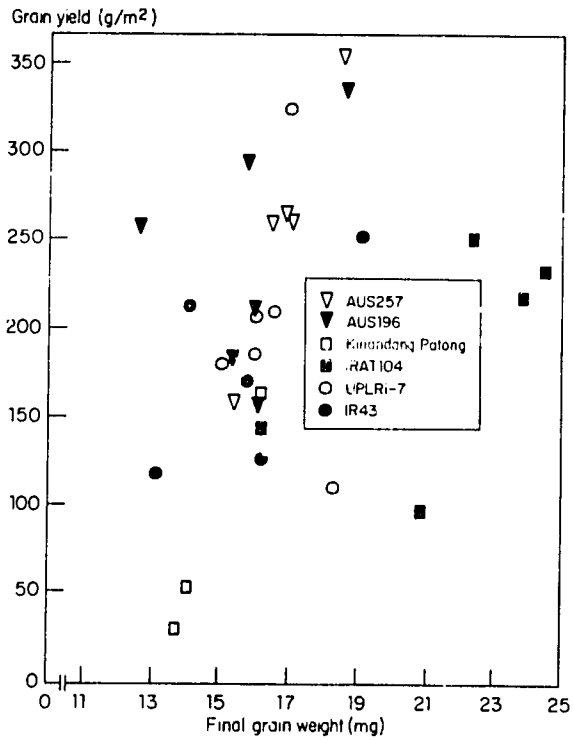
Grain yield. Although few varieties can be directly compared, yield differences in response to water deficit at different growth stages were evident (Fig. 12). Yield data were probably complicated by weather factors, particularly solar radiation, which dropped after the first week of May. Nevertheless, yield reductions when drought was imposed during grain filling or flowering indicate rice sensitivity to water deficit at the mid-reproductive phase.

Grain growth and yield. Neither final individual grain weight (IGW) nor effective individual grain filling duration (IGFD) was correlated with grain yield (Fig. 13, 14). There was, however, a significant correlation between individual grain growth rate (IGGR) and yield (Fig. 15). Thus IGGR appeared to be the grain growth parameter most closely related to yield for rices subjected to water deficit.

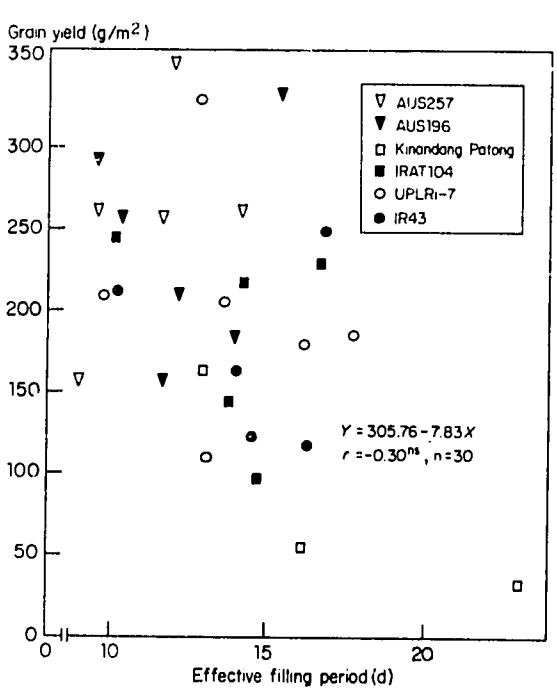
Grain growth characteristics. For all panicle sections and varieties, IGGR was positively correlated with IGW (Fig. 16). Strong but negative correlations were observed between IGGR and effective IGFD. Although IGGR was significantly correlated with both IGW and IGFD, IGW and



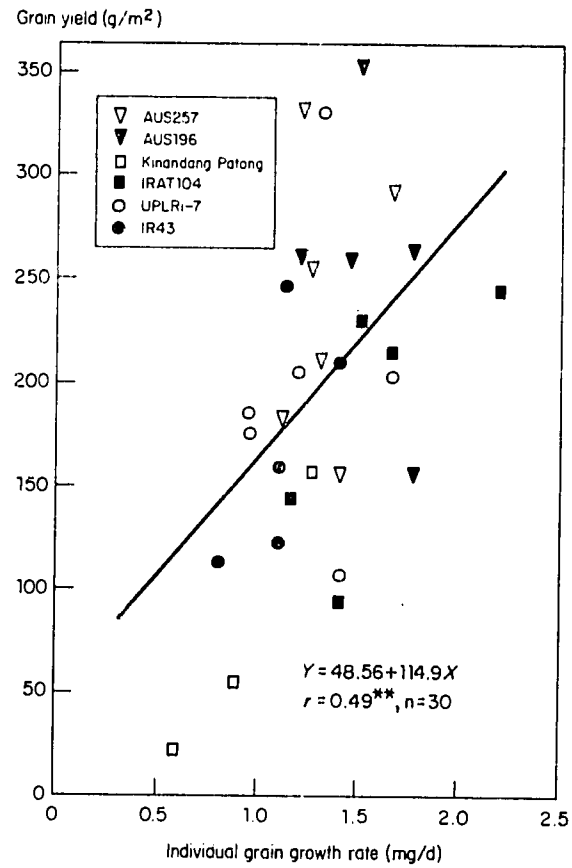
12. Rice grain yield in response to water deficit at different growth stages, IRRI, 1987. Points to the left of the drought period represent cultivars that flowered before the stress and their planting dates; thus they were at the grain filling or maturation stage during stress. Points to the right of the drought period indicate cultivars that flowered after the stress period and their planting dates; thus they were in the vegetative phase to panicle initiation or booting during the stress period.



13. Relationship of final grain weight to grain yield of rice subjected to water deficit at different growth stages, IRRI, 1987. Each point is the average of values computed from 3 panicle sections.



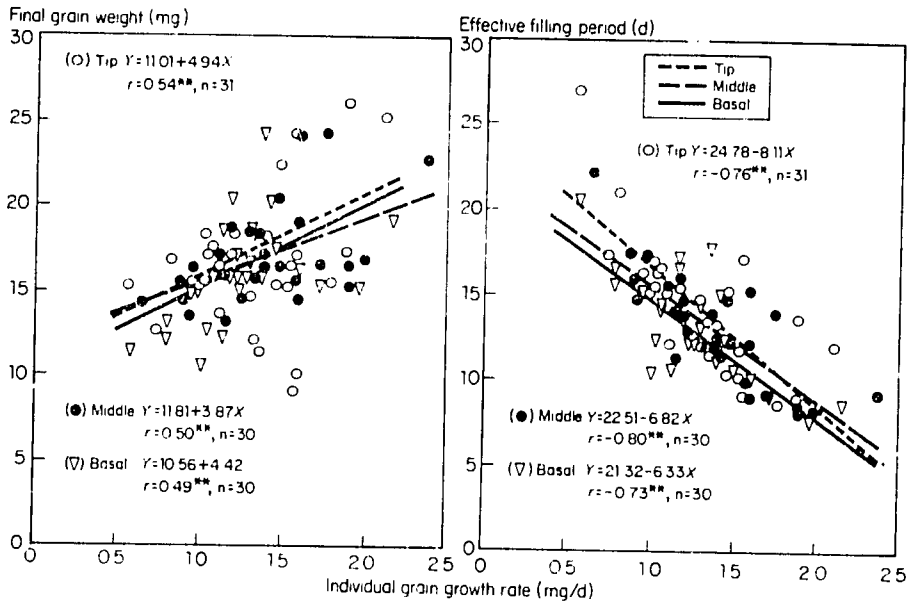
14. Relationship of effective filling period to grain yield of rice subjected to water deficit at different growth stages, IRRI, 1987. Each point is the average of effective filling period computed for 3 panicle sections.



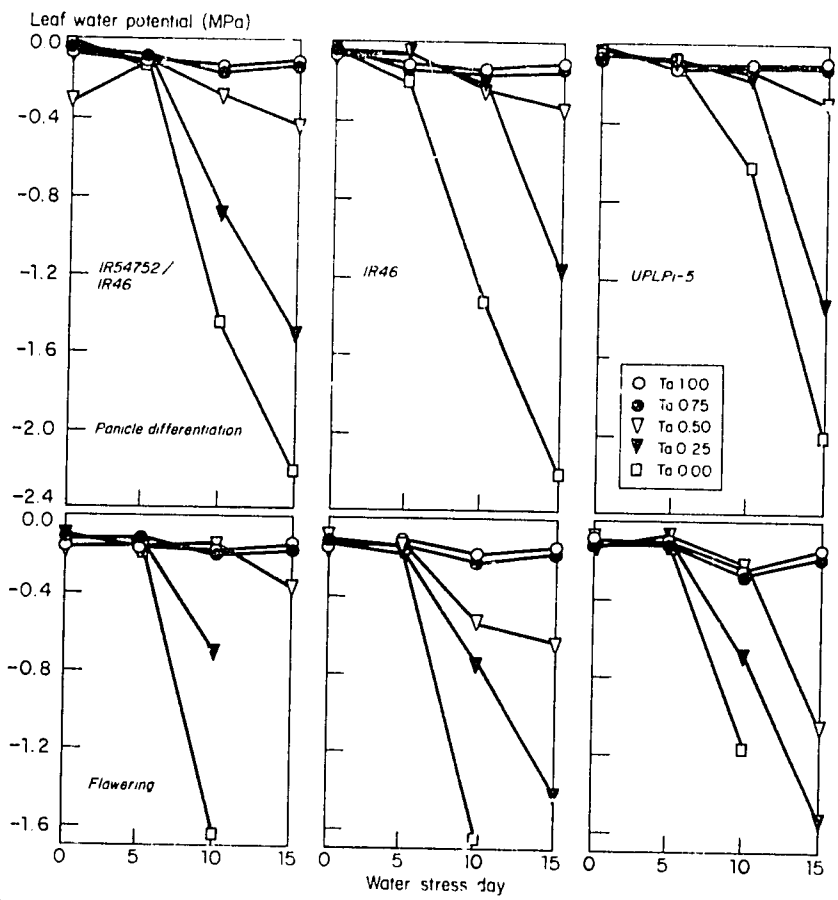
15. Relationship of individual grain growth rate to grain yield of rice subjected to water deficit at different growth stages, IRRI, 1987. Each point is the average of individual grain growth rates across 3 panicle sections.

IGFD were not correlated with each other (r = 0.14).

Drought effects. The effects of water deficit on grain growth characteristics were different for all varieties. For AUS196, IGFD was reduced, and IGGR of basal grains was reduced. For AUS257, IGFD was reduced and, after stress, the onset of growth for middle and basal grains was delayed and IGGR increased. For IR43, IGFD increased. For UPLRi-7, IGGR was reduced and IGFD was increased for middle and basal grains. For Kinandang Patong, IGFD was reduced and IGGR increased. For IRAT104, IGFD was reduced. There were no obvious responses associated with either rice type or drought resistance level. Therefore, further research is needed to determine how grain growth characteristics may contribute to drought resistance.



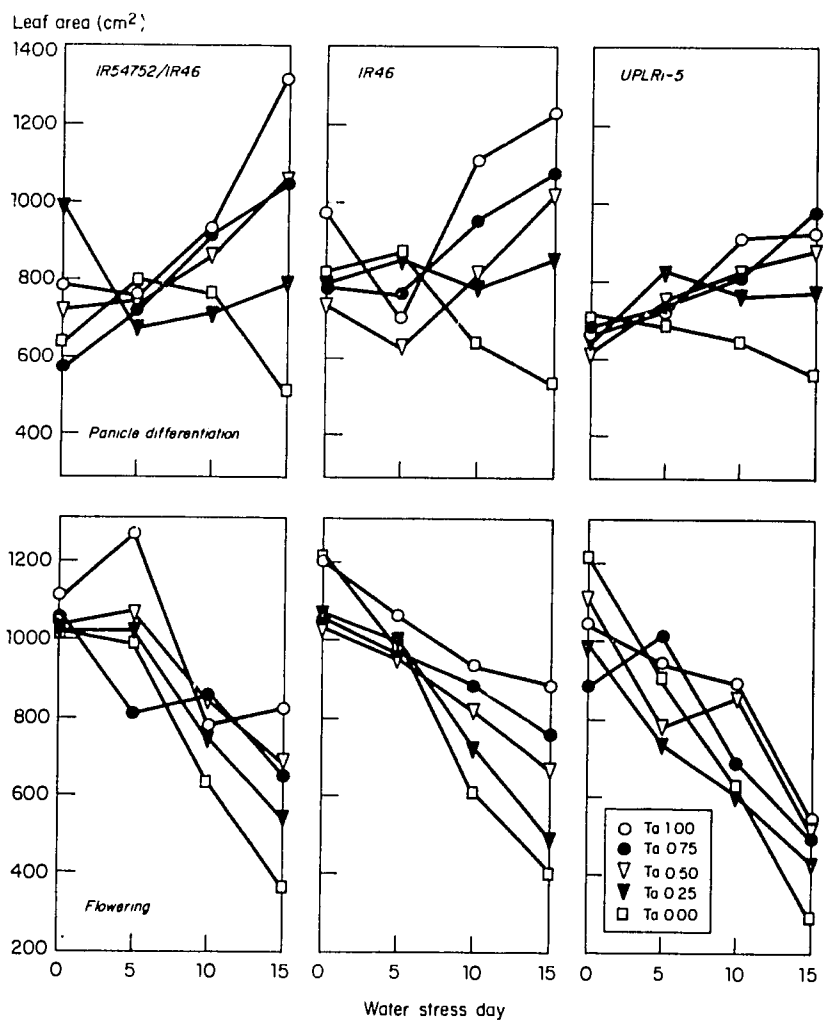
16. Relationship of individual grain growth rates to effective filling period and final seed weight for 6 rice cultivars subjected to water deficit at different growth stages. IRRI, 1987.



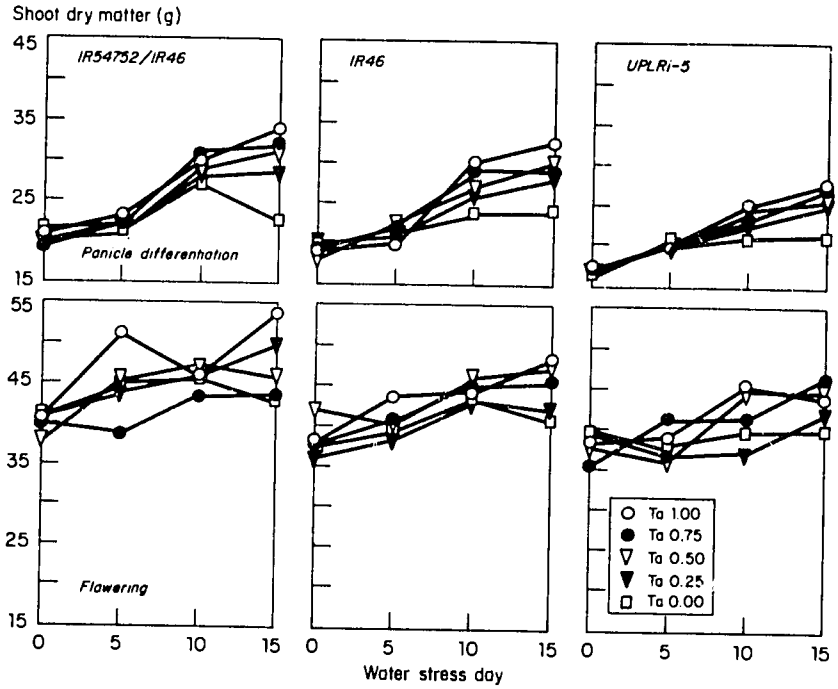
17. Leaf water potential of hybrid, parent, and upland rice in response to intensity and timing of water deficit, IRRI, 1987 WS. Missing data on day 15 are due to plant desiccation beyond permanent wilting. Number following Ta is the ratio of irrigation of specific treatment to continuously irrigated treatment.

Hybrid rice responses to intensity of water deficit at panicle differentiation and flowering (*Agronomy and Rice Farming Systems Program*). Hybrid rices yield up to 30% more grain than inbred varieties under irrigated conditions in China, but no hybrid varieties have been specifically developed for rainfed conditions. To compare the physiological responses of hybrid and inbred rices under water deficit conditions, a greenhouse experiment was conducted in 1987 WS. Three plants each of IR54752/IR46 (F_1 hybrid), IR46 (parent), and UPLRi-5 (local check variety) were grown under simulated upland conditions in plastic pots containing 8 kg soil. Fertilizers were added at rates equivalent to 90-20-37 kg NPK/ha. Two 15-d stress periods were imposed, one at panicle differentiation, the other at flowering. Outside of these stress periods, soil of all pots was kept near saturation. To impose different water stress intensities, water was added daily as a fraction of transpiration in the fully irrigated treatment to give a control (Ta 1.0) and 4 stress treatments (Ta 0.75, Ta 0.5, Ta 0.25, and Ta 0.0). Daily transpiration was measured as the change in pot weight over 24 h.

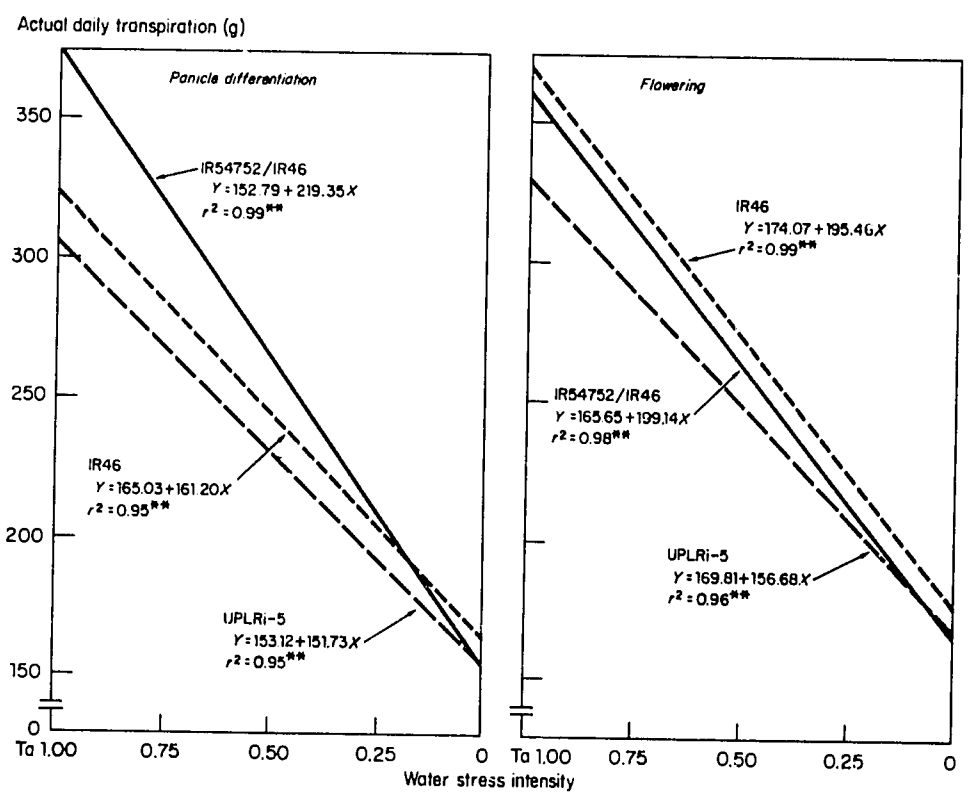
Data on predawn LWP, leaf area, shoot dry weight, transpiration, spikelet sterility, and grain yield are presented in Figures 17-22. Hybrid plants appeared to experience a more severe stress than the parent or upland variety, probably because the



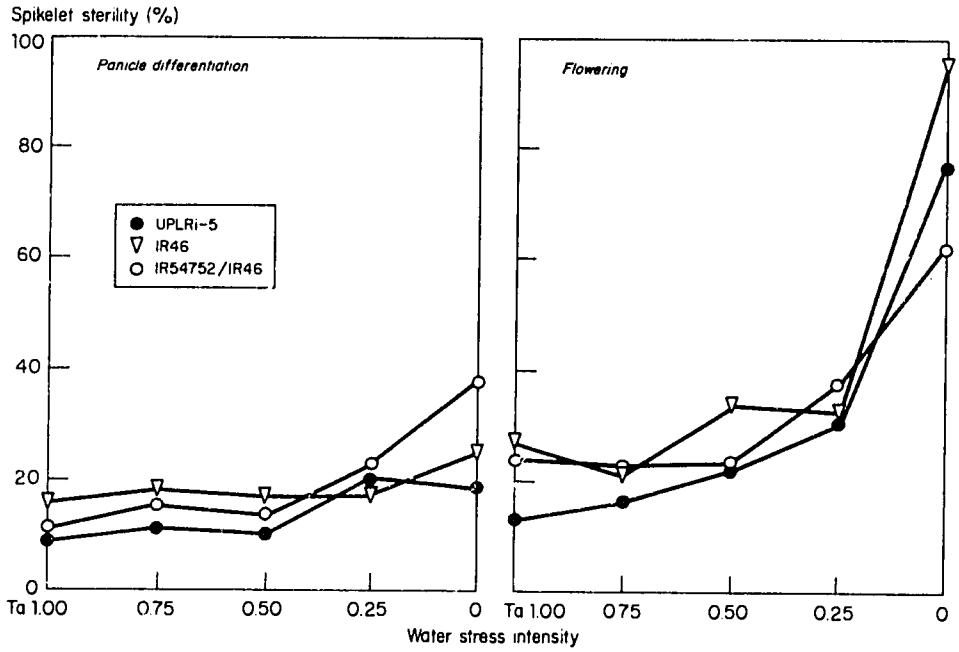
18. Leaf area of hybrid, parent, and upland rice in response to intensity and timing of water deficit, IRRI, 1987 WS. Number following Ta is the ratio of irrigation of specific treatment to continuously irrigated treatment.



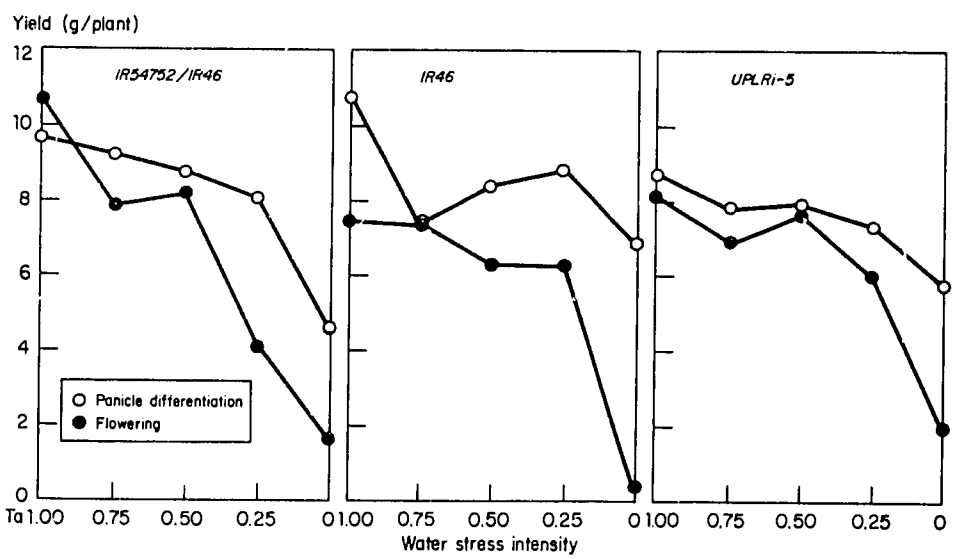
19. Water use efficiency of hybrid, parent, and upland rice in response to intensity and timing of water deficit, IRRI, 1987 WS. Number following Ta is the ratio of irrigation of specific treatment to continuously irrigated treatment.



20. Daily transpiration of hybrid, parent, and upland rice in response to intensity and timing of water deficit, IRRI, 1987 WS. Number following Ta is the ratio of irrigation of specific treatment to continuously irrigated treatment.



21. Spikelet sterility at harvest for hybrid, parent, and upland rice in response to intensity and timing of water deficit, IRRI, 1987 WS. Number following Ta is the ratio of irrigation of specific treatment to continuously irrigated treatment.



22. Grain yields of hybrid, parent, and upland rice in response to intensity and timing of water deficit, IRRI, 1987 WS. Number following Ta is the ratio of irrigation of specific treatment to continuously irrigated treatment.

hybrid had a higher transpiration rate, and soil moisture and root growth were limited by the pots. Under well-watered conditions, the hybrid produced greater leaf area, shoot dry weight, and grain yield than the parent or upland variety. In low and zero irrigation treatments, however, differences among varieties were small. These results suggest that there may be an advantage in growing hybrid rices under upland conditions, especially if rainfall is adequate. Under water deficit, hybrid rice had no apparent advantage over the parent or upland variety in this pot study, but these varieties must be tested under field conditions before firm conclusions can be drawn.

Assimilate translocation of lowland rice in response to water deficit, shade, and herbicide (*Agronomy*). Rice translocates significant amounts of stored assimilates to fill grains, and the fraction of grain yield derived from translocated assimilates increases under stress. We therefore hypothesized that rice yields under stress in general, and specifically drought during the reproductive phase, would be related to the level of stored assimilates and to the ability to translocate stored assimilates. Field research was initiated during 1987 WS under lowland conditions at IRRI with 8 replications of 2 main plot treatments—continuously flooded and drained from 20 d after PI to 10 d after panicle emergence. Within main plots, subplots were combinations of three varieties, three shade, and one herbicide treatment. Stress before, during, or after flowering increased apparent translocation rate (ATR), the fraction of panicle weight derived from remobilized assimilates (Table 23). A combination of stresses further increased ATR. Among the varieties tested, IR46 appeared to have the highest ATR and grain yield. Because of untimely rains, water deficit effects were relatively small, so research is continuing to elucidate the relationship, if any, between ATR and drought resistance.

ROOT STUDIES

Agronomy Department and International Rice Germplasm Center

Leaf water potential and transpiration as affected by root xylem anatomy (*Agronomy*). Differences in rooting depth among rainfed rices have been correlated with plant water status during water deficit. Deep roots enable a plant to maintain high LWP even if the upper soil layers become dry. However, deep roots may need to be coupled with low root axial resistance to extract water efficiently from deep soil layers during drought.

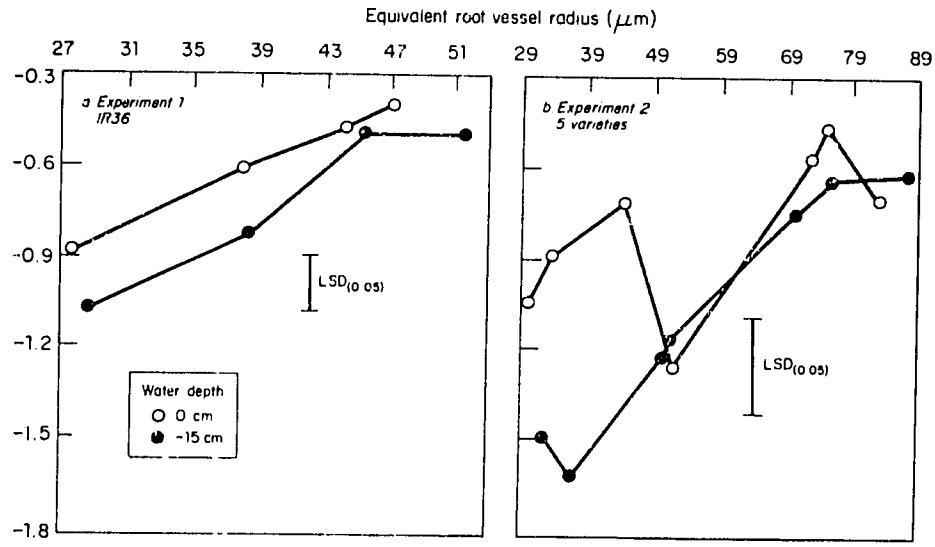
Genotypic variation in number and size of main xylem vessels of seminal and nodal roots of rice was previously reported (Annual report for 1985). A follow-up study was conducted to determine the effects of these root characteristics on LWP and transpiration. IR36, IR20, 63-83, IAC25, and Azucena were grown in a phytotron greenhouse (32/24 °C) in 60-liter plastic pails containing culture solution. At 4 wk after germination, tillers were pruned to 1 main tiller per plant. At 7 wk after germination, roots of the main tillers were pruned to different numbers and then plants were transferred to PVC pipes (8 cm internal diameter, 60 cm

Table 23. Effects of water deficit, shade, and atrazine on assimilate remobilization to grain growth for rainfed lowland rice.[a] IRRI, 1987 WS.

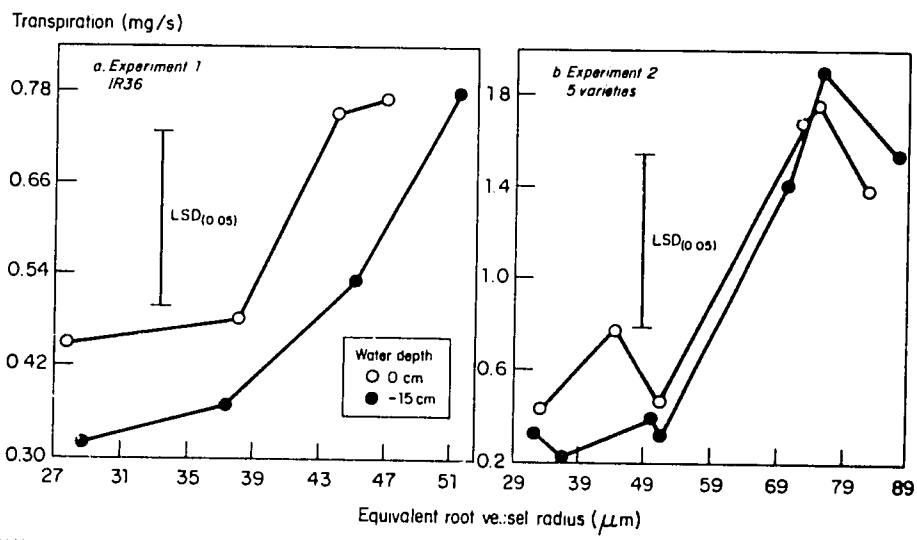
Variety	Treatment	Wet (continuously flooded)		Dry (drained from 20 DAPI to 10 DAPE)	
		Yield (t/ha)	ATR (%)	Yield (t/ha)	ATR (%)
IR64	No shade or herbicide	4.0	4.6	3.9	12.8
	Shade (10-25 DAPI)	3.1	10.3	3.1	22.1
	Shade (5-20 DAPE)	2.8	24.3	2.8	34.2
	Atrazine (5 DAPE, 0.05 kg ai/ha)	3.2	34.1	3.0	39.9
IR46	No shade	4.6	6.3	4.4	8.5
	Shade (10-25 DAPI)	3.6	12.4	3.5	23.4
	Shade (5-20 DAPE)	3.4	28.1	3.3	40.2
Mahsuri	No shade	3.1	4.4	2.9	5.8
	Shade (10-25 DAPI)	2.1	10.1	2.0	11.6
	Shade (5-20 DAPE)	1.8	20.2	1.7	25.4

[a]ATR (apparent translocation rate) = $\frac{WSF - WSM}{WPM - WPF} \times 100$

where WSF = dry weight of stem at flowering, WSM = dry weight of stem at maturity, WPM = dry weight of panicle at maturity, WPF = dry weight of panicle at flowering. DAPI = days after panicle initiation, DAPE = days after panicle emergence.



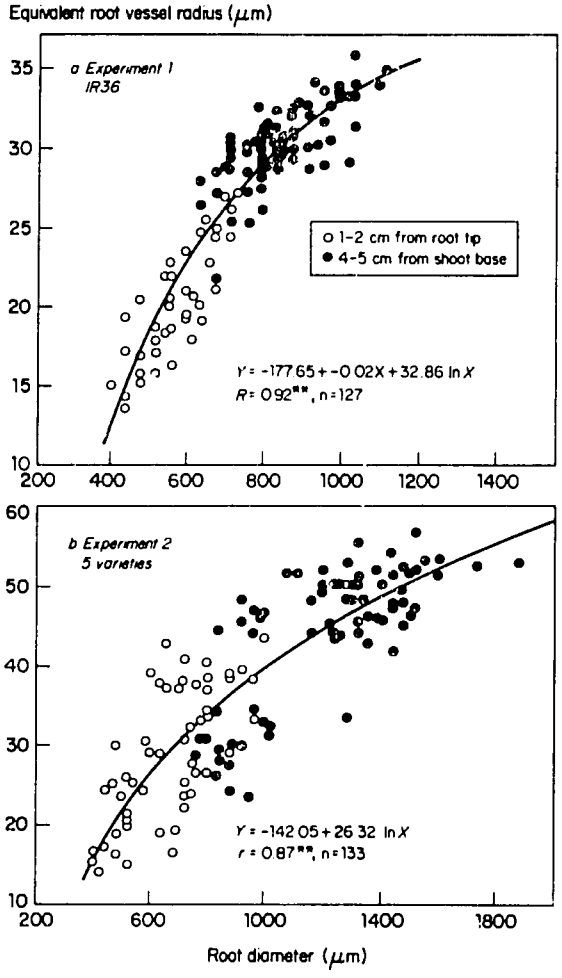
23. Effect of equivalent root vessel radius on leaf water potential a) in IR36 and b) across 5 varieties. IRRI, 1987



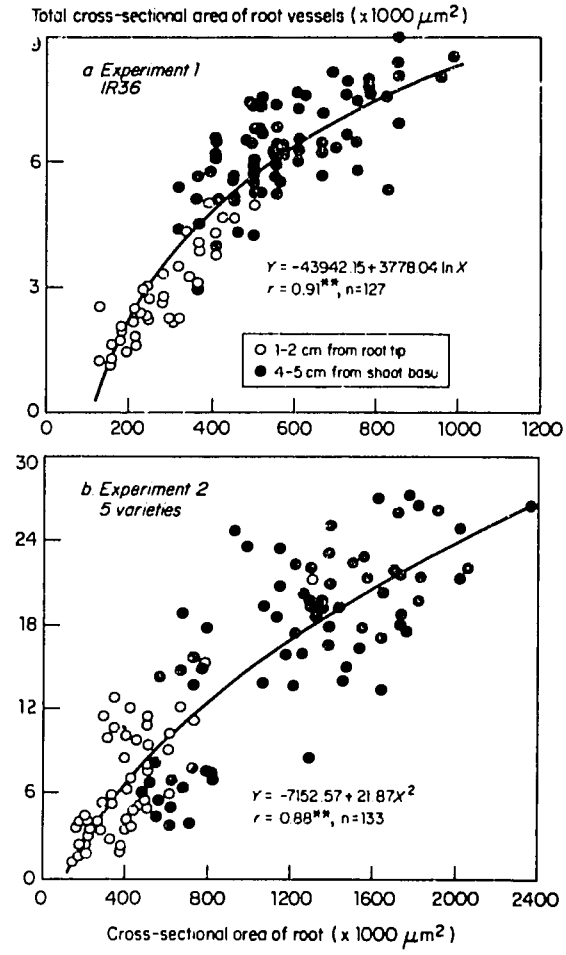
24. Effect of equivalent root vessel radius on transpiration a) in IR36 and b) across 5 varieties. IRRI, 1987.

long) in a phytotron growth cabinet (32/24 °C, 60% RH, 113.4 W m^2 radiation). Root numbers were varied from 1 to 10 per tiller to give a wide range of equivalent root xylem vessel radius – the radius of a vessel that can transport the same amount of water as several vessels in parallel. The culture solution was either kept at the level of the shoot base or lowered to 15 cm below the shoot base 1 d before measurement. Measurements were done when plants were 56-59 d old.

The LWP of IR36 increased as equivalent root vessel radius increased, with LWPs of plants at 0 cm water depth higher than those at 15 cm depth (Fig. 23a). For 5 varieties combined, at equivalent root vessel radius above 50 μm, LWPs at 0 and 15 cm water depth were not significantly different (Fig. 23b). In general, transpiration increased with increase in equivalent root vessel radius (Fig. 24). Equivalent root vessel radius and total cross-sectional area of vessels were positively correlated with root diameter for an individual root (Fig. 25, 26). There were fewer and smaller vessels near the



25. Relationship between root diameter and equivalent root vessel radius a) in IR36 and b) across 5 varieties. IRRI, 1987.



26. Relationship between cross-sectional area or root and total cross-sectional area of root vessel a) in IR36 and b) across 5 varieties. IRRI, 1987.

root tip than near the base of the shoot. Thus, these relationships partly explain the ability of rice cultivars with deep and thick roots to maintain higher LWPs during drought than cultivars with shallow and thin roots.

Genetic studies on drought avoidance mechanisms (*International Rice Germplasm Center*). The root and shoot characters of rice play a major role in drought resistance. The number and size of xylem vessels in the roots are closely related to the capacity of the plant to transport water and nutrients absorbed from the soil, while leaf area is related to transpiration. Genetic analyses of five parents, F_1 and F_2 populations in crosses involving an upland variety, two hill rices, one aus as the female parent, and the drought-susceptible IR20 as the common male parent, were conducted in hydroponic culture.

Initial differences among the 5 parents in number of root xylem vessels and their areas were observed at 20 DAS; maximum growth was at 45 DAS. Moroberekan had higher root xylem vessel number and larger area than the two hill rices from Bangladesh—Mijingem and Mimidim Alang. IR20 and the aus variety Pukhi had the lowest xylem vessel number and area. The growth pattern of root xylem vessel area was more consistent than the vessel number.

The F_1 hybrids in general had a superior root system characterized by thick, heavy, and long roots with a high root xylem vessel number. Analysis of the F_2 populations showed that the

large xylem vessel area of upland and hill rices seems to be generally controlled by a few genes with additive effects. Both xylem vessel number and area are controlled by a few genes of the polymeric model with additive and dominant effects.

The high leaf area of the upland variety was governed mainly by dominant alleles, whereas the high leaf area of hill rices was controlled by genes with additive effects.

Moderately high to high broad sense heritability was observed in xylem vessel number (36-74%), xylem vessel area (44-67%), and leaf area (38-59%).

Phenotypic correlation coefficients showed that root length was significantly and positively associated with both root xylem vessel number and area in crosses involving the two hill rices. In the cross involving the upland Moroberekan, the large xylem vessel number and area were closely related to thick root diameter.

Root diameter was positively associated with leaf area in the crosses Mimidim Alang/IR20 and Pukhi/IR20, but not in the other two crosses. The substantial differences in the relationships of root and shoot characters among the four cross combinations indicate the complexities in combining different traits and in selecting donor parents in breeding for drought resistance.

Genetic evaluation and utilization (GEU) program

Adverse soils tolerance

Soils, Plant Breeding, and Plant Physiology Departments and International Rice Testing Program

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Since 1969, more than 177,000 rices have been screened for soil toxicities and nutrient deficiencies (Table 1). In the 1987 screening, 16% were rated tolerant. Performance trials were continued. We refined our techniques for mass field screening, studied possible mechanisms of tolerance, and explored new methodologies for mass screening for soil stresses.

SALINITY

Soils, Plant Physiology, and Plant Breeding Departments, and International Rice Testing Program

Mass screening (*Soils*). Of the 2,422 tested entries, including those from the salt tolerance breeding program, elite breeding lines, advanced breeding lines, and anther culture-derived lines, 350 were found to have acceptable tolerance. Outstanding entries included IR36, IR42, Cheriviruppu, IR4630-22-2-5-1-3, IR9884-54-3, two IR41985 lines, and an anther culture-derived line AC6510-3.

A test of 130 entries from the International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON) on artificial saline soil with an electrical conductivity (EC) of 8 dS/m confirmed the salt tolerance of IR9884-132-3 and moderate tolerance of Bhurarata 4-10, IR37135-14-2-1-1, and IR19743-25-2-2-3-1.

A total of 243 rices, including entries from the elite breeding lines and those rated tolerant in earlier trials, were tested on salinized plots (EC 6 dS/m) on the IRRI farm. During the dry season (DS), 16 entries were rated tolerant. Although temperatures were lower during the wet season (WS) and the range of scores narrower at 4-7 than 3-9 in DS, only another 16 were given tolerant ratings. Lines IR19431-72-2 and IR34686-179-1-2-2 were given tolerant ratings in both DS and WS, while IR28228-28-1-3-3-2 was rated most tolerant.

Other entries rated tolerant were IR64, IR21567-9-2-2-2-1, IR26957-86-2, IR34686-179-1-2-1, IR44597-61-1-1-3, IR28183-3-2-2-1-1, IR28228-119-2-3-1-1, IR13146-45-2-3, IR44538-128-2-1-3, IR44531-120-1-3-3, IR44541-63-3-2-1, IR44563-107-1-3-6, IR44567-18-2-3-2. IR28228-12-3-1-1-2, IR33043-46-1-3, IR35366-62-1-2-2-3, IR39357-133-3-2-2-2, IR41985-46-1-3, IR42028-50-2-1-3-2-2, IR19431-72-2, IR31892-100-3-3-3-3, IR42329-20-3-2-2, IR37096-50-1-3-3, IR39365-124-3-3-2-3, and IR41167-53-21-4-2.

Most of the entries scored as tolerant can be traced to salt-tolerant parents such as IR42, IR54, IR13423-10-2-3, IR4630-22-2-17, and Cheriviruppu.

Mass screening was conducted in farmers' fields at three locations: Bulacan (DS and WS), Pampanga (DS and WS), and Pangasinan (WS). Salinity is caused by inundation with brackish water and by the capillary rise and evaporation of saline groundwater. The degree of salinity varied with site and with season. It was least in Bulacan (5-7 dS/m) and most severe in Pangasinan (9-11 dS/m). It was more severe in DS.

In Bulacan and Pampanga, the EC decreased with time during the growth period because of the impounding of fresh water for wetland rice, which could have leached down the salts. In Pangasinan, however, the soil was too clayey to allow leaching of salts by the impounded water.

In DS, 59 of 324 rices were rated tolerant. Only three rices showed comparable tolerance at the two sites. Of 324 rices tested in WS, 73 were tolerant; 10 of these showed tolerance at all 3 sites: IR32843-92-2-2-3, IR31086-4-2-1-1-1-1-3, Nona Bokra, IR37003-15-3-33, Rohy 1315-WAR-3-3-B-3, IR28224-3-2-3-2, IR31868-64-2-3-2-2, B5316-120-MR-4-1, IR9884-132-3, and CI333-4. Averaged for all locations and seasons, IR32843-92-2-2-3 reacted consistently.

Yield trial (*Soils*). During DS, the yield capacities of 24 rices previously found tolerant in

Table 1. Summary of screening for chemical stress tolerance. IRRI, 1969-87.

Stress	Entries tested (no.)	Entries found tolerant (no.)	Entries (%) with score <3
Salinity	107,465	20,469	19.1
Alkalinity	26,120	4,232	16.2
Peat soil	2,755	252	9.1
Fe toxicity	6,140	479	7.8
P deficiency	9,457	1,241	13.1
Zn deficiency	22,167	1,867	8.4
Fe deficiency	891	85	9.5
Al or Mn toxicity	2,055	222	10.8
B toxicity	614	133	21.7
Total	177,664	28,980	

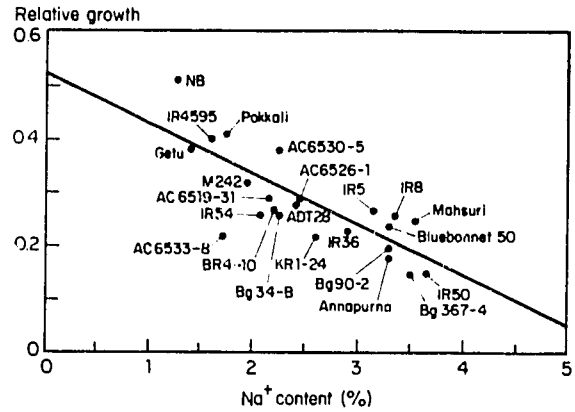
greenhouse and field mass screening were tested on salinized Maahas clay (EC 6 dS/m). Yield ranged from 0.1 t/ha for IR28 to 2.7 t/ha for IR32429-47-3-2-2. IR28228-119-2-3-1-1 gave the highest straw yield (5 t/ha), but grain yield was only 1.8 t/ha.

Evaluation of seedling salt tolerance of lines obtained by anther culture (*Plant Physiology*). The seedling salt tolerance of 4 R_3 lines produced by anther culture that were proven to be salt tolerant in field experiments was determined together with that of 20 other rice varieties and lines. One hundred seedlings per line were grown in normal solution for 1 wk and then salinized at 15 dS/m for 2 wk. Na^+ content, dry weight, and percentage survival of control and salinized seedlings were determined.

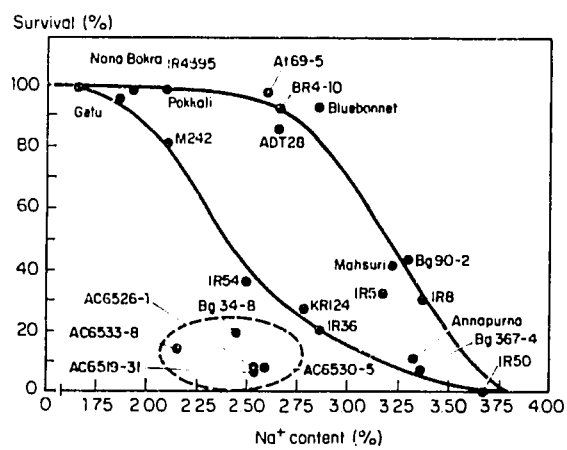
Relative growth was negatively correlated with Na^+ content in the leaf, which was similar to that reported in the IRRI Annual report for 1986, using germinated seeds at 5 dS/m (Fig. 1). Anther-cultured materials have intermediate salinity tolerance in terms of relative growth. Survival percentage was also negatively correlated with Na^+ content in the shoot, with two survival patterns for the varieties (Fig. 2). The LD_{50} (Na^+ content that gives 50% mortality) differed between these 2 groups of varieties. Anther-cultured lines were out of range of these survival patterns and were highly susceptible in terms of survival. This abnormal behavior might be due to genetic variability within each line. Genetically stable cultivars are more homozygous so that varietal differences are within the range of the survival patterns.

The seedling fresh weight histogram of four anther culture R_3 lines was determined to check their homozygosity. At R_4, one stock of AC6533-8 (A), which was a cross between IR4630 and Pokkali, was still heterozygous in nature as far as seedling growth was concerned (Fig. 3). A wide range of fresh weights showed the variation in seedling growth. However, another stock of AC6533-8 (B) was less heterozygous, with considerably fewer peaks. Two other anther-cultured lines derived from the cross IR5657/IR4630 also showed genetic variability and differences in distribution patterns (Fig. 4). IR51500AC-2 was less heterozygous than IR51500AC-3.

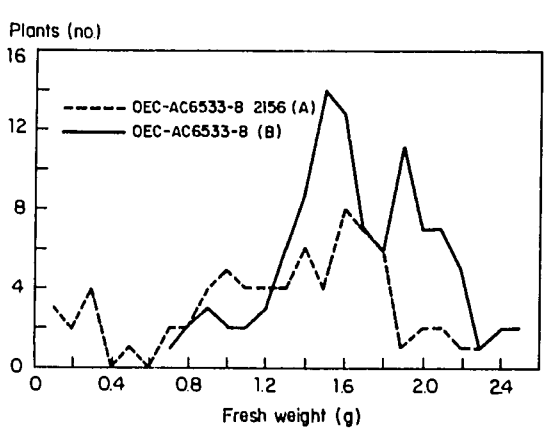
Survival percentage was also related to relative growth at 15 dS/m (Fig. 5). Again, anther-cultured



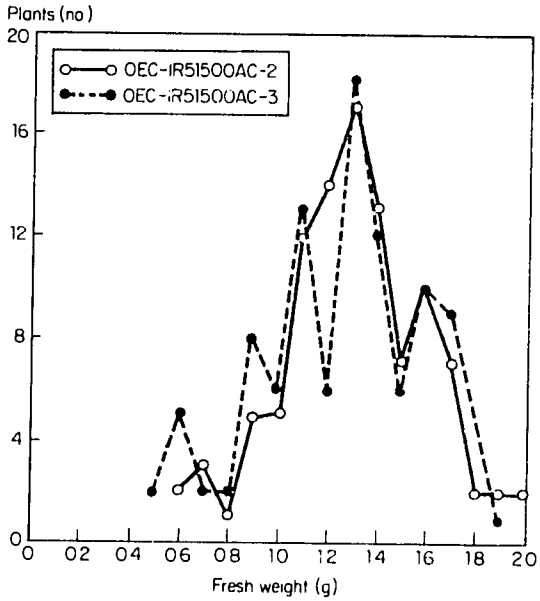
1. Na^+ content in the leaf and relative growth of varieties and lines grown at pH 5, full nutrient concentration, and NaCl at 15 dS/m, IRRI, 1987.



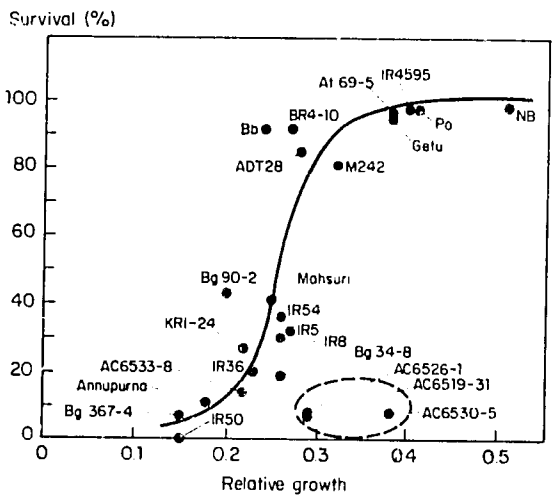
2. Na^+ content in the shoot and survival percentage of seedlings grown at 15 dS/m for 2 wk, IRRI, 1987.



3. Frequency distribution of seedling fresh weight of 2 lines of AC6533-8 grown in normal culture solution, IRRI, 1987.



4. Frequency distribution of seedling fresh weight of 2 lines of IR51500AC-2 grown in normal culture solution. IRRI, 1987.



5. Relationship between survival and relative growth at the seedling stage. IRRI, 1987.

lines deviated from the normal pattern; their relative growth was high, but survival was low. This means that, after salinization, few seedlings survived in anther-cultured lines, but the surviving materials grew well, compensating for the low dry weight of the dead seedlings. The result also implies the presence of genetic variability within the anther-cultured lines.

Theoretically, anther culture-derived material should be homozygous. The reason why anther culture-derived materials included in this study showed such genetic variability needs to be examined. As far as seedling salt tolerance is concerned, the tolerance level of anther-cultured materials included in this study is not high. However, surviving materials (variants) showed good growth under salinized conditions. Further purification of the genetic variability of these materials by screening the tolerant materials under salinized conditions may reveal tolerant variants among them.

Sensitivity of rice seedlings to salinity (*International Rice Testing Program and Plant Breeding*). An experiment using varieties Nona Bokra, Pokkali, IR28, and IR2035-117-3 determined the age at which rice seedlings are highly sensitive to salinity. Pregerminated seeds were sown, one seed per hole, on a styrofoam board with 60 holes and a nylon net bottom. The styrofoam board with 60 seedlings was floated in a 40- × 20- × 15-cm plastic tray filled with 7 liters of nutrient solution maintained at pH 5.0. The seedlings were grown at 29/21 °C (day/night) with a relative humidity (RH) of about 70% in the glasshouse of the phytotron under natural daylight conditions.

Salinity stress of 6800 ppm (EC 12 dS/m) was introduced by adding a 1:1 mixture of NaCl and $CaCl_2$ to the nutrient solution for 4-, 5-, 6-, 7-, 8-, 9-, 10-, 11-, and 12-d-old seedlings. Salinization continued for 14 d. The results indicate (Table 2) that salinity did not affect survival in tolerant varieties Nona Bokra and Pokkali. Sensitive variety IR28 was severely affected by salinity up to 7 d and then gradually gained tolerance. IR2035-117-3 showed sensitivity up to day 6 and then gained tolerance. A varietal difference with regard

Table 2. Percentage of survival of rice seedlings (4 to 12 d old) at salinity of EC 12 dS/m. IRRI phytotron, 1987.

Variety	Survival (%)								
	4	5	6	7	8	9	10	11	12
Nona Bokra	100	100	100	98	96	100	100	100	100
Pokkali	100	100	100	100	100	100	100	100	100
IR28	2	17	12	20	70	70	97	100	100
IR2035-117-3	10	52	57	85	93	92	98	100	100

Table 3. Survival of *Oryza* species at 6800 ppm (EC 12 dS/m) salinity. IRRI phytotron, 1987.

Oryza species	Accession no.	Genome	Seedlings tested (no.)	Seedlings that survived (no.)	Survival (%)
O. glaberrima	100855	AA	25	4	16.0
O. nivara	102163	AA	21	3	14.3
O. punctata	101434	BB	60	5	8.3
O. officinalis	100896	CC	88	5	5.7
O. minuta	101125	BBCC	55	7	12.7
O. latifolia	100885	CCDD	46	6	13.0
O. australiensis	100882	EE	54	1	1.9
O. brachyantha	100115	FF	43	0	0

to salt tolerance was obvious, and sensitive varieties gained tolerance with increased age.

Salt tolerance in wild rices (*International Rice Testing Program*). Seven wild species of *Oryza* and the African cultivated species *O. glaberrima* were evaluated for salt tolerance, using a salinized nutrient solution in the phytotron glasshouse at 29/21 °C (day/night) and 70% RH. Seedlings at the 2- to 3-leaf stage were subjected to salt stress of 6800 ppm (EC 12 dS/m) by adding a 1:1 mixture of NaCl and $CaCl_2$ to the nutrient solution. Salinization continued for 14 d. All species tested were susceptible to salinity during the seedling stage (Table 3). Survival ranged from zero for *O. brachyantha* to 16% for *O. glaberrima*. The tolerant check Nona Bokra showed 100% survival, whereas no seedlings in the susceptible check IR28 survived. Salinity tolerance among the wild species is apparently very low.

Physiology and genetics of salt tolerance (*Plant Breeding*). Our collaborative research program with the University of Sussex, United Kingdom, expanded with the inclusion of studies on the genetics of salt tolerance mechanisms. Crosses made last year with the objective of pyramiding different mechanisms into one variety were advanced under saline soil conditions up to the F_4. Seed samples of each generation were sent to Sussex to determine the efficiency of selection of the desired genotypes. We selected five varieties having different physiological mechanisms for salt tolerance and made crosses in a diallel pattern. These crosses are being studied in Sussex to determine the genetic control of various mechanisms.

Table 4. Embryo and endosperm weights of rices in salinity screening. IRRI, 1987.

Variety or line	Reaction to salinity[a]	Embryo weight (mg)	Endosperm weight (mg)
IR9764-45-2	R	0.47	19.1
IR64	R	0.44	18.0
IR42	R	0.39	15.2
Pokkali	R	0.56	18.6
IR28	S	0.38	16.7
MI-48	S	0.38	16.2

[a]R = resistant, S = susceptible.

Sodium uptake (*Soils*). The sodium uptake of four salt-resistant and two susceptible varieties was studied to elucidate the mechanism of salt tolerance.

The embryo weights of the resistant varieties were higher than those of the susceptible entries (Table 4). This characteristic appears to be an indication of the ability of the plant to grow more vigorously. Under adverse conditions, therefore, the plant possesses the ability to withstand stress.

Mineral analysis revealed that the resistant Pokkali had the lowest Na^+ concentration in the shoots, while the susceptible IR28 and MI-48 had the lowest K^+ content in the roots (Table 5).

The susceptible MI-48 accumulated the highest amount of Na^+ in the shoots, but it had the least in the roots (Table 5), implying that the susceptibility of MI-48 is due to the accumulation of Na^+ in the shoots. The low shoot Na^+ content of Pokkali, on the other hand, is attributable to dilution from rapid vegetative growth.

On the average, resistant varieties had slightly lower ratios of Na^+ to K^+ in the shoots than susceptible IR28 or MI-48, the difference in the

Table 5. Na^+ and K^+ contents of shoots and roots. IRRI, 1987.

Variety or line	Na^+ (%)	K^+ (%)	$Na^+:K^+$
	Shoots		
IR9764-45-2	4.00	2.29	1.7
IR64	4.64	2.13	2.2
IR42	4.26	2.56	1.7
Pokkali	3.04	2.68	1.1
IR28	4.32	2.16	2.0
MI-48	5.04	2.34	2.2
	Roots		
IR9764-45-2	3.22	1.46	2.2
IR64	3.38	1.52	2.2
IR42	3.28	1.22	2.7
Pokkali	3.25	1.33	2.4
IR28	3.89	1.17	3.3
MI-48	2.74	0.74	3.7

$Na^+:K^+$ in the roots being more pronounced. The accumulation of Na^+ in the roots of resistant varieties is balanced out by K^+ ($Na^+:K^+$ = 2.2 -2.7), but susceptibility appears to result in a wider $Na^+:K^+$ of ≥3.3.

ALKALINITY

Soils Department

Mass screening. Of 1,148 entries screened in the greenhouse, 278 were rated tolerant; 15 were rated tolerant during both DS and WS.

Of 102 entries tested in an alkalized soil (pH 8.4, sodium adsorption ratio [SAR] 36) at the IRRI farm during DS, only IR21567-18-3 was rated tolerant, 23 scored 5, and the rest 7-9.

In the same field during WS, a test of 81 entries revealed IR28224-3-2-3-2, IR32809-26-3-3, IR33059-26-2-2, IR37873-16-2-3-3, and IR29725-109-1-2-1 to be tolerant, while 28 were susceptible.

Of 32 IRSATON entries tested in alkalized plots, the best mean scores were given to C5 and IR14632-2-3; 5 entries were found susceptible.

Yield trial. The performance of 16 rices was evaluated in an alkalized field (pH 8.3, SAR 30) at IRRI during DS. In spite of the severe chemical stress compounded by high temperatures, IR33059-26-2-2 and IR29692-99-3-2-1 gave higher grain yields (1.5 t/ha) than the resistant check IR46 (0.4 t/ha).

PHOSPHORUS DEFICIENCY

Soils Department

Mass screening. Varietal differences in P efficiency were studied in culture solution in the greenhouse and in yield trials in a P-deficient farmer's field. Of 1,023 rices, 137 were rated P efficient. Twelve entries were consistently rated P efficient: IR54; tissue culture-derived lines 6514-2, 6514-4, 6526-20, 6526-26, and 6550; IR5657-33-2, IR5960-2-6-3, IR28224-3-2-3-2, IR35710-5-1-1-3, and IR42029-38-1 from the breeding lines; and IR49223 from the deepwater pedigree nursery.

Yield trial. The yield of 32 rices grown with and without P fertilization was tested in DS and WS. Based on a grain yield of more than 4 t/ha on the unfertilized plots, IR65 and IR21567-9-2-2-3-1 were P efficient; 20 varieties were moderately efficient; IR36, with a yield of 2 t/ha, was reconfirmed as moderately susceptible.

Fertilization with 25 kg P/ha gave a mean yield response of 29%. Eight rices had significant increases of 1.4 t/ha.

ZINC DEFICIENCY

Soils Department

Mass screening. Of 875 entries screened on a Zn-deficient soil in Bay, Laguna (pH 7.2, organic C [OC] 4.2%, available Zn 0.12 mg/kg), 289 were rated tolerant. Among these were tissue culture-derived rices and IR20, IR43, IR48, and AC1182.

Yield trials. In a severely Zn-deficient farmer's field in Lapayon, Leganes, Iloilo, Philippines, 21 rices that had been earlier rated promising were further tested for yield performance. Five varieties with grain yield of 3-4 t/ha were considered efficient users: IR8192-31-2-1-2, IR54, IR29723-143-3-2-1, IR4683-54-2, and IR8192-200-3-3-1-1.

Forty-two selected rices were grown in an unfertilized Zn-deficient farmer's field in Laguna. Six lines—IR35361-59-3-3-2, IR42115-33-1-3-6, IR28224-3-2-3-2, IR32307-107-3-2-2, IR29723-143-3-2-1, and IR21567-16-3—with an average yield of 4.3 t/ha performed better than the resistant check IR34. Four of these lines were medium-early to late-maturing in contrast with those rated susceptible, which were all early maturing.

Nutrient imbalance. In a screening trial of the Plant Breeding Department in Block G17 of the IRRI farm for deepwater tolerance in 1987 WS, some plants in the middle portion of the field exhibited leaf yellowing symptoms similar to Zn deficiency or tungro injury. To determine the cause of the symptoms, 25 lines were sampled for micronutrient analysis. For 20 lines where only the end portions of the plots were affected, both healthy and damaged plants were sampled for comparison.

Zn contents of all lines sampled ranged from 16 to 22 mg/kg, all within the critical limit for Zn deficiency stress (20 mg/kg). Healthy and affected plants showed no significant difference in Zn content. However, Fe-to-Zn ratios of affected plants were higher than those of healthy ones (Table 6). The Fe-Zn imbalance appeared to have induced Zn deficiency. This verifies earlier findings on the importance of nutrient balance in the study of micronutrient deficiencies or toxicities, and underscores the usefulness of nutrient ratios as an adjunct to visual scoring in varietal screening tests for micronutrient deficiencies, particularly Zn deficiency.

BORON TOXICITY

Soils Department

Varietal performance. The performance of 19 rices was evaluated on fertilized (75 kg N/ha) artificial B-toxic soils (10 mg B/kg). Grain yields ranged from 3 t/ha for IR50 and IR52 to 5 t/ha for IR28222-9-2-2-2 and IR29723-143. The two lowest yielders were given a score of 2 for B toxicity symptoms (necrotic spots along the edges of the leaf blades), while IR28222-9-2-2-2 was rated 4, confirming previous observations that visual symptoms make a poor criterion for reaction to B toxicity stress.

Table 6. Ranges in Zn, Fe, and Fe:Zn values of 25 lines from Block G17, IRRI, 1987 WS.

	Healthy	With symptoms
	Zn content (mg/kg)	
Range	16-22	16-19
Av	17.5	17.9
	Fe content (mg/kg)	
Range	84-181	104-305
Av	129	221
	Fe:Zn	
Range	4.9-11	6.1-15
Av	7.4	12.3

ALUMINUM TOXICITY

Plant Physiology Department

Screening of upland rice cultivars. Ninety-six upland rice cultivars from the Plant Breeding Department were screened for Al toxicity tolerance in the glasshouse of the phytotron at 29/21 °C. The cultivars were from Bangladesh, Brazil, Bhutan, Colombia, Ivory Coast, Philippines, Japan, and Taiwan, China. Most had been identified as either blast (Bl) resistant or tolerant as well as tolerant of low pH. The screening technique used 2-wk-old rice seedlings grown in nutrient solution with 0 and 30 ppm Al. The maximum root length and relative root length (RRL) were the indices of tolerance. Maximum root length at 30 ppm Al ranged from 6.8 to 16.23, while RRL varied from 0.67 to 1.10. IAC3 was the tolerant check and IR45 the susceptible check. CNA4130 and CNA5166, Brazilian cultivars with tolerance for Bl and low pH, responded best to Al stress. Among the 20 upland IR lines tested, 16 were tolerant. IR47686-11-2-B showed the highest tolerance for Al.

MULTIPLE STRESSES

Soils, Plant Breeding, and Plant Physiology Departments and International Rice Testing Program

Mass screening and yield trials for peat soil problems (*Soils*). On a peat soil in Calauan, Laguna (pH 6.2, OC 19%), 126 entries from elite breeding lines were tested. Six were outstanding: IR36, IR21567-9-2-2-2-1, IR32809-26-33, IR33059-26-2-2, IR34686-179-1-2-1, and IR37873-6-2-3-3-3-1.

In fertilized (50-25-50 NPK) 3- × 5-m plots in a farmer's field adjacent to the mass screening trials in Calauan, 17 selected rices were tested for yield during DS and WS. Scores for tolerance for peat soil problems based on general appearance ranged from 4 to 7. The stress was severe in DS. Maturity

was delayed, resulting in zero yield. However, a significant correlation between plant rating and grain yield was obtained. Average grain yields were the same during both seasons (1.8 and 1.9 t/ha). The tolerance of IR65 and IR8192-31 for the growth-limiting factors in organic soils was confirmed by their yields of 2.5 t/ha.

Mass screening and yield trial for acid upland soils (*Soils, Plant Breeding, and International Rice Testing Program*). Under acid upland conditions in a farmer's field in Bagacay, San Dionisio, Iloilo, 841 rices were screened in WS. The soils (pH 4.2-4.9, 6 ppm available Olsen P) have low cation exchange capacity (4-6 meq/100 g) and high Al saturation. Of the rices, 152 were also tested at Banate, Iloilo, which has similar soil conditions but a different rainfall pattern. The rices included 152 entries from the International Rice Testing Program (IRTP), 217 entries from the Plant Breeding Department, and 472 entries from the International Rice Germplasm Center and the Multiple Cropping Department (MCD). The promising entries that had a score of 5 or better are listed here:

China 988
CR237-61
CR314-5-10
IAC1246
IR12979-24-3-4
IR25588-7-3-1
IR25898-57-2-3
IR26957-45-1
IR29416-B-B-B-6-5-8
IR30696-B-2-B-1-7-2
IR30696-B-2-B-1-7-4
IR30716-B-5-B-1-2-3
IR30716-B-5-B-8-2-1
IR30718-B-3-B-10-1-1-1
IR30718-B-3-B-7-3-18
IR30731-B-2-B-5-10-1
IR30731-B-4-B-6-6-4
IR30870-B-7-B-4-3-1
IR30870-B-8-B-3-1-2
IR30870-B-8-B-3-3-1
IR31851-63-1-2-3-2
IR34450-B-B-5-3-2
IR37526-B-B-B-1
IR38550-B-B-B-4
IR38570-B-B-B-4
IR40449-B-B-4
IR43
IR47686-12-5-B-1
IR47686-13-1-1
IR47686-13-1-1-1
IR47686-13-2-1
IR47686-17-1-B
IR47686-23-3-1
IR47686-23-4-1
IR47686-25-3-1
IR47686-30-4-2
IR47686-31-4-1
IR47686-47-6-1
IR47686-4-5-B-1
IR47686-5-10-B
IR47686-6-4-1-1
IR47686-9-2-B
IR47691-48-2-1
IR47691-49-2-1
IR47698-33-4-1
IR47698-4-4-1
IR47699-27-2-1
IR47699-29-6-B
IR5931-113-1
IR65
IR9256-59
IR9761-19-1
IR9764-45-2-2
IRAT109
IRAT116
IRAT133
IRAT144
ITA212
ITA233
K2B22
Kinandang Patong
Kutiam
Mahsuri
NDR102
P2056-F4-59-2
TOX502-2-SLR2-LS3-B1
Triveni
UPLRi-7

The main mineral stresses in acid upland soils are Al and Mn toxicities and P deficiency. To observe varietal reactions to those stresses, 12 rices were grown during DS on acid aerobic soil in Luisiana, Laguna (pH 4.8, total N 0.241%, OC 2.17%). To observe the distinct manifestations of stress symptoms, plots where another set of the same rices was tested were acidified to pH 3.9 with flowers of sulfur.

Heavy bird damage did not allow grain yield comparisons, but plant observations showed marked varietal differences in reaction to acid upland conditions. At pH 3.9, Aus 454 had the best growth, without any stress symptoms, while UPLRi-7 was rated least tolerant. All entries were given a rating of 3 at pH 4.8. At pH 3.9, symptoms of N deficiency were not observed. Depressing the pH apparently allowed for better N availability.

Earlier varietal tests on acid upland soils showed that japonica rices are good sources of tolerance for the adverse conditions of acid upland soils. During DS, the performance of 39 entries was tested in Cavinti, Laguna (pH 4.1, total N 0.29%, available P 1.21 mg/kg, exchangeable Al 345 mg/kg), to confirm the superiority of japonica over other groups in terms of adaptation to acid upland soil—with and without 40 kg P/ha. Symptoms of mild Mn toxicity were observed regardless of P addition. Most of the entries suffered from P deficiency symptoms on the no-P plots. Forty-six percent of the entries were P responsive (Table 7).

Considered P efficient were varieties that grew well without P fertilization—including IRAT140, UPLRi-5, Kinandang Patong, and GS529—while the poorest performers or the least P-efficient entries were CNA4120 and Chianan 8. Varieties that responded best to P fertilization were the japonicas, CNA4136, and Aus 196.

The yield performance of 72 rices was tested in acid upland soils. Thirty-six of the entries from IRTP (18 from the International Upland Rice Yield Nursery [IURYN]-Early maturity group and 18 from the IURYN-Medium maturity group) were evaluated at 2 sites—Bagacay, San Dionisio, and Fuentes, Banate, Iloilo—in adjacent farmers' fields with soil conditions similar to those used in mass screening. The remaining 36 entries from MCD were tested at only one site in Banate.

Plant height, number of panicles per square meter, grain yield per plot, and scores for vegetative

vigor, drought tolerance, lodging, and phenotypic acceptability including diseases and pests were used in evaluating the relative performance of the varieties.

A mean grain yield of 1.0 t/ha was obtained from the evaluation of 72 rices. The highest yielders with an identical yield of 1.3 t/ha were NDR102 and IR9761-19-1, followed by the IRTP entries CR222-MW10, IR10198-66-2, and N22.

Twelve of 36 entries produced grain yields ≥1.0 t/ha and showed consistent performance at both sites: B36236-TB-49, IR5931-11-3-1, NDR97, and TNAU of the medium maturity group; and CR222-MW10, HPU741, IRAT110, IR10198-66-2, IR25588-7-3-1, IR9761-19-1, NDR102, and NDR84 of the early maturity group. Kutiam, RAU4008-4, N22, and CR164-5 also gave comparable results, but at only one site—the first two at Bagacay and the latter two at Banate.

The highest producer in the MCD group of entries was Aus 257 (1.2 t/ha), followed by IR30716-B-1-B-1-2, IR12979-24-1-6, IR30716-B-2-B-9-1, IR3880-2-3, IR30716-B-1-B-1-6, BPI 319-1, and BR319-1.

Mass screening and yield trial for inland iron-toxic and phosphorus-deficient soils (*Soils, Plant Breeding, and International Rice Testing Program*). In an inland Fe-toxic soil (pH 3.8-4.2, available P 3.6-4.2 mg/kg, exchangeable K 0.02 meq/100 g, OC <1%, active Fe 2.3%), 644 rices were evaluated for their performance in San Dionisio, Iloilo, in WS. The test rices were obtained from IRTP (282 entries) and the Plant Breeding Department (362 entries). About 120 selected varieties that are known to be P-efficient and tolerant of Fe toxicity were further evaluated in DS.

Table 7. Performance of selected rices on an acid upland soil. IRRI, 1987.

Rices	Entries responsive to P (no.)	Entries not responsive to P (no.)
Japonicas	11	13
Indicas	6	5
Aus varieties	1	2

Promising varieties that showed tolerance for those conditions are listed here:

B2791-MR-196-2-3-3-5
B2992B-TB-73-4-2-3-3-3-2
B3016C-TB-263-3-2-1-1-3
B301C-TB-263-3-5
B3623G-TB-46
B3623G-TB-49
B3662E-TB-5-4-4
B3662F-TB-14-2
BH2
BKNFR1094-56-1-1-11
BR11
BR113-47-1-2-1-2
BR51-120-2
BR51-291-3-22
BR51-46-6-HR54
BR51-49-6-HR63
BRB11-448-1-4
BRB11-461-1
BRB16-127-4-2
BRC16-127-4-1
BW297-2
Cablak
Djambaram
Gaw Diaw Bow
IR13149-3-2-2
IR13610-72-2-2E-P2
IR17491-5-4-3-3-P1
IR19661-13-3-2
IR21064-48-2-1E-P
IR21178-43-1-2-2
IR21188-87-3-3-2-2
1721567-16-2-2
IR21567-9-2-2-2-3-1-3
IR21573-2-1-2-2-2
IR21848-65-3-2-2
IR22082-41-2
IR25587-133-3-2-2-2
IR26474-246-1-1
IR26717-1-1-2-1-1
IR26724-246-1-1
IR28228-12-3-1-1
IR2863-35-3-3
IR29385-2-30-3
IR29723-67-2-2-3
IR3116-34-1-2
IR31361-8-3-2-2
IR31375-5-2-1-1
IR31429-20-2-3
IR31432-8-3-2
IR32329-5-2-2
IR33043-46-1-3
IR33059-26-2-2
IR33353-64-1-2-1
IR33380-60-1-2-2
IR34686-179-1-2-3
IR35353-94-2-1-3
IR35361-59-3-3-2
IR37250-44-2-1-1-1-2-2
IR37255-12-1-3-3
IR37256-31-3-1-2
IR37260-6-1-1-4-3-2
IR37263-6-1-3-3-1-1
IR37263-6-1-3-3-1-2
IR37721-130-2-1-3
IR39506-57-5-3-1-3
IR39537-19-3-3-2-2-1
IR39558-17-3-2-2-3
IR42
IR54743-8-11-20
IR54745-2-23-19
IR5785-188-2-1
IR9217-58-2-2
IR9217-6-2-2-2-3
ITA239
KK06-0-10
KK12-18-3-5
Kuatik Putih
Leuang Yai 148
Mahsuri
Nhigue
RD21
RP975-102-2
Satrijo
S-4
TCA80-4
Tilak Chauri
Torompasse
T'Chorno
Untup

Eighty-nine varieties performed well, with a score of 4 or better, an average 14 tillers/hill, and less than 15% unfilled grains. Mahsuri consistently performed better than the other varieties.

One hundred forty-two promising rices and 50 entries from the International Rice Yield Nursery were tested for their yield performance in inland Fe-toxic soils in a farmer's field adjacent to the mass screening site in San Dionisio, Iloilo. Varieties that produced ≥2 t/ha grain yield and scored less

than 4 for phenotypic acceptability, including disease and pest tolerance, were selected for agronomic and soil management studies.

Some of the highest yielding varieties were BR4-9-16-3-1, IR31787-16-1-2-3-2, IR32429-47-3-2-2, IR39357-133-3-2-2-2, IR39385-124-3-3-2-3, and IR39422-19-3-3-3-3 in the very early maturity group (90 d). In the early maturity group (110 d), promising varieties were Chianung san yu 26, C662083, DR33, IR1346, IR13240-108-2-2-3, IR13524-21-2-3-3-2-2, MTU5410-14, SPRLR76012-26-1-1, S287B-39-1-3, and IR24632-145-2-2-3.

Mass screening and yield trial for saline and acid sulfate soil conditions (*Soils, Plant Breeding, and International Rice Testing Program*). A total of 853 rices were evaluated in farmers' fields at 3 Iloilo sites: Santo Rosario, Pili, and Lanjagan. The test material was obtained from the Plant Breeding Department (559 entries) and IRTP (294 entries). The former included 125 advanced lines, 63 traditional varieties, 2 hybrid lines, 22 varieties from West Africa, 27 bulu varieties, and 320 anther culture lines. The IRTP material was entries from IRSATON, the International Tide-Prone Rice Observational Nursery, International Rainfed Rice Shallow Water Observational Nursery, and acid lowland screening sets. Bulus, traditional varieties, and advanced lines were tested at two sites only.

The soils (pH 3.6-3.9, available P 4.0-5.0 mg/kg, active Fe 1.2-1.8%, exchangeable Al 120-160 mg/kg, acetate soluble SO_4^- 0.2-0.4%) were strongly saline because of tidal influence and had acid sulfate conditions. The salinity ranged from 5 to 23 dS/m, being higher in months with less rainfall and in DS. During July, September, and October, these fields were also affected by floods, in which case the plants remained submerged for 2-5 d. The longest submergence was in Santo Rosario, which became flooded at 2 d after transplanting.

Mahsuri performed best at all sites. Untup, Nona Bokra, Malama, and Osok gave comparable results. The other promising entries in at least two of the three sites were

AT69-5
B2791B-MR-257-3-2KP2
B36236-TB-49
B5316-12D-MR-4-2
Banih Kuning
BR11
BR4
BR51-49-6-HR-54
BR51-49-6-HR-63
BRB20-3B-17
BW272-2
BW272-8
BW295-5
Cablak
CN505-5-3-1
IR10206-29-2-1
IR13365-253-3-2
IR1529-680-3-2
IR15810-260-1-3-1-3
IR19661-30-1-2-3-2
IR19725-1-2-2
IR20925-33-3-1-1-2-8
IR21064-48-2
IR21820-154-3-2-2-3
IR21848-65-3-2-2
IR26724-246-1-1
IR28150-84-3-3-3-2
IR28228-119-2-3-1-1
IR2863-35-3-3
IR28905-3-1-0-0
IR29385-2-30-3
IR31375-3-3-1-1
IR3262-3-9-4-5
IR3351-38-3-1
IR35666-62-1-1-1
IR37255-12-1-3-3
IR37255-21-3-2-1
IR37255-21-3-3-2
IR37256-31-3-3-2
IR37257-41-3-2-3
IR37260-6-1-1-1-6-1
IR37260-6-1-1-4-3-2
IR37263-6-1-3-3-1-1
IR37263-6-1-3-3-1-2
IR38851-33-3-3-2-2-3
IR38853-4-3-2-2-3
IR40578-13-2-2-3-2-2
IR40692-21-2-1-3-3-3
IR42
IR44504-36-2-3-3
IR44504-6-3-1-2
IR44582-71-2-2-2
IR44706-21-1
IR4595-4-1-13
IR4630-22-2-5-1-3
IR51500-AC-944-1
IR51500-AC-944-2
IR51500-AC-944-3
IR51500-AC-944-4
IR51500-AC-944-5
IR51500-AC-951-9
IR51500-AC-952-3
IR51500-AC-952-5
IR51500-AC-953-2
IR51500-AC-954-23
IR51500-AC-954-7
IR51500-AC-954-9
IR51500-AC-956-16
IR51500-AC-957 16
IR51500-AC-957-22
IR51500-AC-957-23
IR51500-AC-958-11
IR51500-AC-958-7
IR5785-118-2-1
IR8236-B-B-57-2-1
RTN15-2-1-1-1
SR26-B
Torompasse
T'Chorno

The yield performance of 122 lines was evaluated in a farmer's field with moderately saline-acid sulfate conditions in Lanjagan. Before transplanting, the field was flushed 3 times with fresh water, with 8-10 h of drying between flushings. Soil pH after flushing and throughout the growth period was 4.8-5.2, and salinity ranged from 6 to 11 dS/m.

All varieties were scored at flowering for phenotypic acceptability, and their plant height, tiller count, and grain yield were measured at harvest (plot size of 10 m^2).

Of 122 test lines, only 25 (20.5%) produced a grain yield of 1 t/ha or more. Of these, 4.9% yielded up to 1.3 t/ha, 7.4% up to 1.5 t/ha, 4.1% up to 1.8 t/ha, 3.3% up to 2.0 t/ha, and 0.8% up to 2.3 t/ha. B4259-48-13, Mat Candu, IR28526-44-1-1, CR213-1002, and B4259-48-1-1-3 were the highest yielders, with a grain yield of more than 1.8 t/ha.

Varietal screening for coastal saline soils (*Plant Breeding*). We used two coastal saline locations in the Philippines—Santo Tomas and Castuli in Pampanga Province—to test and select advanced breeding lines and varieties. The soil in Santo Tomas is slightly acidic. Salinity stress is higher in Castuli. Both sites are subjected to flash floods during the early part of the WS and drought during later stages.

All tests were done with Cheriviruppu, Nona Bokra, and Pokkali as tolerant checks and IR28 as the susceptible check. Improved salt-tolerant types IR4595-4-1-13, IR9764-45-2-2, and IR9884-54-3 were used as selection guides.

Among the 100 IR advanced breeding lines tested, 42 were found to be tolerant of soil and climatic stresses prevailing at these sites. After evaluation for agronomic traits during the reproductive phase, the following were selected for nomination to IRTP hot-spot screening tests: IR29137-16-1-6, IR31361-8-3-2-2, IR31363-1-1-3-3-2-1, IR31375-3-3-1-1, IR31376-1-2-1-1, IR37255-21-3-3-2, and IR37260-6-1-1-1-6-1.

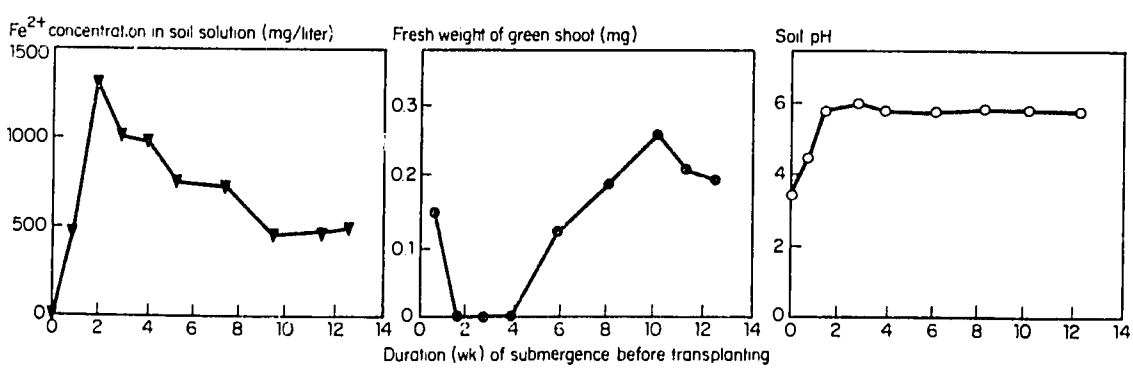
P efficiency being an important trait that contributes to adverse soils tolerance, we screened 60 upland varieties and breeding lines and 24 bulu varieties in Santo Tomas and Castuli. In addition to salt-tolerant and -susceptible checks, Mahsuri was included as a P-efficient check. In Santo Tomas, 10 upland breeding lines performed well, expressing some salt tolerance. Others died about 3 wk after planting because of salinity. Mahsuri was acceptable. In Castuli, all except Mahsuri died 1 wk after planting, probably because of very high salinity. Among the bulus, eight—Bulu Dalam, Cicih Kapok, Gedangan Tjoklat, Gendjah Bulu, Ketan Banteng, Ketan Lumbu, Malama, and Untup—performed as well as Mahsuri and the other tolerant checks. In fact, when salinity increased to about 20 dS/m at the end of the season, they were still flowering, but they survived. They were selected for improvement of agronomic characters by breeding.

Varietal differences in tolerance for acid sulfate soils (*Plant Physiology*). Two disorders in rice plants grown under acid sulfate soils (topsoil from Albay, Philippines) were observed. The first appeared just after transplanting as discoloration and drying of leaves and, in severe cases, seedling death. The second disorder was very poor plant growth at early growth stages.

The first disorder can be attributed to Fe toxicity due to high concentration of Fe^{2+} in the soil solution, with the critical point at about 500 mg/liter (Fig. 6). It was not affected by high amounts of acetate buffer (1 M, pH 3.0)-extractable Fe^{2+} in the soil. The concentration of Fe^{2+} in the soil solution increases after flooding and subsequently decreases with time (Fig. 6).

Varietal differences in tolerance for the first disorder were observed. Seedlings of tolerant varieties were characterized by a higher ratio of shoot dry weight to plant height, dry weight ratio of root to shoot, and vigorous roots (number, dry weight, and root activity) (Table 8). The disorder can be minimized by using seedlings with nursery soil still attached to the roots.

The second disorder, resulting in growth retardation, seemed to be caused mainly by P deficiency and Fe toxicity; it was observed at tillering.



6. Effect of duration of submergence in acid sulfate soil (Balza topsoil) on growth of IR64, concentration of Fe^{2+} in soil solution, and soil pH. IRRI, 1987.

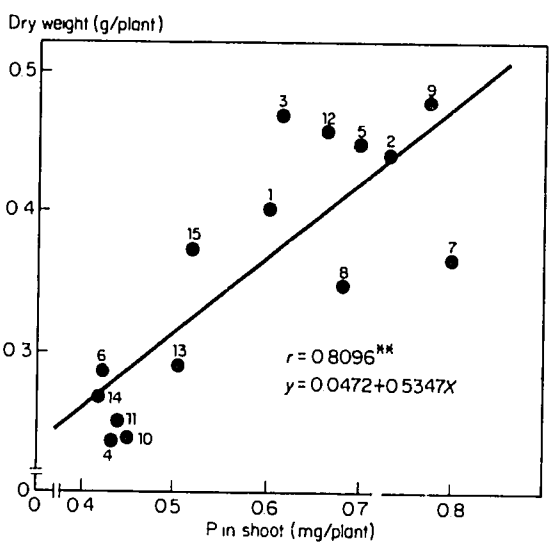
Table 8. Correlation coefficients[a] between the first disorder and characteristics of seedling. IRRI, 1987.

Seedling characteristic	Plant condition in Balza soil (1 WT)[a]	
	Seedling survival percentage	Mean dry weight of green leaf blade
Shoot height	-0.1788	-0.2013
Shoot dry weight	0.5073	0.5126
Shoot dry weight:shoot height	0.5734*	0.6151*
Number of roots	0.6924**	0.7124**
Root dry weight	0.6453**	0.6268**
Root dry weight: shoot dry weight	0.5448*	0.5104
Root activity (mg of α-naphthylamine oxidized/g of dry weight of root per h)	0.5657*	0.5461*
Root activity (mg of α-naphthylamine oxidized/seedling per h)	0.6175*	0.5871*

[a]WT = week after transplanting.

Table 9. Correlation coefficients between dry weight of plants grown in 2 soils at 1 mo after transplanting and characteristics of seedlings. IRRI, 1987.

Seedling characteristic	Shoot dry weight	
	Balza soil	Maahas soil
Shoot dry weight in Maahas soil	0.6389*	–
Seedling		
Shoot height	0.5418*	0.6782**
Shoot dry weight	0.7185**	0.7257**
Shoot dry weight:shoot height	0.2647	0.0285
Number of roots	0.4628	0.1044
Root dry weight	0.2934	0.1603
Root dry weight:shoot dry weight	-0.2075	0.3699



7. Relationship between amount of P in plant and dry weight of plant at 1 mo after transplanting, IRRI, 1987. 1 = Khao Setha, 2 = KDML 105, 3 = Maha Deveredere, 4 = Mahsuri, 5 = Patnai 23, 6 = Siam Halus, 7 = IR9764-45-2-2, 8 = IR8192-200-3-3-1-1, 9 = IR64, 10 = IR54, 11 = IR52, 12 = IR46, 13 = IR45, 14 = IR42, 15 = IR36.

Table 10. Tolerance of some lines and varieties for multiple stresses. IRRI, 1987.

Variety or line	Tolerance for
	Flooded conditions
IR9764-45	P deficiency, Zn deficiency, salinity, alkalinity, salinity-alkalinity, B toxicity
IR28224-3	P deficiency, Zn deficiency, salinity, alkalinity, salinity-alkalinity, B toxicity, peat soil
IR28150-84	Zn deficiency, salinity, salinity-alkalinity, peat soil
	Upland conditions
UPLRi-7	Acid, calcareous
IR50	Acid, calcareous

Varietal differences in tolerance for this disorder were likewise noted. Seedlings of tolerant varieties were characterized by bigger seedlings (dry weight and plant height) and more vigorous plant growth in normal soil (Table 9). These plants possessed better P absorption ability (Fig. 7) but not higher P content (dry weight basis) in the shoots (r=-0.3809).

The trend in varietal differences in the first disorder is not related to that in the second disorder (r= 0.4173), and the disorders can be reduced by using good seedlings through appropriate nursery practices.

Multiple chemical stresses (*Soils*). In outdoor concrete tanks at IRRI, the tolerance of several lines for multiple chemical stresses was confirmed by their general appearance and grain yield (Table 10). These lines and varieties show promise as substitutes for costly and repeated amendments.

Genetic evaluation and utilization (GEU) program

Deepwater and flood tolerance

Plant Physiology, Plant Breeding, Agronomy, Multiple Cropping, and Soils Departments

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SCREENING FOR SUBMERGENCE TOLERANCE

Plant Physiology Department

In concrete tanks in the greenhouse, 21,495 entries—including 1,519 entries from the germplasm bank (GB) and 16,764 entries from the pedigree nurseries for rainfed lowland, medium deep rainfed lowland, drought-prone rainfed lowland, and deepwater rice—were screened for submergence tolerance. Among GB entries, Adalat, Jagar, Kusunkatiki, and Tanki were outstanding after retesting under more severe conditions.

Progenies of FR13A generated from tissue culture at Murdoch University in Western Australia were tested; 50% of the 46 entries were superior to FR13A.

SCREENING FOR ELONGATION ABILITY

Plant Physiology Department

A total of 308 entries from the International Rice Deepwater Observational Nursery, the International Floating Rice Observational Nursery (IFRON), and the International Tide-Prone Rice Observational Nursery were screened for elongation ability. Hybridization block and GEU elite lines were also screened for elongation ability. BR222-8-191-3-2, BR523-168-2, DWC-8-283, and Khama 49/8-x-12, all from IFRON, were the most outstanding entries.

SCREENING FOR DEEPWATER TOLERANCE

Soils and Plant Breeding Departments

Mass screening. In Tamisaac, Concepcion, Iloilo, 408 rices were tested for elongation ability and deepwater tolerance in farmers' fields. The rices were sown in furrows spaced at 30 cm in dry soil conditions before the onset of rains. After germination, the water depth in the field was gradually increased to 75 cm over 1.5 mo and maintained at this level throughout the growing period. But because of heavy rains at 25 d after seeding (DAS), 40 DAS, and 67 DAS, the water level exceeded 1.2 m. During these periods, the taller varieties were submerged for 5-9 d and the shorter ones for longer.

Nine of the entries were outstanding. They had a plant height of about 1.0 m or more and a flood tolerance score of 4 or better, and they produced considerable yields despite submergence (Table 1).

Observational trial. Also in Tamisaac, under hydrological conditions similar to those for mass screening, 30 rice varieties were evaluated for tolerance for deepwater conditions in an adjacent farmer's field. This trial also faced similar flood conditions as the nearby mass screening plots.

Those with plant height of more than 1.0 m, tiller count ≥20/hill, and a score of 5 or better included IR33225-21-3-1-3, BE-3, IR33352-59-3-1-3, IR31375-5-2-1-3, RP975-109-2, IR33380-31-3-3-3, and IR38699-21-2-2-1. In this group, IR33380-31-3-3-3 and RP975-109-2 produced the highest grain yield of 5.1 t/ha.

Medium deepwater yield trial. The yield performance of 36 rice varieties that had been identified as promising was evaluated in a farmer's field in Tamisaac, Iloilo. Plant height, tiller count per hill, submergence tolerance score, and grain yield were considered.

A mean yield of about 1.2 t/ha was obtained. Only 4 varieties—BR11, IR33380-31-1-1-3, IR33238-25-2-3-2, and B4259-39-2-3—produced a grain yield ≥1.5 t/ha. A grain yield of 1.0-1.5 t/ha was produced by IR33380-60-1-2-2, IR13149-71-3-2-3, IR21567-9-2-2-2-1, IR21531-2-2-2-1-3-3-1, IR19319-5-3-3-2-1, and IR26760-76-2-1-2-3. All these varieties had a plant height ≥100 cm and a tiller count ≥20/hill.

CHANGES IN CELL LENGTH AND NUMBER

Plant Physiology Department

Deepwater rices (DWRs) are different from modern rices in having a long vegetative phase. During this period, the internodes (I) formed (I13 to I5) generally elongate. This elongation is the result of increases in both cell length and cell number.

Studies were conducted to determine whether cell number or cell length is the main contributing factor in the internode elongation of Habiganj Aman VIII (HBJ VIII), a DWR known for internode elongation ability even in shallow water.

Counting from the top, internode elongation in HBJ VIII was evident in internode 12 (I12) and

Table 1. Plant height, flood tolerance scores, and grain yield of 9 deepwater-tolerant rices. Tamisaac, Iloilo, Philippines, 1986.

Variety or line	Plant height (cm)	Tolerance score	Grain yield (t/ha)
HTFR78010-6-502-1-1-3-2	98	4	1.4
BKNFR81023-9-1-4-4	150	4	1.4
BKNFR81023-9-1-2-1	125	3	1.7
BKNFR81023-9-2-3-1	125	4	1.6
IR31343-62-3-2-1-1-3-1	95	4	1.5
IR33284-4-502-1-2-1-2-1	125	4	1.3
IR35710-5-1-1-3-1-3	115	4	1.4
IR38789-151-3	112	4	1.2
Klip Maek Nak	160	4	1.2

Table 2. Internode length, cell length, and cell number in the longitudinal section of each internode of Habiganj Aman VIII under irrigated conditions.[a] IRRI, 1987.

Internode position from top	Internode length (cm)	Average cell length[b] (μm)	Cell number
1[c]	29.2	74.6 a	3914 a
2	19.4	88.8 bc	2185 b
3	16.7	77.5 abc	2155 b
4	19.5	111.0 c	1757 bc
5	16.2	69.8 ad	2321 b
6	14.7	76.2 ab	1929 b
7	12.7	58.1 de	2186 b
8	8.5	60.6 de	1403 c
9	6.8	40.2 ef	1700 c
10	6.0	55.6 de	1084 d
11	3.51	49.8 ef	705 e
12	1.80	38.6 ef	466 f
13	0.441	26.0 eg	170 g
14	0.225	21.7 g	157 g
15	0.225	20.4 g	110 h
20	0.114	21.5 g	53 i

[a]The parenchymatous cells were measured in the third cell layer from the outermost cells of a vascular bundle in the pith. [b]The average of the top, middle, and base of each internode except internode 1 (4 parts) and internodes 13-20 (only middle part). [c]Peduncular internode.

progressively increased up to 15 during the vegetative phase (Table 2). The last four internodes—11, 12, 13, and 14—generally elongated during the reproductive phase. The last—or peduncular—internode was the longest.

Cell length was more or less the same for the elongated internodes during the vegetative phase in HBJ VIII. It was largest in 14, reaching 111.0 μm. Cell number progressively increased from the lowest internode to 17. The peduncular internode had the most cells.

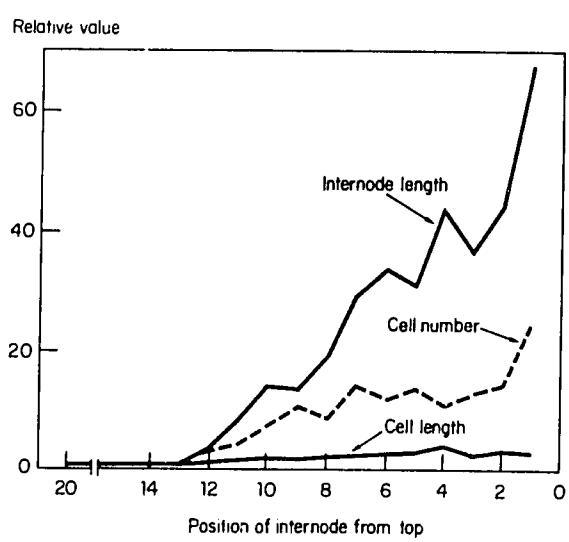
Based on 113, which is the lowest unelongated internode, the relative values of cell length and cell number in the increasing internode length are shown in Figure 1. Increase in cell number is more important than increase in cell length in accounting for increasing internode length.

Although obtained from only one cultivar, these findings indicate the importance of intercalary meristem induction or promotion in internode elongation. This explains differences in growth response to endogenous growth regulators, depending on their ability to induce intercalary meristem or limited cell elongation.

INHERITANCE OF PLANT AND INTERNODE ELONGATION ABILITY

Plant Breeding Department

We investigated crosses involving floating, modern variety (MV) elongating, and MV nonelongating parents. The F_1, F_2, BC_1P_1, and BC_1P_2, along with their parents, were space-seeded, and 5-wk-old populations were subjected to abrupt flooding of 1 m for 1 wk. Plant height was recorded before and after submergence, along with internode length.



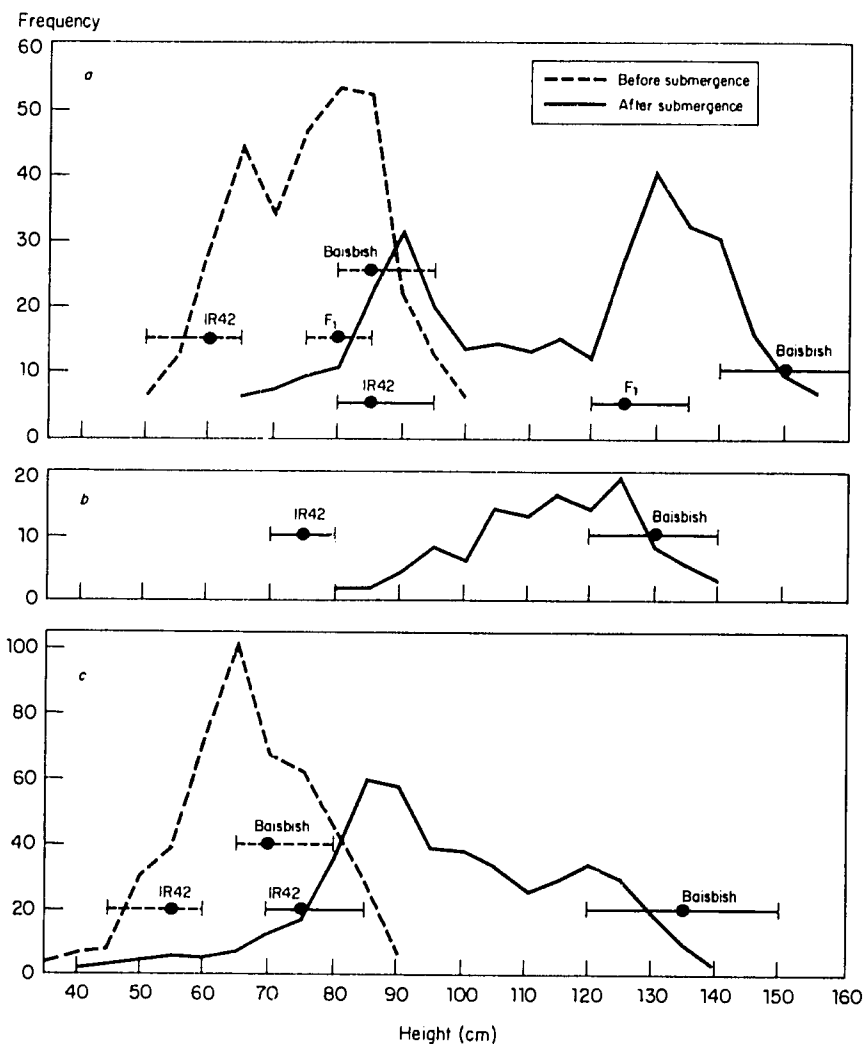
1. Relative value of cell length, cell number, and internode length in each position, IRRI, 1987.

$$\text{Relative value} = \frac{\text{value of each position}}{\text{value of 13th position}}$$

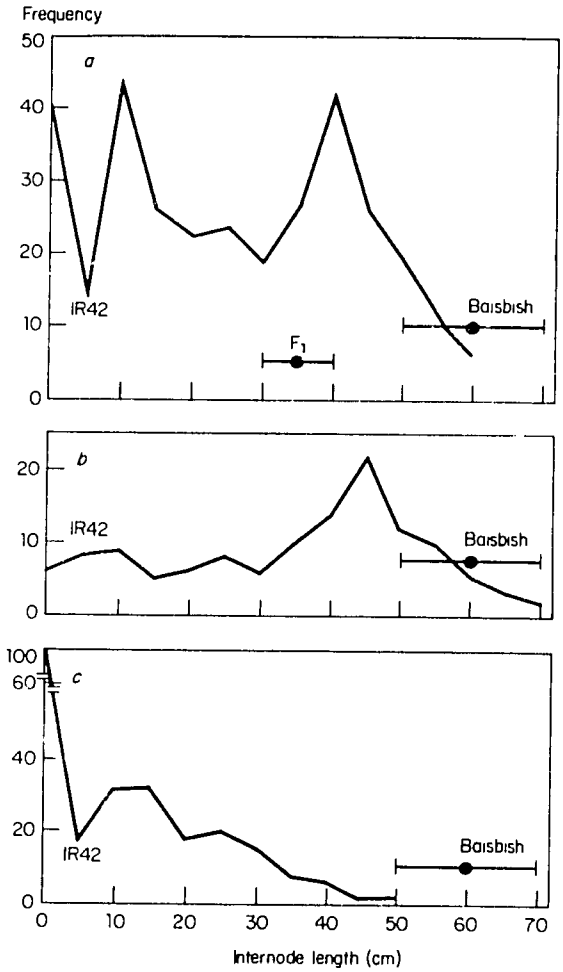
Frequency distributions of plant height and internode length were plotted at 5-cm intervals.

Baisbish/IR42. *Plant height.* The frequency distribution of height in the F_2 of Baisbish/IR42 before submergence was almost bimodal; after submergence it had two distinct peaks, separated at 105 cm (Fig. 2). One hundred forty-four plants in the low height category and 178 tall plants gave a good fit to a 7:9 ratio. The distribution of height in BC_1 (Baisbish/IR42//Baisbish) progenies was clearly unimodal after submergence, and all plants were rated elongating. The distribution of height in backcross progenies of (Baisbish/IR42//IR42) was unimodal, with one sharp peak before submergence, and bimodal after submergence. Of 460 plants, 345 were in the nonelongating category and 115 in the elongating category, giving a good fit to a 3:1 ratio.

Internode length. Baisbish had 0.5-1 cm internode length in some of its plants before submergence. Distribution of internode length in the F_2 of Baisbish/IR42 indicated 3 peaks at 0, 10, and 40 cm (Fig. 3). However, the population could be clearly seen at 30 cm length, having the lowest frequency curve and making the population bimodal if the 0-30 cm range of length is grouped



2. Frequency distribution of height in a) F_2 of Baisbish/IR42, b) BC_1P_1, and c) BC_1P_2, IRRI 1987. Horizontal lines show the range of height of parents and F_1 plants about the means (solid circles).



3. Frequency distribution of internode length in a) F_2 of Baisbish/IR42, b) BC_1P_1, and c) BC_1P_2, IRRI, 1987. Horizontal lines show the range of internode length of parents and F_1 plants about the means (solid circles).

together in category one and those with 30 cm and above in the second category. Out of 322 plants, 149 were in the first and 173 in the second category, which provided a good fit to a 7:9 ratio. Backcrossing the F_1 with Baisbish provided the expected result: distribution was unimodal, though some plants were devoid of internodes. Internode elongation is very much related to plant vigor. In backcross progenies with IR42, the distribution of internode length was not clear.

Baisbish/IR11141-6-1-4. *Plant height.* In the F_2, distribution of height was unimodal before submergence, but bimodal after submergence, with two clear peaks (Fig. 4). It could be divided into 2 categories, one with height up to 120 cm and the second with height 120 cm or higher. This fitted well to a 1:3 ratio of nonelongating:elongating. In the BC_1F_1 to the floating parent, Baisbish showed normal distribution of height after submergence and exceeded the parental range both ways. The BC_1F_1 progenies with MV elongating parent IR11141-6-1-4, on the other hand, were clearly bimodal, separating into 2 equal categories and fitting well to a 1:1 ratio.

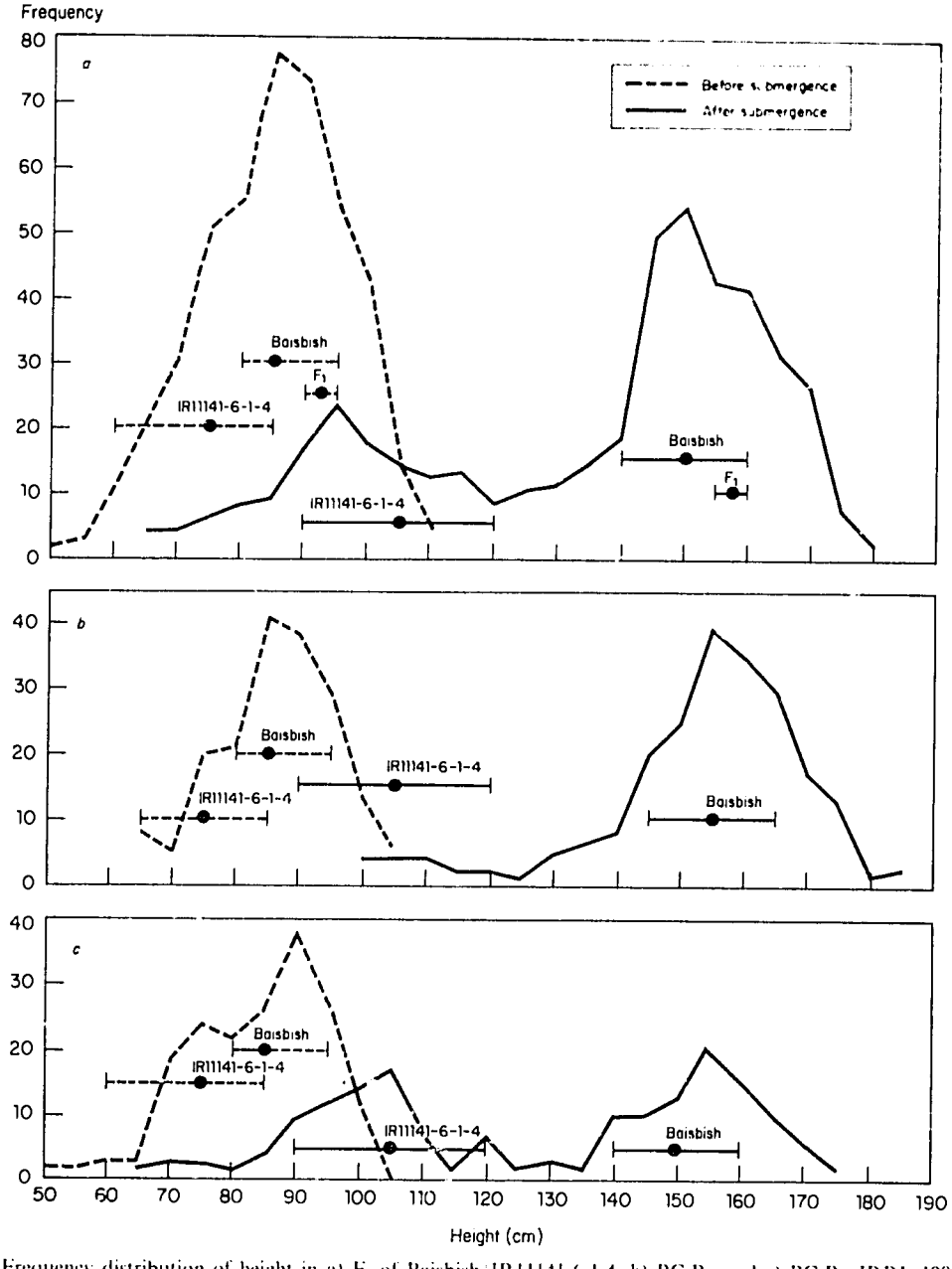
Internode length. The distribution of internode length in the F_2 of Baisbish/IR11141-6-1-4 was distinctly bimodal (Fig. 5), with the F_1 range almost coinciding with the Baisbish range. If the 0-30 cm length is considered in one category and 30-80 cm in another, 119 plants in the first and 321 in the second were obtained, conforming to a 1:3 ratio. The distribution of internode length in the backcross to Baisbish was almost unimodal, but with some transgressive segregation beyond Baisbish. Some segregants like IR11141-6-1-4 were also obtained. The behavior of BC_1 progenies with IR11141-6-1-4, however, showed a clearly bimodal distribution pattern for internode length. The lowest frequency was obtained for plants with 30 cm length, which divided the population into 2 categories. Of 178 plants, 82 were in first and 96 in the second category, giving a good fit to the expected 1:1 ratio.

The short submergence employed for studying elongation in DWR showed clearcut genetic segregation and in the case of crosses between floating and MV nonelongating parents indicated segregation for elongation due to two complementary genes. The crosses between floating and MV elongating parents, however, segregated in a 3:1 ratio, indicating that the parents differed in 1 locus.

YIELD POTENTIAL OF PROMISING DEEPWATER RICES

Agronomy Department

A field trial to determine the inherent yield potential of some promising DWRs was continued at IRRI. Eight promising DWRs underwent seed increase in dry season (DS) and were transplanted in wet season (WS) in a replicated trial. Fertilizer

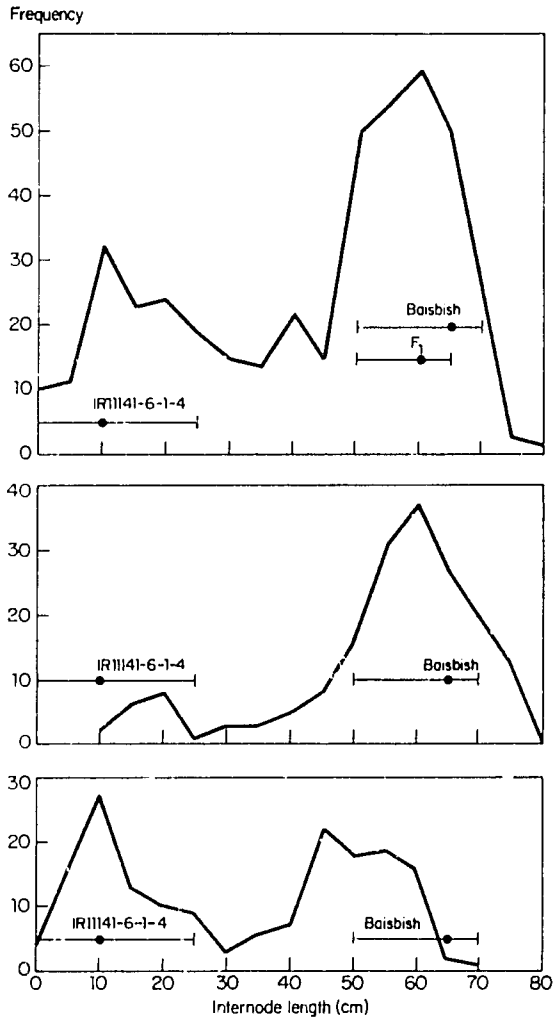


4. Frequency distribution of height in a) F_2 of Baisbish/IR11141-6-1-4, b) BC_1P_1, and c) BC_1P_2, IRRI, 1987. Horizontal lines show the range of height of parents about the means (solid circles).

rates were 0 and 58 kg N/ha as urea supergranules (USG). Water in the pond gradually rose to 20 cm because of rainfall and seepage between ponds before the water level treatment of 5 cm/d was imposed at 30 d after transplanting (DT).

No difference between fertilizer treatments was obtained. IR28333-10-1-1 yielded highest at 3.3 t/ha. Most of the rices were affected by tungro virus; hence, grain yields were low (Table 3).

Data on tiller number were obtained at 30 DT until the 100-cm water depth. Generally, tillers decreased with increasing water with or without fertilization (Fig. 6).



5. Frequency distribution of internode length in a) F_2 of Baisbish/IR11141-6-1-4, b) BC_1P_1, and c) BC_1P_2, IRRI, 1987. Horizontal lines show the range of internode length of parents of F_1 plants about the means (solid circles).

NITROGEN FERTILIZER EFFICIENCY IN MEDIUM DEEPWATER (50-cm) AND DEEPWATER (100-cm) RICES

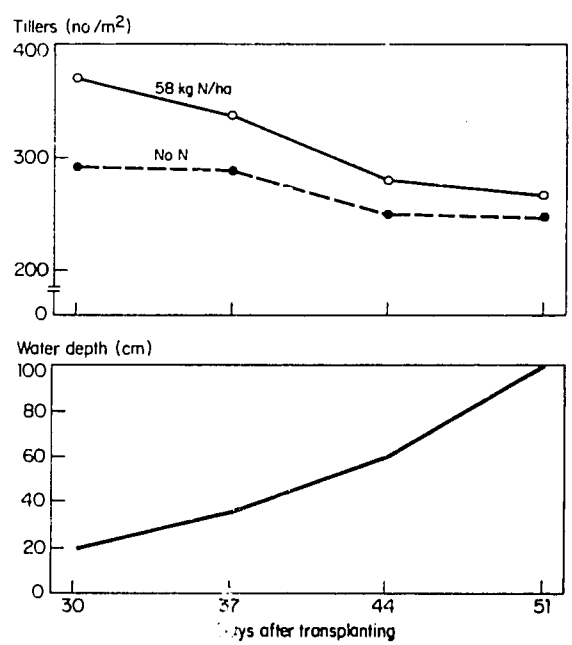
Agronomy Department

Studies on N fertilizer efficiency in medium deepwater (maximum depth: 50 cm) and deepwater (maximum depth: 100 cm) rices continued at the IRRI farm. Three N sources—prilled urea (PU), sulfur-coated urea (SCU), and USG—at 3 N rates (29, 58, and 116 kg N/ha) were applied: 2/3 PU or SCU broadcast and incorporated (B&I) + 1/3 foliar spray of urea solution at 5-7 d before panicle initiation, and deep placement of USG. Water depth was increased by 5 cm/d starting at 30 DT and was maintained at 50 and 100 cm until harvest.

Table 3. Grain yield of some promising deepwater rices. IRRI, 1987 WS.

Deepwater rice variety or line	Grain yield (t/ha)
IR21038-77-P2-5-2-3-1	1.5 b
IR26662-196-2-1-1-3-3-2	1.0 bc
IR28333-10-1-1	3.3 a
IR21071-53-2-2-2-1E-P1	0.5 bc
IR13260-100-E-P3	0.9 bc
IR11288-B-B-69-1	0.6 bc
IRBKNFR 76026-3-2-2-2	0.4 c
RD19 (check)	0.6 bc

Medium deepwater. Two photoperiod-insensitive rices were used: IR21037-2-1-2E-P3-6 in DS and IR28932-9-3-3-2 in WS. At 29 kg N/ha, IR21037-2-1-2E-P3-6 yielded at most 1.0 t/ha more than the control (Table 4). No yield difference was observed when N rates increased from 29 to 58 and 116 kg N/ha. In most cases, yield tended to decrease with increasing N level because of lodging at high N rates. Foliar spraying of urea solution



6. Effect of water stress on tillering of deepwater rices. IRRI, 1987 WS.

Table 4. Effect of N source, rate, and application method on grain yield (t/ha) of 2 rice cultivars at 50-cm water depth. IRRI, 1987 DS and WS.

Treatment[a]	Dry season (IR21037-2-1-2E-P3-6)	Wet season (IR28932-9-3-3-2)
No fertilizer N	3.5 def	2.6 d
29 kg N/ha		
PU, B&I	4.4 abc	2.8 cd
2/3 PU B&I + 1/3 foliar spray of urea solution at 5-7 DBPI	4.5 ab	2.9 bcd
SCU, B&I	4.3 abc	2.7 cd
USG, 10-12cm deep placement	4.5 ab	2.8 cd
58 kg N/ha		
PU, B&I	4.2 abc	4.1 a
2/3 PU B&I + 1/3 foliar spray of urea solution at 5-7 DBPI	3.9 bcd	3.3 a-d
SCU, B&I	4.8 a	3.6 a-d
USG, 10-12 cm deep placement	4.3 abc	3.9 ab
116 kg N/ha		
PU, B&I	4.5 ab	3.8 abc
2/3 PU B&I + 1/3 foliar spray of urea solution at 5-7 DBPI	3.7 cde	3.6 a-d
SCU, B&I	3.0 f	3.6 a-d
USG, 10-12 cm deep placement	3.2 ef	4.2 a

[a]PU = prilled urea, SCU = sulfur-coated urea, USG = urea supergranules, B&I = broadcast and incorporated, DBPI = days before panicle initiation.

following B&I gave no advantage over a full dose B&I.

In WS, IR28932-9-3-3-2 responded to higher N rates. Yield at 29 kg N/ha was almost similar to that of the unfertilized control, an indication of low N use efficiency at this rate.

Table 5. Effect of N source, rate, and application method on grain yield of IR21038-77-P2-5-2-3-1-1 at 100-cm water depth. IRRI, 1987 DS.

Treatment	Grain yield (t/ha)
No fertilizer N	2.0 h
29 kg N/ha	
PU, B&I	2.3 gh
2/3 PU B&I + 1/3 foliar spray of urea solution at 5-7 DBPI	2.4 fgh
SCU, B&I	3.6 bc
USG, 10-12 cm deep placement	2.9 d-g
58 kg N/ha	
PU, B&I	3.0 c-f
2/3 PU B&I + 1/3 foliar spray of urea solution at 5-7 DBPI	2.1 h
SCU, B&I	3.1 cde
USG, 10-12 cm deep placement	4.5 a
116 kg N/ha	
PU, B&I	3.9 ab
2/3 PU B&I + 1/3 foliar spray of urea solution at 5-7 DBPI	3.3 bcd
SCU, B&I	3.2 cd
USG, 10-12 cm deep placement	2.5 e-h

Deepwater. Photoperiod-insensitive IR21038-77-P2-5-3-1-1 was used in DS, while BKNFR76026-3-2-2-2, a promising photoperiod-sensitive line from Thailand, was used in WS.

In DS, deep-placed USG gave the highest yield of 4.5 t/ha at 58 kg N/ha. IR21038-77-P2-5-3-1-1 yielded at most 2.5 t/l more than did the unfertilized control (Table 5). PU gave higher yields with increased N rates, while deep-placed USG gave lower yields with higher N rates. SCU B&I gave the highest yield at 29 kg N/ha, USG deep placement at 58 kg N/ha, and PU at 116 kg N/ha. This suggests that in DS, lower rates of N as SCU and USG were efficiently used.

In WS, BKNFR76026-3-2-2-2 was damaged by tungro, and no yield was obtained.

ADAPTATION TRIALS FOR DIFFERENT SUBMERGENCE CONDITIONS AND SEEDLING AGES

Multiple Cropping Department

The use of aged seedlings of traditional photoperiod-sensitive cultivars is common in

Table 6. Properties of soil surface materials in a medium deepwater experimental site. Bay, Laguna, Philippines, 1985-86.

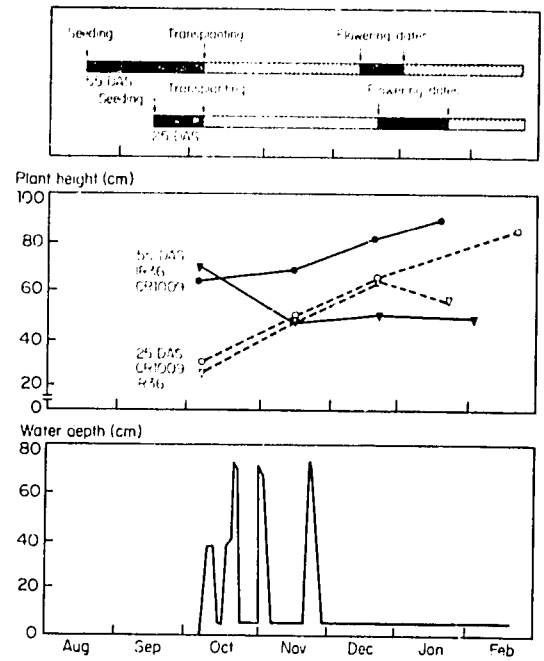
Property	Value
pH	7.2
Organic C (%)	4.09
Total N (%)	0.38
Available P (ppm)	36
Available Zn (ppm)	.01
Cation exchange capacity (meq/100 g soil)	49.35
Particle size analysis	
Clay (%)	52
Silt (%)	42
Sand (%)	6

Taxonomic classification: clayey, isohyperthermic, Typic Tropaquent

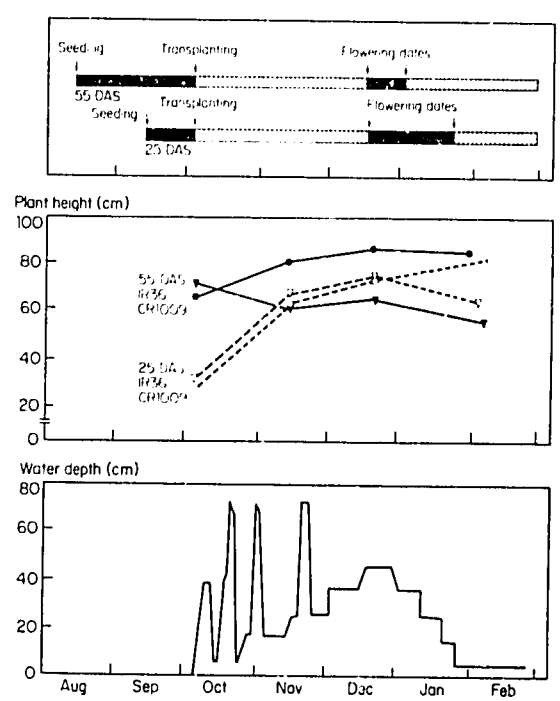
medium deepwater areas where supply and level of water are unpredictable. Fifteen rice cultivars of varying seedling age sensitivity and photoperiod sensitivity were tested in simulated medium deepwater conditions on an Andaqueptic Haplaquent in Bay, Laguna, to determine their reactions to submergence conditions and seedling age. Transplanting was done on the same day at 25 or 55 d after seeding (DAS). Soil properties of the experimental site are given in Table 6.

Three water regimes were applied: WR I = shallow water with flash flooding (Fig. 7), WR II = medium deepwater until flowering with flash flooding (Fig. 8), and WR III = medium deepwater for the duration of the crop cycle with flash flooding (Fig. 9).

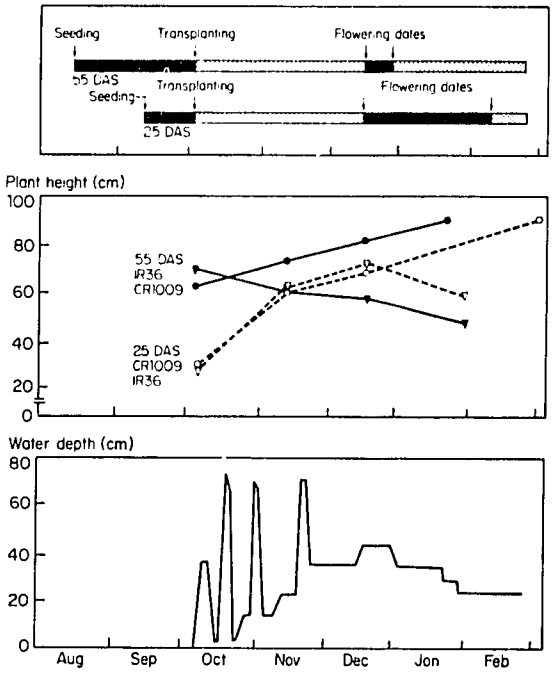
The crop experienced 2 d of submergence 4 times during the season because of flooding: at 3, 11, 24, and 44 DT. In the 25-DAS treatment, the mean plant height of the 15 cultivars showed a similar increasing trend with time in the 3 water regimes. In the 55-DAS treatment, however, except for CR1009 and BR593-676-1, there was a 10- to 15-cm decrease in the initial plant height of the cultivars at 40 DT, with little change thereafter until maturity. The plant height of CR1009, unlike IR36, was not adversely affected by late transplanting in the three water regimes (Figs. 7-9). The decrease in height of most cultivars in the 55-DAS treatment was due to the death of the longer leaves from transplanting shock several days after planting. Although the plants retillered, height did



7. Growth periods of 15 cultivars and plant height of 2 cultivars at 0, 40, and 60 d after transplanting and at harvest in relation to water depth under water regime I, Bay, Laguna, Philippines, 1985-86. DAS = days after seeding.



8. Growth periods of 15 cultivars and plant height of 2 cultivars at 0, 40, and 60 d after transplanting and at harvest in relation to water depth under water regime II, Bay, Laguna, Philippines, 1985-86.



9. Growth periods of 15 cultivars and plant height of 2 cultivars at 0, 40, and 60 d after transplanting and at harvest in relation to water depth under water regime III, Bay, Laguna, Philippines, 1985-86.

not markedly increase because delayed transplanting shortened the time for vegetative growth.

On the average, flowering date was delayed about 25 d when cultivars were transplanted at 55 DAS in the 3 water regimes. However, the delay in the flowering dates due to late transplanting in each water regime varied widely among the cultivars, ranging from 9 to 37 d for WR I, 3 to 34 d for WR II, and -7 to 30 d for WR III. Generally, the cultivars flowered earlier in the shallow water conditions (WR I) than in the two medium deepwater conditions at both seedling ages.

There were significant differences in grain yield of the 15 cultivars at 2 transplanting times in the 3 water regimes (Table 7). Generally, grain yield decreased with seedling age in all water regimes. Significant interaction effects were observed between seedling age at transplanting and variety in all water regimes, indicating that reactions to delayed transplanting varied widely among cultivars. Yield reduction in early-maturing, photoperiod-insensitive IR36 was 50-70% compared with 0-50% for CR1009 across water regimes. Short-statured and early-maturing varie-

Table 7. Mean grain yield of 15 cultivars planted at 2 seedling ages under 3 water regimes.[a] Bay, Laguna, Philippines, 1985-86.

Variety or line	Grain yield (t/ha)											
	25 DAS					55 DAS					Grand mean	Rank
	WR I	WR II	WR III	Mean	Rank	WR I	WR II	WR III	Mean	Rank		
CR1009	5.50	3.40	4.33	4.41	1	3.87	3.87	1.83	3.19	1	3.80	1
Wagwag Faire	4.97	4.60	3.37	4.31	2	3.10	2.20	3.47	2.92	2	3.62	2
IR5	3.60	3.53	2.87	3.33	4	2.83	2.17	1.43	2.14	3	2.74	3
IR13146-45-2-3	3.67	3.23	2.47	3.12	5	2.43	1.57	1.53	1.84	4	2.48	4
IR19083-22-2-2	4.07	3.63	2.80	3.50	3	1.90	1.20	0.90	1.33	9	2.42	5
BR11	3.37	2.77	1.93	2.69	6	1.77	1.67	1.13	1.52	6	2.11	6
IR19431-72-2	3.30	2.07	2.33	2.57	7	2.23	1.53	1.07	1.61	5	2.09	7
IR4829-89-2	3.03	1.50	2.03	2.19	9	1.83	1.80	0.87	1.50	7	1.85	8
IR46	2.77	1.80	2.53	2.37	8	1.57	1.20	0.73	1.17	11	1.77	9
BR593-676-1-7-1	2.93	1.83	1.40	2.05	11	1.37	1.33	1.40	1.37	8	1.71	10
IR4819-77-3-2	2.73	1.37	2.43	2.18	10	1.50	0.97	0.73	1.07	13	1.63	11
BE3	2.27	1.50	1.47	1.75	13	1.07	1.30	1.43	1.27	10	1.51	12
IR64	2.17	1.63	1.53	1.78	12	1.47	1.13	0.73	1.11	12	1.45	13
IR36	2.00	1.03	0.93	1.32	14	0.73	0.53	0.53	0.60	14	0.96	14
KDML 105	0.43	0.67	0.30	0.47	15	0.37	0.50	0.33	0.40	15	0.44	15
Mean	3.12	2.30	2.18			1.86	1.53	1.20				
LSD	0.70	1.11	0.70			0.70	1.11	0.70				

[a]DAS = days after seeding. WR = water regime.

ties were unsuitable for medium deepwater conditions, particularly when transplanted late. Wagwag Faire and CR 1009 consistently performed well at both transplanting times in the three water regimes.

The results indicate that improved cultivars are required with specific adaptation for the medium deepwater situation. In establishing selection criteria, breeding programs must consider the medium deepwater environment as unique. There may be spillover benefits from lines bred in shallow water environments, but the more recently developed outstanding shallow water materials tested do not appear to have strong potential for medium deepwater conditions.

Genetic evaluation and utilization (GEU) program

Adverse temperature tolerance

International Rice Testing Program and Plant Physiology and Plant Breeding Departments

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IRTP COLD TOLERANCE TRIALS

International Rice Testing Program

Information on cold tolerance was obtained from results (received and analyzed in 1987) of 23 trials of the 1986 International Rice Cold Tolerance Nursery (IRCTN) conducted at 23 locations in 15 countries. The best performing entries across locations were JKAU(K)450-126-10, JKAU(K)450-126-2, Ching shi 15 (Acc. 36852), JKAU(K)450-172-10, Z-Yah-Tsan (Acc. 04648), Akiyudaka, and Suweon 303.

Ching shi 15 (Acc. 36852) had been given good scores for cold tolerance in several earlier tests. Several entries performed very well at specific locations. Detailed information on the performance of entries appears in the IRTP section of this report.

KOREA-IRRI COLLABORATIVE PROJECT

Plant Physiology and Plant Breeding Departments

Rice cold tolerance screening nursery. A total of 969 entries were screened in 9-m plots with continuously flowing cold water. Each entry was planted in 1 column and subjected to a water temperature gradient of 17 °C at the inlet and 21-25 °C at the outlet. Resistant and susceptible check varieties were placed after every 20 entries.

Phenotypic acceptability and fertility at 17 °C are the best measure of cold tolerance in this nursery. The best entries, with a phenotypic acceptability score of 1 and fertility >80% at 17 °C water temperature, were SR12212-T4, HR6441-B-B-11, HR7381-AC7, and Z-Yah-Tsan. These two traits have a correlation of 0.70, and cold-tolerant entries are easily identified. Other entries with high spikelet fertility and phenotypic acceptability are shown in Table 1. HR-AC lines were derived from anther culture. The good IR lines showed poor leaf color and seedling vigor (Table 1) but recovered during the later stages. This is typical of cold-tolerant indica lines. Other traits measured included heading duration, culm length, spikelet and panicle number, leaf color at early and maximum tillering, and panicle exsertion.

Growth duration ranged from short (107 d) to medium (131 d). The short-duration lines have the advantage of avoiding low temperature at the critical reproductive phase in case of early autumn. However, their yield potential is less than that of medium- and long-duration lines, as less time is left for tiller development and grain filling. Most of

Table 1. Characteristics of entries in the rice cold tolerance screening nursery with phenotypic acceptability of 1 or 2, and fertility >80%. Chuncheon, Korea, 1987.

Variety or line	Fertility (%)	Days to heading (no.)	Culm length (cm)	Spikelets (no./panicle)	Panicles (no./hill)	Leaf color[a]	Seedling vigor[a]	Panicle exsertion[a]
HR6441-B-B-11	85	107	71	109	13.7	1	2	3
HR6994-AC2	83	129	69	89	14.7	1	2	3
HR7381-AC7	84	129	75	151	12.3	2	2	3
HR7381-AC9	87	134	77	104	11.7	1	2	3
Hukuhikari	80	110	83	95	15.7	1	1	3
IR20913-B-60	90	123	114	124	10.0	7	6	3
IR9202-25-1-3	81	123	111	105	13.7	7	4	3
Kasalath	82	122	117	165	15.0	5	6	3
SR10248-40-2-5	83	110	64	81	11.7	1	2	3
SR10255-B-57-5	92	113	72	86	11.3	1	2	3
SR10255-B-92-3	83	112	75	80	11.7	1	2	3
SR11138-20-5	89	109	58	119	14.7	1	2	3
SR11144-47-1	89	108	63	132	10.0	1	2	3
SR11325-24-2	93	114	74	93	16.0	1	2	3
SR12212-T2	81	131	95	114	14.0	1	2	3
SR12212-T4	80	131	95	101	16.0	1	2	3
YR6453-ACP127	83	122	77	126	12.7	1	2	3
Z-Yah-Tsan	89	124	116	145	12.0	2	3	1

[a]By the *Standard evaluation system for rice* scales.

these entries have short culms (≤ 80 cm), although some indica and IR lines have culm length >100 cm. In previous yield trials, lines with culm length >100 cm showed serious lodging when planted at N levels >120 kg/ha. These entries also have high tillering capacity (>10 tillers per hill) and spikelets per panicle (80-151), and possibly high yield potential. Yield testing for these entries will be done in the 1988 cropping season.

This nursery was started in 1978; 10,526 entries have been tested so far.

Pedigree nursery. The pedigree nursery consisted of 2-m plots with continuously flowing water at 20 °C. Sixty-three F_2 populations, 10 F_5 lines, and 35 hybrid crosses were grown. A total of 704 plants and 7 bulk populations were selected from the F_2, 145 plants from F_5 lines, and 30 plants from hybrid crosses. Selected entries are shown in Table 2.

Seven F_2 bulk populations were sampled for single-seed descent in an experiment to test a shuttle breeding mechanism. The use of 20 °C water temperature in the pedigree nursery made it easier to screen for cold-tolerant lines. Many entries were discarded, and the few selected lines were distributed to research centers.

Screening for cold tolerance at anthesis. Heading is the second stage that is most sensitive to low temperatures. The maximum temperature at anthesis must be sufficiently high (>20 °C) to induce pollen shedding.

The 1987 IRCTN entries were grown in pots and placed under 19 ± 1 °C air temperature for 10 d during anthesis. Entries with spikelet fertility >60% were Akiyudaka, H231-85, Stejaree 45, and Barkat (K78-13).

Observational yield trials. Thirty-five entries were grown under normal farmers' field conditions with 200 kg N/ha. The yields were generally higher than in the previous year. The highest yield of 8.1 t/ha was obtained from HR4627-40-3-1-4, an indica/japonica line with high panicle number and spikelets per panicle. Entries with yields >7 t/ha are shown in Table 3. Correlation analysis of all entries showed that yield was highly correlated with harvest index (r=0.90), heading duration (r=0.65), spikelets per panicle (r=0.53), panicle number (r=0.48), and 1000-grain weight (r=0.45). The standardized coefficients showed the following order of importance for higher yield: harvest index > days to heading > fertility > spikelets per panicle > 1000-grain weight > culm length.

Table 2. Pedigree nursery selection at 20 °C water temperature. Chuncheon, Korea, 1987.

Entry	Designation or cross	Plants selected (no.)
	Selections from F_2 populations	
CG3	Sasanishiki/Gihobyeo	30
CG7	M 101/Sangpungbyeo	30
CG8	Pungsanbyeo/YR3583-7-3-7-1	30
CG12	Pungsanbyeo/B2983B-SR-13-4-1	30
CG17	Tatsumimochi/Odaebyeo	30
CG22	Pungsanbyeo/HR3784-49-4-1	30
CG25	Yongmoonbyeo/SR1207-62-1	30
CG27	Seolagbyeo/No. 11	30
CG28	Seolagbyeo/Stejaree 45	30
CG29	Seolagbyeo/Hokuriku 109	30
CG30	Jinbu 4/Ching Hsi 15	30
CG32	Sterajee 45/Odaebyeo	30
	SR15066	104
	SR15069	71
	SR15070	61
	SR15071	4
	SR15111	14
	SR15112	30
	SR15454	30
	SR15458	30
	F_2 single-seed descent bulk populations	
KIC-6	Yeongsanbyeo/P. 15	Bulk
KIC-9	Chucheongbyeo/P. 15	Bulk
KIC-10	Yongmoonbyeo/Sangpungbyeo	Bulk
KIC-16	Yeomyeongbyeo/Sangpungbyeo	Bulk
KIC-17	Yeomyeongbyeo/Sangpungbyeo	Bulk
CG10	Pungsanbyeo/Sangpungbyeo	Bulk
CG15	Sangpungbyeo/IR9202-25-1-3	Bulk
	Selections from F_5 families	
	SR10983	10
	SR11010	25
	SR12764	75
	SR12774	5
	SR12777	10
	SR13128	20
	Selections from hybrid crosses	
	IR54756A/Suweon 294	5
	IR54756A/Iri 361	5
	IR54756A/Iri 362	5
	HR1619A/Suweon 294	5
	HR1619A/Iri 371	5
	HR1619A/IR9761-19-1R	5

Screening for cold tolerance at the seedling stage. The cold tolerance facilities at Chuncheon can screen breeding lines at various stages: seedling, tillering/vegetative, meiotic, anthesis, and throughout the growth stages. For cold tolerance screening

Table 3. Entries with yields >7 t/ha at the observational yield trials. Chuncheon, Korea, 1987.

Line	Days to heading (no.)	Culm length (cm)	Panicles (no./ hill)	Spikelets (no./ panicle)	Fertility (%)	1000-grain weight (g)	Yield (t/ha)	Harvest index
HR4627-40-3-1-4	118	72	12.6	140	72	23.6	8.11	0.58
IR20913-B-60	120	96	12.2	163	60	21.6	7.75	0.52
SR10843-68-1-2	125	71	10.7	121	77	28.8	7.46	0.50
SR10635-32-1-B-5	117	66	11.8	125	84	24.7	7.22	0.53
SR10549-B-299	118	70	12.4	116	70	24.6	7.08	0.55
SR10939-66-3-2-1	123	70	13.2	91	80	31.5	7.06	0.55

at the seedling stage, 15-d-old seedlings (planted in trays) were subjected to 12 °C continuously flowing water for 10 d. Leaf discoloration scores were taken based on the *Standard evaluation system for rice* (SES). A total of 562 entries from 10 IRTP nurseries were tested; 51 entries had high tolerance for low temperature at the seedling stage (Table 4).

Salt tolerance for low temperature areas. With increasing investments in reclaiming coastal lands for rice cultivation, the need for salt-tolerant japonica varieties is becoming urgent. Similar varieties are also in high demand in the rice-growing countries of the Middle East.

A high level of salt tolerance is not found among japonicas and hence has to be obtained from indicas. Well-known salt-tolerant indicas such as Nona Bokra and Pokkali do not flower under temperate conditions because of their sensitivity to photoperiod and low temperature. Moreover, they do not possess tolerance for low temperature. These and the incompatibility barrier between indicas and japonicas are serious constraints to the development of salt-tolerant japonica varieties.

As an initial step to a breeding program, photoperiod-insensitive, salt-tolerant indica types that can grow and reproduce under Korean conditions were screened at two coastal land research stations in Namyang and Ghewa. The nursery consisted of 50 IR advanced lines and 40 F_1 anther culture derivatives.

All entries expressed a good level of salt tolerance, but, except advanced line IR10198-66-2 and three anther culture derivatives of cross IR51492 (IR4630-22-2-5-1-3/IR5657-33-2), all others had a duration very much longer than desired. Compared with that in Los Baños, crop duration was prolonged by about 6 wk on the average. This was possibly due to a lack of cold tolerance in the lines tested. With those results, screening of very short-duration, salt-tolerant breeding lines will be continued, and an indica/japonica hybridization program will be initiated with the objective of transferring salt tolerance from indicas such as Pokkali and Nona Bokra to japonicas.

Table 4. Nurseries tested and number of selected entries with cold tolerance at the seedling stage. Chuncheon, Korea, 1987.

Year and nursery[a]	Entries tested (no.)	Entries selected (no.)
1987 IURYN-E	22	1
1987 IURYN-M	38	6
1988 IURYN-E	9	1
1988 IURYN-M	15	2
1987 IURON	138	13
1988 IURON	80	2
1987 IRCTN	83	10
1988 IRCTN	61	9
1987 Acid Upland	71	4
1988 Acid Upland	45	3

[a]IURYN-E and -M = International Upland Rice Yield Nursery-Early and -Medium, IURON = International Upland Rice Observational Nursery, IRCTN = International Rice Cold Tolerance Nursery.

SCREENING OF AFRICAN RICE GERMPLASM FOR COLD TOLERANCE

Plant Physiology Department

Low temperature is a problem in many rice-growing areas of Africa, especially in the Sahel. To identify varieties tolerant of low temperature and

adapted to African conditions, screening of the African germplasm collection in the International Rice Germplasm Center was started in 1986. The outstanding varieties can be used directly or as donor parents in varietal improvement.

Initial screening of the 178 accessions from Madagascar was reported in 1986. Other African varieties were subsequently screened.

Tanzania. A total of 65 entries were screened at the seedling stage (12 °C water temperature), panicle initiation (PI), and anthesis. Except for ES076 and ES078 (Zira), which received a score of 3, the entries were susceptible to low temperature at the seedling stage, i.e., the leaves became yellow or the plants died.

Several entries were found tolerant at PI and anthesis (Table 5). Afaa Kilombero 1-196 was the most tolerant of low temperature at PI. ES053 (Ringa), Lindi Safari, ES018 (Straw), and ES042 showed very low sterility at low temperature during anthesis. Afaa Kilombero 1-196, ES010 (Supa India), and ES059 (Bishore) were outstanding at both stages.

Table 5. Cold-tolerant varieties from Tanzania at panicle initiation or anthesis.[a] IRRI, 1987.

Accession no.	Variety	Sterility (%)	
		Panicle initiation	Anthesis
06479	Gamti 1-34	37	15
06480	Afaa Mwanza 0-746	57	15
06481	Afaa Mwanza 1-104	19	78
06485	Afaa Kilombero 1-196	10	18
06491	Lindi Safari	77	6
07533	HR19	52	16
56161	ES003	33	10
56163	ES010 (Supa India)	18	16
56167	ES018 (Gold)	26	13
56168	ES018 (Straw)	42	8
56173	ES027 (Mbawambili)	50	15
56181	ES040 (Turiani)	23	15
56183	ES042	30	9
56184	ES043	17	38
56186	ES044 (Wahi)	60	13
56192	ES053 (Ringa)	–	3
56194	ES059 (Bishore)	16	13
56205	ES072	15	24
56208	ES076	–	17
56210	ES078 (Zira)	19	–
56213	ES081 (Shindado)	17	–
56214	ES082	60	12

[a]Plants subjected to 17 °C for 5 d at panicle initiation or 21 °C at anthesis for 5 d.

Other African countries. Countries in the Sahel generally have low-temperature problems during the cropping season. A total of 1,331 entries from 16 African countries were screened for cold tolerance at the seedling stage. Only 4% were tolerant, 27% were moderately tolerant, and 69% were susceptible. The 56 tolerant entries are shown in Table 6. Among them, 20 were indicas and 6 javanicas; the rest were of an unknown variety group. The outstanding entries came from Liberia, Ivory Coast, and Sierra Leone. None of the 230 entries from Senegal had cold tolerance at the seedling stage.

The most resistant entries were Wacee, Yetigbi, Baihiway Gbayawgi, and Baihiway Willingi from Liberia. They might be useful in the Sahel.

The listed cold-tolerant materials at the seedling stage will be screened further for tolerance at PI and anthesis.

COLD TOLERANCE IN SOME BULU VARIETIES

Plant Breeding and Plant Physiology Departments

Most of the traditional varieties grown in low-temperature areas of South and Southeast Asia belong to the bulu type. In the Philippines, all varieties grown in high altitude ricelands are bulus.

More than 600 bulus have been evaluated for agronomic traits at IRRI, and 24 have been selected as desirable types for hybridization. These varieties and the commonly grown ones of the Philippines were screened for seedling tolerance under controlled conditions. Their level of tolerance, rated by SES, is as follows:

IRRI selections:

Score of 5: Bali Kuning, Binuggon PS417, Barehan, Bulu Dalam, Cicih Gedangân, Cicih Kapok, Gendjah Bulu, Inbu-An, Ketan Banteng, Ketan Djambon, Ketan Kuwule, Ketan Lumbu, Lembajungan, Malama, Osok, Padang Djambe (Gundil), Pinikitan, Putih Bibaluk, Radjalele, Sampangan, Satrijo, Untup

Score of 7: Djawa Lurik, Gedangan Tjoklat, Irik

Philippine varieties:

Score of 3: Binnugon, Onggon, and Madduli

Score of 5: Donnal, Innawis, Onggon (brown), and Pinidua.

Table 6. Cold-tolerant African rices at the seedling stage. IRRI, 1987.

Accession no.	Variety
Ivory Coast	
15097	62-18
16074	H. T. Moro
16077	Non-Non (N)
16096	Maleba L
38560	IRAT106
38565	IRAT111
40622	IB10
47004	IS31
47054	1-IS52-C 77
50805	Dagnonkpobeu
50818	Fantigbe
50819	Fossa
50838	Guibie
50848	Klopodi (509)
50849	Klouaba
50893	Vareklouaba
50894	Veka
50895	Venoua Seka (594)
50906	Yoro Bane 565
50920	Zomokli
56656	Mabadagloun
56770	Yohokpa
56771	Seihue
56772	Louokpa
56815	Sahima
56826	Fissawle
56827	Mategbe 1
56857	Srito
56880	Zokoule
56881	Yopieleu
56892	Gbapou
56903	Gblo
56931	Wlehou
Liberia	
61453	Graga
61465	Moloue
61471	Wacee[a]
61472	Yetigbi[a]
63119	Baihiway Gbayawgi[a]
63120	Baihiway Willingi[a]
63163	Comblah 6
63164	Comblah 7
63165	Comblah 8
63283	Jah
63289	Jangaway
63290	Jaou
63291	Jaou
63292	Jaun
Nigeria	
63225	Ex Zaki Biam
Sierra Leone	
63237	Filiyon
63240	Flegie
63319	Koni
63320	Kpamoenyayeh
63427	Sokoni
63433	Tobohun
64206	Buluhan Yakei 289
Zimbabwe	
64709	TGR1277

[a]Received a score of 1; the rest received a score of 3.

In general, the varieties tested do not possess a high level of cold tolerance at the seedling stage. However, among the high-altitude bulus of the Philippines, Binnugon, Onggon, and Madduli have shown an acceptable level of tolerance, and those are exactly the varieties farmers consider as early maturing. These varieties are of the same growth duration as others under normal temperature conditions, and their earliness at high altitudes is quite likely due to cold tolerance.

A BIOCHEMICAL APPROACH TO SCREENING FOR COLD TOLERANCE

International Rice Testing Program

Polar lipids from cold-tolerant rice genotypes exhibited higher linolenic acid (C18:3) content under both low and normal temperatures. They also showed a null allelic situation at the Esterase 2 isozyme locus (Est-2^0). Less tolerant or susceptible genotypes either had Est-2^1 or Est-2^2 alleles, as reflected by their slow or high mobility electrophoretic bands. Investigations revealed that Est-2^1 and Est-2^2 isozymes compete for the choline-ester precursors of polyunsaturated fatty acids to convert them to free unsaturated fatty acids, thus reducing the formation of polyunsaturated fatty acids. Further, the free unsaturated fatty acids are metabolized to short-chain saturated fatty acids, resulting in higher levels of the latter in Est-2^1 and Est-2^2 genotypes. As the short-chain saturated fatty acids, especially nonanoic acid (C9:0), are involved in seed dormancy, the amount of the acid needed to impose dormancy on seeds would be relatively less for Est-2^1 and Est-2^2 genotypes. Hence, based upon the germination response at a given amount of nonanoic acid and their Esterase-2 allelic situation, rice genotypes can be screened for cold tolerance. This amount has been determined to be 5 mM. This novel approach with two-tier screening has been found to be effective in laboratory screening for cold stress. The two levels of screening include 1) determining the germination response to nonanoic acid, and 2) identifying the types of allele of the Esterase 2 isozyme present in the genotype.

Genetic evaluation and utilization (GEU) program

Innovative breeding methods

Plant Breeding, Agronomy, Plant Physiology, Agricultural Economics, and Soils Departments

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HYBRID RICE

Plant Breeding, Agronomy, Plant Physiology, and Agricultural Economics Departments

Identification of heterotic combinations (*Plant Breeding*). During the 1987 dry season (DS), we evaluated 47 experimental rice hybrids developed at IRRI in comparison with the best recommended inbred varieties of different growth durations in replicated yield trials (RYTs). Sixteen rice hybrids yielded significantly higher than the best inbred varieties of comparable growth duration (Table 1). The 1987 wet season (WS) trials, comparing F_1 hybrids with inbred varieties, failed because of severe tungro virus and heavy lodging at flowering due to typhoons and torrential rains. Yields of check varieties in these trials ranged from 0.7 t/ha (IR54) to 2.9 t/ha (IR66), compared with hybrid yields of 0.6 t/ha (IR54754A/IR29723-143-3-2-1R) to 3.1 t/ha (IR54752A/IR46R).

Comparison of some promising F_1 rice hybrids and commercial varieties in trials conducted during 1986-87 identified nine heterotic hybrids (Table 2). Some of these hybrids were also evaluated in India, Indonesia, Malaysia, and Vietnam. Results obtained there are discussed in the section on Cooperative Country Projects.

In yield trials of the irrigated rice breeding program at IRRI, a number of promising experimental rice hybrids were evaluated along with recommended inbred varieties and new elite cultivars. The 1986-87 results (Table 3) showed that the early-maturing experimental hybrid

Table 1. Experimental rice hybrids yielding significantly higher than commercial inbred rice. IRRI, 1987 DS.

Hybrid or variety	Yield (t/ha)	Days to maturity (no.)
IR46830A/IR29723-143-3-2-1R	6.4	112
IR46830A/IR50R	6.1	112
IR46830A/IR9761-19-1R	6.0	112
IR46830A/IR13292-5-3R	6.1	112
IR46828A/IR13524-21-2-3-3-2-2R	5.6	110
IR58 (check)	4.6	112
LSD (5%)	0.9	–
IR54752A/IR2797-125-3-3-2R	7.8	130
IR54752A/IR25167-9-2-2-1-2-2-2	7.4	125
IR54752A/ARC11353R	7.4	134
IR54752A/IR29512-81-2-1R	7.2	130
IR54752A/IR28118-138-2-3-3R	7.0	137
IR54752A/IR31833-38-2-2-2R	6.9	135
IR54752A/IR64R	6.8	127
IR54752A/IR21526-4-3-3R	6.8	130
IR54752A/IR29511-122-3-3-1	6.7	130
IR54 (check)	6.0	128
IR64 (check)	5.2	120
IR66 (check)	5.0	127
IR28150-84-3-3-2	5.9	131
LSD (5%)	0.6	–
IR54752A/ARC11353R	6.8	128
IR54752A/IR46R	6.8	130
IR54 (check)	5.8	128
IR64 (check)	5.0	121
IR66 (check)	5.0	118
IR28150-84-3-3-2 (check)	5.2	131
LSD (5%)	0.5	–

Table 2. Yields of some F_1 rice hybrids compared with those of inbred commercial varieties of similar growth duration in replicated yield trials. IRRI, 1986 and 1987.

Hybrid or variety	Yield (t/ha)			
	Dry season		Wet season	Mean
	1986	1987	1986	
Duration 100-110 d				
IR46830A/IR29723-143-3-2-1R	7.0	6.4	4.0	5.8
IR46830A/IR50R	6.8	6.1	4.1	5.7
IR46830A/IR9761-19-1R	6.4	6.0	3.6	5.3
IR58 (check)	5.7	4.6	3.0	4.4
LSD (5%)	0.8	0.9	0.6	
Duration 115-125 d				
IR54752A/IR64R	–	6.8	3.9	5.4
IR64 (check)	–	5.2	2.9	4.0
IR54 (check)	–	6.0	2.3	4.2
LSD (5%)	–	0.6	0.6	
Duration 125-135 d				
IR54752A/IR46R	7.0	6.2	3.4	5.5
IR54752A/IR54R	6.5	6.5	2.5	5.2
IR54 (check)	5.6	5.8	1.9	4.4
IR64 (check)	5.4	6.2	2.9	4.8
LSD (5%)	0.5	0.9	0.6	
IR54752A/ARC 11353R	6.8	7.4	2.3	5.5
IR54 (check)	5.6	6.0	2.3	4.6
IR28150-84-3-3-2 (check)	4.7	5.9	2.8	4.5
LSD (5%)	0.5	0.6	0.6	
IR54752A/IR25167-9-2-2-1-2-2-2	–	7.4	2.5	5.0
IR54752A/IR29512-81-2-1R	–	7.2	2.6	4.9
IR54 (check)	–	6.0	1.9	4.0
IR28150-84-3-3-2 (check)	–	5.9	2.5	4.2
LSD (5%)	–	0.6	0.6	

Table 3. Yields of elite rice hybrids and of best inbred varieties and cultivars in replicated yield trials of the irrigated rice breeding program. IRRI, 1986 and 1987.

Hybrid or variety	Growth duration (d)	Yield (t/ha)				
		Dry season		Wet season		Mean
		1986	1987	1986	1987	
IR46830A/IR9761-19-1R	108	7.7	6.9	4.2	3.9	5.7
IR58 (check)	106	6.4	5.9	3.4	2.9	4.7
IR50 (check)	106	6.6	4.8	2.5	3.1	4.2
IR28 (check)	105	5.9	5.9	3.7	3.2	4.7
IR36 (check)	112	7.0	6.3	3.4	2.0	4.7
IR42015-83-3-2-2-2	107	6.4	6.3	4.5	4.4	5.4
IR54752A/IR64R	121	–	6.8	–	2.8	4.8
IR54 (check)	123	–	6.3	–	2.8	4.6
IR28228-12-3-1-1-2	128	–	6.0	–	4.6	5.3
IR68 (check)	119	–	6.2	–	3.4	4.8
IR64 (check)	119	–	6.3	–	3.4	4.8

IR46830A/IR9761-19-1R yielded 1 t/ha higher than inbred varieties of similar duration: IR58 and IR50 (105-110 d), and IR36 and IR64 (110-120 d). The same combination, when compared with the newly developed elite line IR42015-83-3-2-2-2, showed a similar yield advantage in DS but none in WS (Table 3). This hybrid, however, cannot be promoted for commercial use because the male sterile parent IR46830A shows very low outcrossing (less than 10%), which will make seed production uneconomical.

Several other medium-duration rice hybrids—IR54752A/IR64R, IR54752A/IR54R, and IR54752A/IR29512-81-2-1R—showed inconsistent yield performance in these trials, primarily because of the occurrence of 5-20% sterile and partially fertile plants in hybrid rice plots. Seed for these hybrids was produced using techniques involving natural outcrossing on the male sterile parent. Partially sterile and partially fertile plants can occur because of restorer gene segregation in the male parent or instability in pollen sterility in the female parent. Both these defects are being corrected in the breeding program by purifying male and female parents of heterotic hybrids. In this context, we also studied the extent of yield loss due to the occurrence of sterile plants (like the female parent) and fertile plants (like the male parent) in the population of the hybrid IR54752A/IR64R. Results (Table 4) indicated that the mixture of sterile plants in the F_1 population tended to reduce the yield. A 10% mixture with sterile plants reduced yield by about 15%, which was statistically nonsignificant but large enough to offset the yield advantage of hybrids over the best inbreds. Mixtures with R plants also tended to reduce hybrid yield, but the reduction was inconsistent.

Table 4. Effect of mixtures with male sterile and restorer plants on yield of rice hybrid IR54752A/IR64R.[a] IRRI, 1987.

Type of mixture	Yield (t/ha) with mixture percentage of					Mean yield (t/ha)
	0	1	3	5	10	
Male sterile	4.0	3.7	3.6	3.4	3.4	3.6
Restorer	3.9	4.2	3.5	3.9	3.4	3.8
Mean	3.9	3.9	3.6	3.7	3.4	3.7

[a]LSD (5%) for 2 main plots (type of mixtures) = 0.6 t/ha, LSD (5%) for 2 subplots (% of mixtures) = 0.4 t/ha.

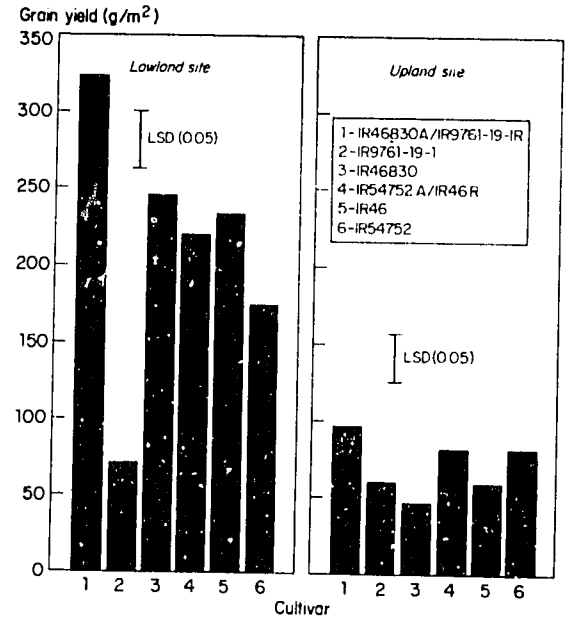
Adaptability of hybrid rice to a rainfed environment (*Agronomy and Plant Breeding*). Hybrid rices have been reported to have stronger and better distributed roots than inbred lines. Because drought resistance depends, in part, on a good root system, a preliminary study determined 1) the feasibility of growing hybrid rices under rainfed conditions and 2) the drought resistance of hybrid rices. Two hybrids (IR46830A/IR9761-19-1 and IR54752A/IR46R) and their parents were direct

seeded and grown under strictly rainfed conditions in a rainfed lowland field and an upland field on the IRRI farm. IR46, one of the parents, served as the local check. Urea (90 kg N/ha) was topdressed a few days after seeding (DAS) when ample water was available. A water deficit occurred from 45 to 60 DAS, with a maximum stress of 69 and 4.9 kPa soil moisture tension at 20 and 60 cm soil depth.

Hybrid IR46830A/IR9761-19-1R gave the highest yield, with 105% midparent heterosis for the lowland trial and 78% for the upland (Fig. 1). Better-parent heterosis for the same cross was found to be 33% and 64%, respectively. Hybrid IR54752A/IR46R exhibited only 7-8% midparent heterosis in the 2 trials and yielded about the same as IR46. Although not statistically analyzed, grain yield appeared higher at the lowland than at the upland site.

At both sites, there were no significant differences in root length density among hybrids and better parents down to 40 cm soil depth.

These results suggest that selected hybrid rices can be grown under rainfed conditions, where they will exhibit heterosis for grain yield even when subjected to water deficit.



1. Grain yield of hybrid rices and their parents. IRRI, 1987 WS.

Physiological mechanism of heterosis in seedling growth of japonica/indica F_1 hybrids (*Plant Physiology and Plant Breeding*). Vigor in initial

Table 5. Average values of total seedling dry weight and growth attributes of F_1 rice hybrids and parents at 21 d after seeding. IRRI phytotron, 1987.

Hybrid or parent	Seedling dry weight (mg)	Leaf area (cm^2)	Leaf N content (%)	N uptake in shoot (mg/plant)	Embryo weight (mg)	Endosperm weight (mg)
		Japonica/japonica				
MS1001 (1985) Akihikari	115.4	25.9	4.77	3.74	0.58	18.23
Ishiokamochi 7	108.3	27.8	5.03	3.80	0.63	17.87
MS1001/Ishiokamochi 7	147.5	31.6	4.76	4.67	0.67	17.44
Hatafusamochi	167.1	37.8	4.85	5.35	0.66	18.43
MS1001/Hatafusamochi	142.1	31.3	4.76	4.50	0.64	16.25
Ishiokamochi 20	113.3	28.7	5.17	4.12	0.43	15.91
MS1001/Ishiokamochi 20	120.4	27.2	4.81	3.97	0.64	16.98
Roma	164.3	34.6	4.91	5.60	0.71	26.70
MS1001/Roma	149.6	35.6	4.87	4.92	0.67	16.40
		Japonica/indica				
MS1003 (1986) Akihikari	87.1	19.3	4.80	2.95	0.67	18.28
Shinseiwai 1	138.7	36.2	5.39	5.38	0.51	17.08
MS1003/Shinseiwai 1	204.8	45.4	5.31	7.36	0.58	18.21
Milyang 23	125.7	28.1	4.96	4.42	0.44	19.62
MS1003/Milyang 23	161.2	33.8	4.94	5.51	0.55	18.81
Suweon 251	100.6	22.4	5.39	3.91	0.64	16.74
MS1003/Suweon 251	170.3	33.2	5.19	6.07	0.53	16.18
Kanosen 11	187.3	41.9	5.29	6.95	0.48	16.40
MS1003/Kanosen 11	189.6	39.5	5.12	6.76	0.45	18.72

growth was considered the principal trigger for heterosis of F_1 rice hybrids. As previously reported (Annual report for 1986), higher initial growth in F_1 hybrids is related to bigger embryo size in F_1 hybrids crossed within indica varieties obtained from cytoplasmic male sterile (CMS) lines. To attain more information on the mechanism involved in heterosis at initial growth, studies on F_1 hybrids derived from parental genotypes having contrasting genetic background such as japonica/indica crosses were considered useful.

Each of four japonica/indica and japonica/japonica F_1 hybrids, together with parental varieties, were evaluated for embryo weight, endosperm weight, leaf area, N uptake, and initial growth performance. Pregerminated seeds were grown in culture solution for 21 d inside the phytotron with day/night temperature of 29/21 °C.

Some of the physiological traits attributed to seedling growth of the F_1 hybrids are given in Table 5. All F_1 rice hybrids used in the experiment exhibited positive heterosis in plant dry weight at 21 DAS (Table 6). Heterosis and heterobeltiosis in seedling dry weight were higher in japonica/indica F_1 hybrids than in japonica F_1 hybrids. Heterosis in embryo weight of japonica hybrids ranged from 3 to 27%, with a mean value of 11%. In japonica/indica hybrids, however, heterosis in embryo weight was not evident. The presence of positive heterosis in embryo weight of F_1 japonica hybrids and negative heterosis in japonica/indica hybrids can be explained from the behavioral distribution pattern of embryo weight in these varieties (Fig. 2). The distribution pattern of embryo weight in japonica hybrids (a) was similar to that of the better parent; in japonica/indica hybrids, embryo weight was either similar to that of the lower parent (b) or in between the parents (c). Again, heterosis in endosperm weight in both F_1 hybrids was not apparent.

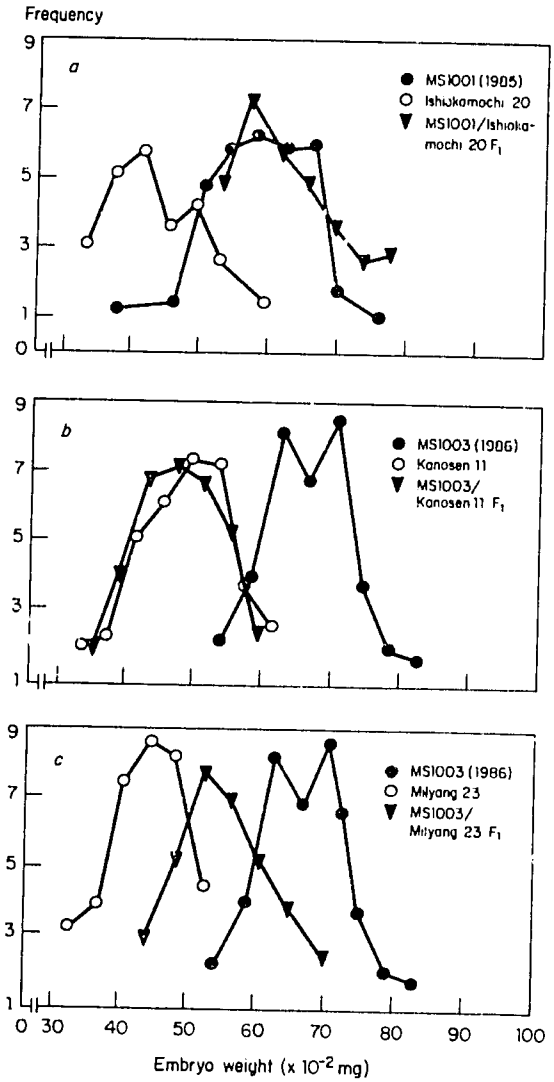
Heterosis in leaf area was highly positive in japonica/indica crosses, ranging from 28 to 63%. Except for MS1003/Kanosen 11, heterobeltiosis in leaf area was also highly positive in these crosses. The same tendency was observed in total N uptake by the plant. However, heterosis and heterobeltiosis in N content were not evident in either hybrid.

From the standardized regression coefficient values using a multiple linear regression equation,

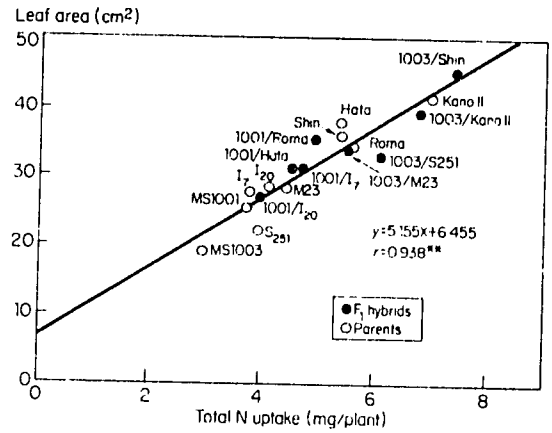
Table 6. Heterosis and heterobeltiosis for growth parameters in F_1 hybrids.[a] IRRI, 1987.

Hybrid	Heterosis (%)						Heterobeltiosis (%)					
	Seedling dry weight	Leaf area	N content	Total N uptake	Embryo weight	Endosperm weight	Seedling dry weight	Leaf area	N content	Total N uptake	Embryo weight	Endosperm weight
					Japonica/japonica							
MS1001/Ishiokamochi 7	132	118	97	124	111	97	128	114	94	122	106	95
MS1001/Hatafusamochi	101	98	99	99	103	89	85	83	98	84	96	88
MS1001/Ishiokamochi 20	105	99	97	101	127	99	104	95	93	96	110	93
MS1001/Roma	107	118	101	106	104	73	91	103	99	87	94	61
Mean	111	108	99	108	111	89	102	99	96	97	102	84
					Japonica/indica							
MS1003/Shinseiwai 1	181	163	104	176	98	103	148	125	99	137	86	99
MS1003/Milyang 23	151	142	101	149	99	99	128	120	99	125	82	95
MS1003/Suweon 251	181	159	101	176	81	92	169	149	96	155	79	88
MS1003/Kanosen 11	138	128	101	136	78	108	101	94	97	97	67	102
Mean	153	148	102	159	89	100	137	122	98	129	79	96

[a] Akihikari, a japonica variety, was the male sterile line used.



2. Frequency distribution of embryo weight in japonica/japonica F_1 hybrids (a), and japonica/indica F_1 hybrids (b and c). IRRI, 1987.



3. Relationship between leaf area and total N uptake in F_1 hybrids and parent varieties at 21 d after seeding. IRRI, 1987.

the contributions of embryo and leaf area to seedling dry weight were 3 and 9%, respectively. Therefore, higher leaf area expansion in F_1 hybrids can be considered the primary factor for heterosis for seedling growth. Besides, leaf area was significantly related to higher N uptake rate (Fig. 3).

These results, together with our previous findings, suggest that heterosis in the embryo is related to heterosis in seedling dry weight in F_1 hybrids crossed with rices of similar genetic background, such as in indica/indica and japonica/japonica crosses. However, higher N uptake rate would be a more important physiological characteristic responsible for heterosis in F_1 hybrids.

Combining ability of cytoplasmic male sterile and restorer lines (*Plant Breeding*). We evaluated 10 CMS lines, their maintainers, and their restorers for general combining ability (GCA) for yield using the line/tester design. GCA reflects the average performance of a line in a series of hybrid combinations and gives plant breeders a basis for selecting desirable parental lines to develop heterotic hybrids. Estimates of GCA effects over six environments—designated E1 to E6—created by growing the materials at three fertility levels during two seasons (Table 7) indicated that IR54752A and IR58057A were the best general combiners among the CMS lines, and that IR46 and IR54 were the best general combiners among the restorers. These results are further confirmed by the fact that several crosses with IR54752A, IR46R, and IR54R yielded significantly higher than parents in other trials (Table 1, 2).

We also found that GCA effects interacted significantly with environment. Therefore, it is necessary to estimate combining ability over different environments before selecting parents possessing good combining ability.

Development and introduction of new CMS lines (*Plant Breeding*). We identified seven new wild aborted (WA) CMS lines developed in the genetic background of rice cultivars bred at IRRI (Table 8). Seeds of these lines are being multiplied for distribution to and evaluation by national programs.

Table 7. General combining ability effect of parents for yield estimated over 6 environments. IRRI, 1987.

Variety or line	Yield (g/m²)						
	E1	E2	E3	E4	E5	E6	Av
			CMS lines				
IR46828A	- 67.9**	- 73.2*	- 82.2*	- 5.1ns	68.2*	57.2*	- 17.2
IR46831A	- 66.3**	-135.5**	- 70.2ns	- 5.2ns	36.5ns	34.6ns	- 34.3
IR48483A	-129.7**	-161.0**	-231.5**	- 30.9ns	- 10.2ns	- 17.7ns	- 96.9
IR54754A	122.8**	330.6**	347.6**	115.1**	100.7**	60.5*	179.6
IR17492-18-10-2-2-3A	1.7ns	- 86.5**	- 19.9ns	- 87.6**	-117.6**	- 92.1**	- 67.0
IR54753A	70.0**	23.7ns	98.4**	28.4ns	- 11.6ns	1.5ns	34.1
IR58057A	232.6**	302.3**	320.6**	86.7**	38.1ns	53.1*	172.2
IR22107-113-3-3A	- 24.4ns	- 23.8ns	-113.8**	- 42.5*	- 24.9ns	6.7ns	- 39.2
IR54758A	- 82.0**	-202.9**	-231.6**	-126.5**	-147.6**	-121.8**	-152.1
IR54756A	- 52.9*	25.6ns	- 17.5ns	67.7**	74.4**	31.4ns	20.8
SE	25.3	32.7	36.5	20.5	27.9	24.7	
			Restorers				
IR36	- 44.9*	-114.9**	-106.0**	- 41.0*	- 50.3*	41.8*	- 66.5
IR46	166.8**	247.1**	324.9**	145.9**	145.5**	139.2**	194.9
IR54	85.3**	182.9**	208.9**	111.6**	113.3**	50.1*	125.3
IR58	- 97.7**	-126.7**	-216.1**	- 99.9**	-104.9**	- 52.5*	-116.3
IR62	-114.4**	-229.4**	-306.3**	- 93.5**	- 60.2*	- 90.1*	-149.0
IR64	20.6ns	3.3ns	13.3ns	10.8ns	- 16.7ns	- 24.9ns	0.8
IR9761-19-1	- 15.7ns	37.9ns	81.2**	- 33.9*	- 24.6ns	20.0ns	10.8
SE	21.2	27.3	30.6	17.1	23.3	20.7	

Table 8. New wild aborted type cytoplasmic male sterile lines developed at IRRI, 1987.

Line	Parentage		Days (no.) to 50% flowering	
	Female	Male	Wet season	Dry season
IR58052A	97A/12*IR4763-73-3-11	IR4673-73-3-11	71	76
IR58053A	IR46830A/11*IR19746-27-3-3-1-3	IR19746-27-3-3-1-3	73	81
IR58054A	V20A/10*IR22103-26-6-2*	IR22103-26-6-2	77	89
IR58055A	97A/10*IR19728-9-3-2-3-3	IR19728-9-3-2-3-3	76	87
IR58056A	V20A/10*IR25474-41-2-3-2	IR25474-41-2-3-2	92	95
IR58057A	97A/10*IR19661-283-1-3-2	IR19661-283-1-3-2	103	111
IR58058A	V20A/10*IR12979-24-1	IR12979-24-1	89	100

We also received 11 CMS lines (Table 9) from national programs for evaluation at IRRI. The seven CMS lines introduced from India possessed MS577A cytoplasm. Their pollen grains, when stained with 1% I-KI solution, stained normal like fertile pollen grains; however, they were not viable, because the bagged panicles did not set any seed. The Indian CMS lines, although adapted to the tropics, were not suitable as parents for developing hybrids because of their normal-looking pollen grains, which will pose problems in roguing hybrid seed production plots. The CMS lines Er-Jiu-Ai 1A from China and RD21A-23 from Thailand were found unstable for pollen sterility at IRRI. The remaining two CMS lines from China were stable, however. Line Large Sigma A possesses large exserted stigma, a useful trait for increased outcrossing. All CMS lines from China and Thailand were highly susceptible to tungro virus and are therefore not adapted to the tropics. Consequently, we still have to depend on IRRI-bred CMS lines to develop hybrids for the tropics.

Table 9. Performance of CMS lines introduced at IRRI, 1987.

Line	Source of cytoplasm	Origin	Days (no.) to 50% flowering	Remarks[a]
MS18A	MS577A	India	65	Pollen grains stain normal but viable
Madhu A	MS577A	India	84	Pollen grains stain normal but viable
Mangala A	MS577A	India	69	Pollen grains stain normal but viable
Pragathi A	MS577A	India	87	Pollen grains stain normal but viable
ES18A	MS577A	India	63	Pollen grains stain normal but viable
Intan Mutant A	MS577A	India	88	Pollen grains stain normal but viable
Pushpa A	MS577A	India	80	Pollen grains stain normal but viable
Er-liu-Ai 1A	?	China	63	Mostly withered, sterile pollen grains but some stain normal, susceptible to RTV
Lian Tang Zhao A	?	China	63	Sterile pollen, stable, susceptible to RTV
RD21A-23	WA	Thailand	87	Unstable for pollen, susceptible to RTV
Large stigma A	?	China	71	Sterile pollen, stable, susceptible to RTV

[a]RTV = tungro virus.

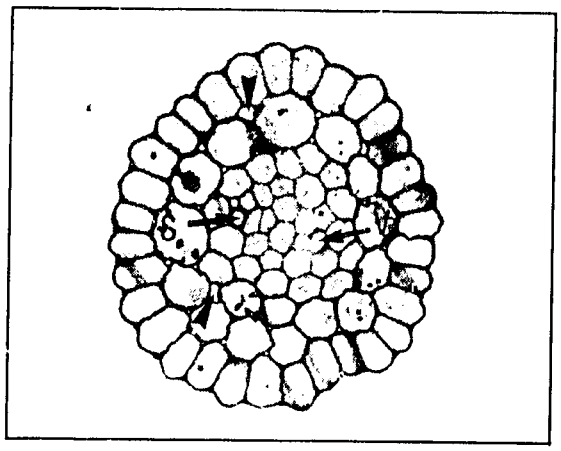
Identification and purification of new restorer lines (*Plant Breeding*). During the year, we identified 73 new restorer lines among elite lines developed at IRRI and those introduced from national programs. Most promising are IR66R, IR70R, IR31868-64-2-3-33R, IR32429-68-3-3-3R, IR32809-26-3-3R, IR35366-28-3-1-2-2R, IR35366-62-1-2-2-3R, IR37721-9-2-1-3R, and IR39357-133-3-2-2-2R from IRRI; C1321-90R and MRC11055-430R (Philippines); Mahsuri R (Malaysia); PDR76-D10-D8-D1-R (Pakistan); Iri 378R, Suweon 341R, and Milyang 83R (Korea); and 5167R (Colombia).

The frequency of true-breeding restorer genotypes in populations of elite lines ranged from 13 to 100%; the remaining plants were mostly partial restorers and occasionally nonrestorers.

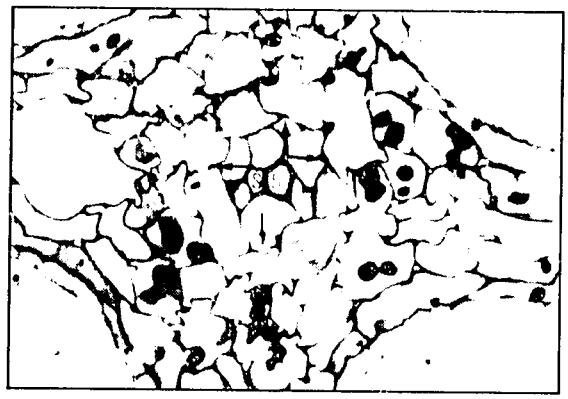
Cytohistological basis of cytoplasmic male sterility (*Plant Breeding*). We studied CMS line V20A and its fertile maintainer V20B for microsporogenesis and for vasculature of the stamens, using advanced microtechniques such as light microscopy with plastic embedding and semithin sectioning, and aniline blue-fluorescence microscopy.

Detailed analysis of microsporogenesis in V20B indicated that the process is similar to that reported in maize, barley, rye, sorghum, and wheat. We did not observe striking differences between V20A and V20B.

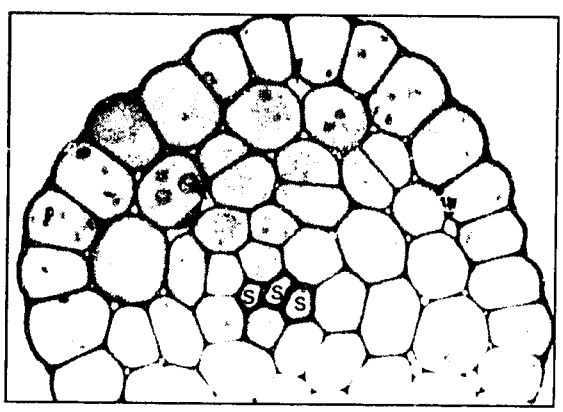
We also examined vascular tissues in filaments and connectives of V20B and V20A when their microsporogenesis was at the pollen mother cell (PMC) stage. Differentiation of the phloem (sieve tubes) in the filaments and connectives in V20A was more or less comparable to that in V20B, but significant abnormalities in xylem development occurred in both filaments and connectives of V20A (Figs. 4-7). More than 200 spikelets of V20A were examined by fluorescence microscopy; only pieces of xylem vessel elements were occasionally observed in the upper portions of the filaments or



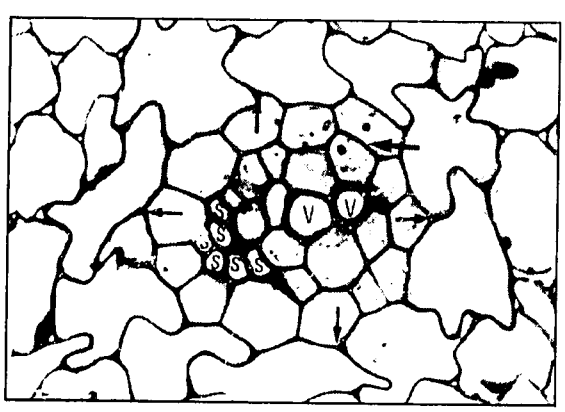
4. Cross section of V20B filament, IRRI, 1987. Arrows = intercellular spaces. 600X.



7. Cross section of the connective in V20A anther at the pollen mother cell stage, IRRI, 1987. Note that sieve tubes (S) are present, but the area of the vascular band is very small (arrows), and the xylem is not differentiated. 1500X.



5. Cross section of V20A filament showing sieve tubes (S) and intercellular spaces (arrows), IRRI, 1987. Note that the xylem is not differentiated. 1500X.



6. Cross section of the connective in V20B showing the vessel element (V), sieve tubes (S), and the whole area of the vascular band (arrows). IRRI, 1987. 1500X.

the connectives. Failure of xylem tissues to differentiate in the stamens of V20A remained until heading.

Another significant abnormality in V20A was the cell organization of the vascular bundles found in the connective tissue early in the PMC stage; the transverse section of CMS anthers showed poorly organized connective tissue; and the transverse area of the vascular bundles showed a very small vascular column consisting of 3-15 cells in the CMS line V20A (Fig. 7). In the fertile line V20B, the vascular column was generally composed of 30 cells with a relatively regular vascular sheath (Fig. 6).

Several other CMS lines derived from WA sources—IR48483A, IR46830A, IR54752A, IR54753A, IR54756A, IR54758A, IR58019A, and IR58025A—were also analyzed to study xylem differentiation in filaments and connective tissues. We observed complete failure of xylem differentiation in filaments and connectives of all these lines. These studies clearly indicated that a failure of xylem differentiation in the stamen could be a characteristic effect of WA CMS lines.

We also examined the vasculature of lodicules from the preceding CMS lines, including V20A, and their fertile maintainers. In fertile lines, development of vessel elements was observed starting from the early microspore stage of microsporogenesis, when development of vessel elements in the stamen had just finished. Before

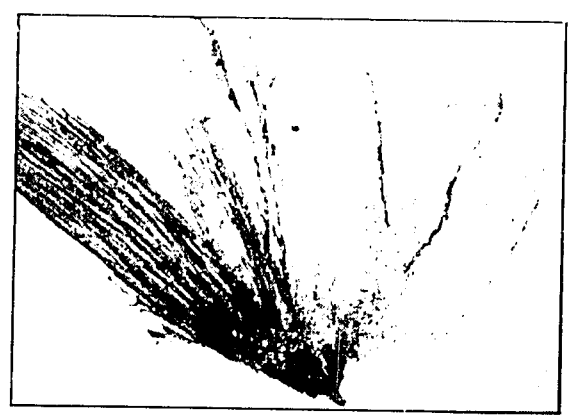
heading, all the fertile maintainers showed well-differentiated lodicules, with many strands of vascular bundles arranged like the ribs of a fan (Fig. 8); each vascular bundle had one strand of vessel elements and one strand of sieve tubes. Conversely, all the WA sterile lines had lodicules with either partially or extremely degenerated vessel elements, although sieve tubes were normally differentiated. In CMS line IR54753A, for example, only a few vessel elements were found in the lodicules (Fig. 9). Differentiation of vessel elements in the lodicules of IR46830A was the best among the nine CMS lines studied but was still not comparable to that in the fertile maintainer (Fig. 10). We also observed a direct relationship between the extent of development of vascular bundles on the lodicules and the opening of the spikelets of CMS lines.

The vascular tissues within the filaments and the connectives constitute the major organ responsible for transporting water and various nutrients to the developing microspores or pollen grains. Poorly developed vascular tissues mean a poor supply of water and nutrients, causing starvation and metabolic imbalance in the developing microspores. We believe that degeneration of vascular tissues in filaments and connectives may be the primary cause of pollen abortion in WA cytosterile lines.

Hybrid rice seed production (*Plant Breeding*). Seed of 34 rice hybrids involving IRRI-bred CMS lines IR46830A, IR54752A, IR54753A, and IR54754A was produced, employing techniques developed in China using 4:2 to 6:2 female:male ratios and 20- × 20-cm plant spacing. Seed yields were very low —3-278 kg/ha in DS and from 9-112 kg/ha in WS—primarily because of poor outcrossing rate or unsatisfactory synchronization of flowering in male and female parents. We are conducting experiments to study the causes of low seed yield and to develop a package of practices to produce higher yields in hybrid rice seed production plots. The results of some experiments conducted during the year are summarized in the following sections.

Effect of female:male row ratio on hybrid seed yield. During 1987 DS, we studied the effect of 1-4 female rows:1-4 male rows on the outcrossing and seed yield of CMS line IR54752A in the IR54752A/B seed multiplication plot. The experiment was in a

8. Microphotograph of V20B lodicule showing vessel elements, IRRI, 1987. Note that the dark areas on the left are highly lignified cells that are in contact with the palea. 75X.



9. Microphotograph of the lodicule from IR54753A, showing seriously degenerated xylem. IRRI, 1987. 75X.

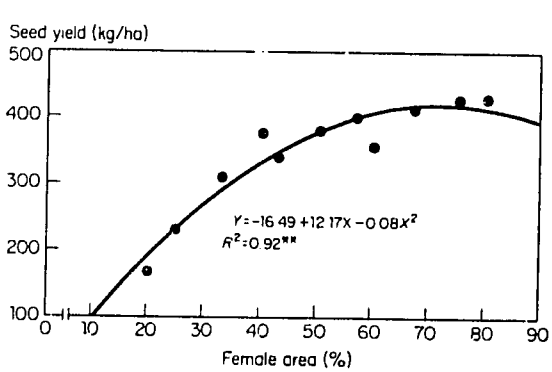
10. The lodicule of IR46830A, showing that xylem tissue is not well developed. IRRI, 1987. 75X.

split-plot design with number of male rows of IR54752B as main plots and number of female rows of IR54752A as subplots, with 20- × 20-cm spacing. Seed yield was directly proportional to increase in area (ranging from 20 to 80%) under female rows (Fig. 11). The percentage of outcrossing of the CMS line ranged from 13 to 15% and did not differ significantly among treatments.

In another set of experiments conducted during 1986 WS and 1987 DS, seed yield was determined from CMS line IR54752A on a single-row basis. The treatments were 2:2, 4:4, 3:2, 6:4, 5:2, 10:4, and 6:2 in 1986 WS and 8:1 and 8:2 in 1987 DS. No differences were found for per row seed yields between treatments, although the 4:4 and 6:4 row ratios gave lower seed yields. In 1987 WS, the highest seed yield (246 kg/ha) was obtained with the 8:2 row ratio. Seed yield in WS was always lower than in DS. The spacing used in these experiments (20 × 15 cm) was closer than in the previous experiment (20 × 20 cm). It appears that hybrid seed yield can be increased by increasing the ratio of female to male plants per unit area.

We still do not understand clearly why the increased number of male rows per unit area did not increase outcrossing percentage in CMS lines. We need to monitor closely the pollen load created by varying the number of male rows. In the meantime, we are using an 8:2 row ratio with a spacing of 20 × 10 cm.

Effect of concentration and time of application of GA_3 on outcrossing rate and seed yield of a CMS line. Following the pot experiment conducted in 1986 WS (Annual report for 1986), a field experiment determined the optimum concentration and time of application of GA_3 for hybrid rice seed production. Results (Table 10) indicated that 60 ppm GA_3, when sprayed at initial heading, increased seed yield significantly. Concentration × time of application effects were significant.



11. Effect of area of female rows on seed yield of CMS line IR54752A in CMS line multiplication plot. IRRI, 1987 DS.

Table 10. Seed yield of CMS line IR54752A as affected by concentration and 3 times of application of GA_3. IRRI, 1987 DS.

Concentration (ppm)	Yield (kg/ha)			
	Full booting	Initial heading	20% heading	Mean
0 (control)	485	456	489	477
30	510	434	309	418
60	358	564	472	465
60 (twice)[a]	468	518	498	495
Mean	485	493	442	464

LSD (5%) to compare effect of concentrations = 90
LSD (5%) to compare effect of time of application = 80

[a]Second application was given 3 d after the first.

Search for a substitute for GA_3 to increase outcrossing and hybrid rice seed yield. GA_3, although effective in increasing hybrid rice seed yield, is rather expensive. We are therefore searching for a cheaper alternative. We tested the efficacy of urea and boric acid spray compared with GA_3 application and control treatments at full booting, initial heading, and 20% heading. Yield differences between various treatments were statistically nonsignificant, and GA_3 and urea treatments were comparable. It appears that 1.5% urea spray may be a substitute for GA_3.

In a separate pot experiment, we studied the effect of urea on spikelet opening in CMS line IR54753A. The panicles from the plant sprayed with 2% urea showed 36% spikelet opening compared with 17% for the control. We are conducting more in-depth studies on the effect of urea as a substitute for GA_3 on hybrid seed yields.

Identification of promising F_1 rice hybrids in Korea, India, Indonesia, Malaysia, and Vietnam (*Plant Breeding*). Evaluations were made of experimental hybrids in 1986 and 1987. Results are given in the section on Cooperative Country Projects.

Ratooning performance of IRRI hybrids in Bangalore, India (*Plant Breeding*). See Cooperative Country Projects.

Effect of plant density and nitrogen level on yields of F_1 hybrids and elite inbred cultivars (*Plant Breeding*). In a collaborative experiment with the Crops Experiment Station, Suweon, Korea, two hybrids, V20A/Milyang 46R and IR54756A/Suweon 287R, yielded significantly higher than the best inbred cultivar. See Cooperative Country Projects for details.

Economics of hybrid rice in China (*Agricultural Economics*). The Agricultural Economics Department, in collaboration with the Chinese Academy of Agricultural Sciences, studied resource use and productivity of hybrid rices and conventional japonica and indica rice varieties in Jiangsu Province, China. We also evaluated the economics of hybrid rice seed production in the same province. Detailed results are reported in the section on Cooperative Country Projects.

Screening for wide compatibility varieties in rice (*Plant Breeding*). Wide compatibility rice varieties (WCVs) produce fertile F_1 plants in intervarietal indica/japonica crosses. Such varieties were first identified in Japan. Their use would enable us to exploit indica/japonica heterosis and produce higher frequency of recombinants in such crosses.

We screened 41 rice cultivars from IRRI's germplasm bank. These cultivars were crossed with three indica and three japonica testers, and cultivars producing normally fertile F_1 hybrids with both groups of testers were classified as WCVs. Eight cultivars—BPI 76 (indica), N22, Lambayeque 1, and Dular (all aus type), and Moroberekan, PBMN1, Palawan, and Fossa HV (all japonicas)—were identified as WCVs (Table 11). Dular was also reported as a WCV by Japanese rice scientists. Cultivars Ketan Nangka, Pada Bujang Pandek (javanica), Aus 373 (aus), and CP-SLO (intermediate)—found to be WCVs in Japan—showed only partial wide compatibility at IRRI. Work is in progress to study the inheritance of WCV genes and determine the linkage relationships between them and isozyme marker loci, viz., *Pgi-2, Amp-3*, and *Est-2*. The allelic relationship of WCV genes present in different cultivars is also being investigated. We are incorporating WCV genes into indica CMS and restorer lines to exploit yield heterosis in indica/japonica F_1 hybrids.

WIDE HYBRIDIZATION

Plant Breeding and Soils Departments

We continued the evaluation of progenies derived from crosses between three elite breeding lines of *O. sativa* and several accessions of *O. officinalis*. We grew 595 F_6 pedigree rows in DS and 645 F_6 pedigree rows in WS. Thirty-two breeding lines were evaluated in RYTs in DS and 41 in WS along with 350 elite breeding lines from the irrigated rice breeding program. During DS, one of the lines (IR54742-1-18-12) yielded 7.1 t/ha, the highest in the trials. In WS trials, IR54742-18-17-20-15 was the highest yielding entry at 5.4 t/ha. We crossed these lines with other elite lines to incorporate their useful traits such as resistance to brown planthopper (BPH) and whitebacked planthopper (WBPH) in the breeding materials. Many of the lines have been sent abroad to evaluate their resistance to local BPH biotypes.

In 1984, we crossed *O. australiensis* with IR31917-45-3-2, an elite breeding line of *O. sativa*, obtaining several completely sterile F_1 plants. No

Table 11. F_1 spikelet fertility of wide compatibility varieties in crosses with indica (I) and japonica (J) testers compared with check crosses (I/J) and cultivars.

Cultivar	Mean spikelet fertility (%) with			Difference from		
	I testers	J testers	Difference	I/J F_1 mean	I mean	J mean
Moroberekan	75	76	− 1ns	61**	4ns	5*
Fossa HV	66	70	− 4ns	53**	−4ns	−4ns
Palawan	60	74	−14ns	53**	−4ns	−4ns
Pate Blanc MINI	63	71	− 8ns	52**	−5ns	−4ns
BPI 76	70	63	− 7ns	52**	−5ns	−5ns
N22	71	72	− 1ns	56**	−1ns	0
Lambayeque 1	63	76	−13ns	54**	−3ns	−2ns
Dular	61	70	− 9ns	49**	−7ns	−7ns

seeds were obtained upon backcrossing to *O. sativa*. In 1985, we produced 4n *O. sativa* with colchicine treatment and crossed it with *O. australiensis*, obtaining six 3n F_1 plants. Backcrossing the triploid F_1s to *O. sativa* produced 16 BC_1 plants with chromosome number varying from 28 to 31. These plants were again backcrossed to *O. sativa*. Only two BC_1 plants yielded BC_2 progenies. Fifty-five seeds were obtained, and 35 BC_2 seedlings are now growing. We shall determine their chromosome number at flowering.

During 1987, a number of new crosses were made to facilitate the transfer of various traits from selected *Oryza* species into cultivated rice.

Gene transfer from *Oryza minuta* (*Plant Breeding*). *O. minuta*, a tetraploid species with the genomic constitution BBCC, is a rich source of resistance to planthoppers and leafhoppers. Four accessions of Philippine origin were selected as sources of BPH and WBPH resistance and were crossed with IR31917-45-3-2, which is susceptible to both insects. All crosses were made using *O. sativa* as the female. GA_3 (75 ppm) was applied to the pollinated panicles. Seed sets ranged from 0 to 4.2%. Hybrid seed development was slow because of premature embryo and endosperm degeneration, and at 14 d after pollination the seeds started to abort. To ensure hybrid survival, 14-d-old embryos were extracted under sterile conditions, transferred to 1/4-strength Murashige-Skoog medium, and incubated in the dark. Upon germination, the hybrid plants were transferred to light and then to a nutrient solution. The seed set and embryo rescue data are shown in Table 12.

The F_1 hybrids were intermediate between the parents in plant type, although the panicles were very similar to those of *O. minuta*. All hybrids were triploid, having the ABC genomic constitution, and were completely male sterile.

The hybrids were then backcrossed with the recurrent parent (IR31917-45-3-2). From a total of 31,850 spikelets pollinated, only 7 small, shriveled BC_1 seeds were produced. After embryo rescue, four plants were obtained, two of which died, presumably because of abnormalities in chromosomal constitution. The remaining two plants were tetraploid (AABC), possessing two genomes of *O. sativa* (AA) and one copy of each of the two genomes of *O. minuta* (BC). The two AABC tetraploids were further backcrossed, giving seed sets of 0.05% and 0.02%. From the 10 poorly developed BC_2 seeds produced, 9 embryos were extracted. Only two embryos germinated, producing two viable BC_2 plants, whose chromosome number will be determined upon flowering.

The success of BC_1 production was limited by the high female sterility in the F_1 hybrids. The production of amphiploids through colchicine treatment of the hybrid is an alternative route to the advancement of this cross. Colchicine treatment of the *O. sativa*/*O. minuta* hybrid (ABC) should double its chromosome number and produce amphiploids (AABBCC) with higher fertility than the original hybrids. Upon backcrossing, the amphiploids should yield a higher frequency of BC_1 plants.

Amphiploid production was attempted by the treatment of 1,085 young nodally derived shoots with 0.05% colchicine plus 1.5% dimethyl sulphoxide for 48 h. Although shoot mortality was high, 55 survived and produced vigorous plants. Nine of these were partially fertile, producing pollen-bearing anthers and 163 selfed seeds. These seeds are currently being grown to determine their chromosome constitution.

These partially fertile plants were also backcrossed with IR31917-45-3-2, further producing 12 BC_1 seeds. Of the nine embryos extracted, four

Table 12. Seed set and embryo rescue data from crosses of *O. sativa* (IR31917-45-3-2) with selected *O. minuta* accessions. IRRI, 1987.

O. minuta accession no.	Spikelets pollinated (no.)	Seed set		Embryos cultured (no.)	Embryos that germinated		True hybrids obtained (no.)
		no.	%		no.	%	
101089	529	16	3.0	10	6	60.0	4
101096	1117	43	3.8	1	0	--	–
101099	213	0	0	0	--	–	–
101141	1553	66	4.2	29	14	48.3	14

germinated, increasing the number of BC_1 plants available to six.

In addition to their BPH and WBPH resistance, IR31917-45-3-2 and *O. minuta* (101089, 101141) differ in their response to the Philippine isolates of bacterial blight (BB) and blast (Bl). Both parents and hybrids have been tested for their resistance to each pathogen (see section on Disease Resistance).

Transfer of genes affecting yield potential (*Plant Breeding*). The potential of wild *Oryza* species as sources of genes capable of increasing the yield potential of cultivated rice is being explored. Two approaches are being pursued: 1) the transfer to *O. sativa* of genes from species having high biomass and leaf area but a different genomic constitution, and 2) the transfer of genes from closely related AA genome species.

For the first approach, two high-yielding irrigated rice varieties (IR36 and IR64) were crossed with four accessions of *O. latifolia* (CCDD), using *O. sativa* as the female parent. Seed sets ranged from 0 to 19.7% (Table 13), and in all cases the hybrid seed was poorly developed. Following embryo rescue, embryo germination ranged from 0 to 89.3%. These F_1 hybrids are currently being backcrossed with their respective recurrent parents (IR36 or IR64), and colchicine treatment is under way for amphiploid production. In this cross, an additional method of colchicine treatment involving immersion of the roots and crown of young hybrid tillers in colchicine solution for 5 h is being used. Procedures such as addition line production and the induction of translocations will be used to facilitate the introgression of genes influencing yield potential from *O. latifolia* into *O. sativa*.

The second approach involves the transfer of traits from the AA genome species *O. nivara* and *O. rufipogon* ("*O. perennis*") into cultivated rice. In this case, gene transfer should result from interspecific chromosome pairing and recombination in the F_1 hybrid and later generations. The strategy is to advance the hybrids by selfing and backcrossing, thereby creating a series of segregating populations derived from F_1, BC_1F_1, BC_2F_1, BC_3F_1, and BC_4F_1 plants. The extent of variation for yield potential-related parameters will be simultaneously assessed in the different populations under field conditions.

For this study, crosses were made between *O. sativa* (IR36, IR64) and five accessions of *O. nivara* (101973, 103422, 103826 plant #1, 103826 plant #3, 103839) and between *O. sativa* (IR54, IR64) and four accessions of *O. rufipogon* ("*O. perennis*") (100692, 100907, 103817, 103848). The seed sets obtained from the *O. nivara* crosses ranged from 9.1 to 62.2% in crosses with IR36 and from 13.9 to 28.9% in crosses with IR64 (Table 14). The first batch of hybrid seed was sown, and these plants were backcrossed with the recurrent *O. sativa* parent, giving seed sets of 11.3-39.2%. Hybrid pollen fertility was high, ranging from 70 to 90%, and consequently F_2 seed was obtained from all plants. The seed sets from the *O. rufipogon* ("*O. perennis*") crosses ranged from 18.5 to 73.0% in crosses with IR54, and from 28.1 to 62.8% in crosses with IR64 (Table 14). Backcrossing with the recurrent parent gave seed sets ranging from 5.3 to 23.1%. Pollen fertility of the IR54/*O. rufipogon* hybrids varied considerably between individual plants, indicating that a genetic incompatibility mechanism may be operating in this cross combination. It may therefore be necessary to eliminate the IR54 cross combinations from this study. In comparison, the pollen fertility of the IR64/*O. rufipogon* hybrids ranged from partial (31-70%) to full (91-100%); the majority showed fertility levels of 71-90%. Backcrossing with IR64 resulted in seed sets of 12.4-22.9%. Additional F_1 hybrid plants will be backcrossed and selfed, and BC_1F_1 plants will be sown to produce BC_2F_1 progeny.

Evaluation of *Oryza glaberrima* under upland conditions (*Plant Breeding and Soils*). Upland rice is often exposed to adverse soil conditions, one of which is P deficiency. *O. glaberrima* is cultivated in West Africa, often under an upland environment, and may therefore be a potential source of tolerance for such adverse soil conditions. With the help of the Soils Department, 881 accessions of *O. glaberrima* obtained from the International Rice Germplasm Center were seeded during 1987 DS at a P-deficient upland trial site (Luisiana, Laguna) to explore the level of variation within this species for tolerance for P deficiency. The *O. glaberrima* accessions were classified into apparent upland and deepwater types. Two resistant checks (IRAT104 and Azucena) and three susceptible checks (Plah Sew, Pokkali, and IR32307-107-3-2-2) were planted at regular intervals throughout the two replications. Fertilizer levels were minimal (pre-seeding application of 25 kg N/ha as $(NH_4)_2SO_4$

Table 13. Seed set and embryo rescue data from crosses of *O. sativa* (IR36, IR64) with selected *O. latifolia* accessions. IRRI, 1987.

Cross combination	Spikelets pollinated (no.)	Seed set		Embryos cultured (no.)	Embryos that germinated	
		no.	%		no.	%
IR36/Acc. no. 100963	254	11	4.3	10	7	70.0
IR36/Acc. no. 100964	413	4	0.1	4	0	0
IR36/Acc. no. 100965	430	4	0.1	4	0	0
IR36/Acc. no. 100966	454	33	7.3	28	25	89.3
IR64/Acc. no. 100963	501	26	5.2	24	15	62.5
IR64/Acc. no. 100964	269	0	0	–	–	–
IR64/Acc. no. 100965	429	0	0	–	–	–
IR64/Acc. no. 100966	472	93	19.7	69[a]	54	78.3

[a]Embryos extracted from only 78 of the total 93 seeds.

Table 14. Seed set obtained from *O. sativa/O. nivara* and *O. sativa/O. rufipogon* ("*O. perennis*") crosses and backcrosses with recurrent parent. IRRI, 1987.

Cross combination	Hybrid			Plants backcrossed (no.)	Backcross			Hybrid pollen fertility range[a]
	Spikelets pollinated (no.)	Seed set			Spikelets pollinated (no.)	Seed set		
		no.	%			no.	%	
				O. nivara				
IR36/101973	22	2	9.1	0	–	–	–	
IR36/103422	163	42	25.8	2	433	71	16.4	F
IR36/103826-1	39	15	38.5	0	–	–	–	
IR36/103826-3	37	23	62.2	1	278	109	39.2	F
IR36/103839	181	81	44.8	2	881	249	28.3	F
IR64/101973	339	55	16.2	4	1021	115	11.3	F
IR64/103422	72	10	13.9	4	653	116	17.8	F
IR64/103826-1	256	74	28.9	4	817	135	16.5	F
IR64/103826-3	378	109	28.8	4	1207	412	34.1	F
IR64/103839	271	55	20.3	4	987	207	21.0	F
				O. rufipogon ("O. perennis")				
IR54/100692	92	17	18.5	0	–	–	–	
IR54/100907	108	35	32.4	5	1388	320	23.1	CS-F
IR54/103817	89	65	73.0	3	454	24	5.3	CS-F
IR54/103848	163	87	53.4	3	234	54	23.1	PS-F
IR64/100692	146	41	28.1	4	757	173	22.9	PF-F
IR64/100907	116	62	53.4	4	913	203	22.2	F
IR64/103817	128	36	28.1	5	1753	217	12.4	F-FF
IR64/103848	78	49	62.8	5	1090	149	13.7	PF-FF

[a]CS (completely sterile) = 0%, PS (partially sterile) = 11-30%, PF (partially fertile) = 31-70%, F (fertile) = 71-90%, FF (fully fertile) = 91-100%.

and 25 kg K/ha as muriate of potash followed by 25 kg N/ha at maximum tillering). Very few *O. glaberrima* accessions showed tolerance for P deficiency. Of the 881 accessions screened, 63 were selected for rescreening under similar conditions in Caliraya, Laguna, during 1987 WS. High levels of Bl infection demonstrated a degree of genotypic variation for Bl resistance. Although these accessions showed little tolerance for P deficiency, certain accessions showed earlier vegetative vigor and a higher tillering ability than the tolerant checks. The greater vigor of accessions such as 103329, 103350, 104174, 104232, 104278, and 104527 will be studied further under controlled conditions.

BIOCHEMICAL MARKERS

Plant Breeding Department

Methodological studies. Studies to identify new polymorphic genes coding for isozymes and analyze isozyme expression in various organs have been pursued. The following isozyme genes have been found to be reliably expressed within microspore callus cultures derived from several varieties and crosses: *Adh-1, Sdh-1, Icd-1, Cat-1, Pgi-1, Pgi-2, Pgd-1, Pgd-2, Got-1, Got-2, Amp-1, Amp-2, Amp-3, Amp-4, Acp-1, Acp-2, Acp-3, Acp-4, Est-1, Est-2, Est-9,* and *Mal-1.*

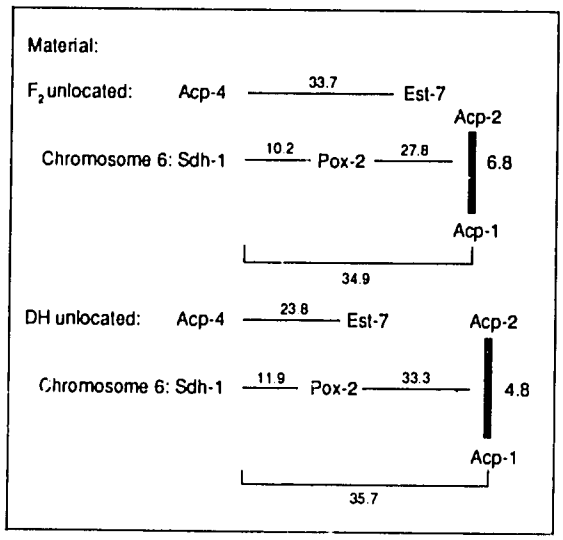
Use of isozyme markers to monitor genetic segregation and recombination. In rice intraspecific remote crosses, natural isozyme polymorphism permits handling the F_1s readily used in current breeding programs with a high number of heterozygous isozyme markers that are mostly scattered on the rice chromosomes. Thus, analyzing the isozyme constitution of F_2 plants or of anther culture lines derived from such crosses provides an insight into genome recombination events. It can also help detect restrictions to the genetic recombination and segregation due to the specific action of hybrid sterility factors or to in vitro selection. An example of segregation of heterozygous isozyme markers observed in F_2 plants, anther culture calli, and anther culture lines together deriving from a japonica/indica F_1 cross, is given in Table 15. The significant deviations from the expected ratios observed within the F_2 at loci *Pgd-1, Acp-4,* and *Amp-2* — likely related to the selection and certation that occur in rice distant hybrids—also occurred within the anther culture derivatives. Moreover, the anther culture process seems to generate in this cross additional weak deviations at loci *Pgi-1* and *Est-7* toward the japonica allele, since they are not noted among the F_2 population. However, the rough linkage estimates based on F_2 data are compatible with estimates based on F_2 data and data previously recorded on other F_2s (Fig. 12).

Isozyme classification. In addition to 14 isozyme loci already located on specified chromosomes, new genes are being located through trisomic analysis. Linkage studies have determined the association of isozyme loci (i.e., *Amp-3, Est-2,* and *Pgi-2*) on chromosome 3 with agronomic traits such as wide compatibility and photoperiod

Table 15. Comparison of segregati[illegible] 13 heterozygous isozyme markers among F_2 plants, anther culture-derived calli, and anther culture-derived lines of t[illegible] is IRAT177/Apura.[a] IRRI, 1987.

Isozyme marker	IRAT177	Apura	Segregation		
			F_2 progeny	Anther culture-derived calli	Anther culture-derived lines
Icd-1	F	S	54: 95:40 ns	234:210 ns	24:18 ns
Pgi-1	F	S	45: 94:50 ns	182:264 S**	14:28 S*
Sdh-1	F	S	43:102:44 ns	216:226 ns	24:18 ns
Pox-2	A	P	47:142 ns	*b*	21:21 ns
Acp-1	F	S	49: 93:43 ns	92: 90 ns	19:23 ns
Acp-2	A	P	44:144 ns	*c*	25:17 ns
Est-9	S	F	57: 87:43 ns	214:186 ns	18:24 ns
Amp-2	S	F	50: 74:64 S**	186:258 S**	18:24 ns
Pgd-1	F	S	63: 71:44 S**	293:137 S**	29:13 S*
Acp-4	S	F	37: 31:24 S**	*c*	30:12 S*
Est-1	A	P	41:148 ns	135:115 ns	24:18 ns
Est-7	P	A	30: 86 ns	*b*	14:28 S*
Mal-1	S	F	*c*	131: 59 S**	*c*

[a]Tillers at booting for AC-derived line production, as well as F_2 seeds, were harvested on the same F_1 plants in Guadeloupe during 1986 DS. F_1 anthers for anther culture-derived calli production were plated at IRRI during 1987 WS. Allele designations adopted are F (fast) vs S (slow) when the parents differed in the migration speed of the allozymes, and A (absence) vs P (presence) when the parents differed in the presence of a band. SS:SF:FF or AA:AP+PP for the F_2 progeny and SS: FF or AA:PP for the anther culture-derived calli or lines. Chi square tests for homogeneity: F_2 fit to a 1:2:1 or a 1:3 segregation; anther culture-derived calli or lines fit to a 1:1 segregation; S* = significant at the 5% level; S** = significant at the 0.5% level; ns = not significant at the 5% level. [b]Isozymes not detectable in microspore callus analysis. [c]Number of samples successfully analyzed too small.



12. Representation of the linkages among isozyme markers estimated from F_2 plants and anther-culture lines derived from the cross IRAT177/Apura. F_2 recombination rates evaluated through the maximum likelihood method. DH rough estimates obtained directly from anther culture line data.

sensitivity. Rice germplasm is routinely classified by isozyme polymorphism. As many as 700 upland and deepwater entries and another set of 144 varieties carrying different *Xa* genes for BB resistance (Table 16) have been assigned to their respective groups. A reference set of 300 varieties has been classified for studying disease resistance.

TISSUE CULTURE

Plant Breeding Department

In recent years, research on rice tissue culture has employed mainly anther and somatic cell cultures, with occasional embryo rescue techniques. The scope of our tissue culture research was expanded in 1987 to include two other techniques—isolated pollen culture and protoplast culture.

The benefit derived from isolated pollen culture is the same as that in anther culture, i.e., shortening the breeding cycle by immediate fixation of homozygosity. In addition, isolated pollen culture permits manipulating the microspores in the same manner as single cells for possible selection of pollen grains that carry the genes coding for resistance to a particular stress. This technique also eliminates the possible inhibitory effects of the anther wall. Pollen grains can also be natural cellular "vectors" and can be used in genetic transformation studies.

On the other hand, efficient protoplast culture is a prerequisite to successful research on gene transfer. Protoplasts could also function as "gametes" in somatic hybridization and may solve sexual incompatibilities in distantly related species.

Anther and isolated pollen culture. *Genetic studies on callus formation and green plant regeneration ability in anther culture.* The mode of inheritance of callus formation and green plant regeneration was investigated using 16 genotypes from a 4-parent diallel set. Understanding of this mechanism is important in transferring these characteristics from highly culturable into recalcitrant varieties. Data showed the preponderance of additive gene effects and the presence of partial dominance in the control of callus induction. Callus induction was likewise shown as a recessive character. Reciprocal differences in callus induction were nonsignificant, indicating that this character is solely nuclear.

The predominance of additive gene effects on the control of plant regeneration was observed. Moreover, the absence of maternal effects and the fact that green plant regeneration is a recessive character controlled by only a few genes were also noted.

Establishment of a protocol on isolated pollen culture. Taipei 309, considered a model variety in anther culture because of its high efficiencies of callus induction and plant regeneration, was used to establish a protocol for isolated pollen culture. The importance of cold shock and preculture of anthers was observed. Addition of the amino acid

Table 16. Isozyme classification of some varieties carrying the *Xa* resistance gene to bacterial blight, IRRI, 1987.

Xa group	Varieties analyzed (no.)	Varieties (no.) in each isozyme group						Varieties successfully classified (%)
		I	II	III	IV	V	VI	
Xa-3	54	4	6	0	0	7	35	96.3
Xa-4	28	26	0	0	0	0	0	92.8
xa-5	55	11	41	1	0	0	0	96.4
Xa-7	3	0	3	0	0	0	0	100.0
Xa-10	4	4	0	0	0	0	0	100.0

proline at callus induction increased plating efficiency and subsequent plant regeneration.

Somatic cell culture. *Effect of seed specific gravity on callus induction and plant regeneration.* One of the indices of successful research is the ability to repeat results. Wide variation in results has been common with in vitro experiments. Thus, the starting materials in this case seeds were graded according to specific gravity to determine its effect on the distribution of the true values.

By grading the grains of varieties Nona Bokra and IR28, a lower standard deviation of the means, both in callus production (Table 17) and in plant regeneration (Table 18), was observed. This indicates a narrow range of distribution of the true values of these two parameters. It is best to select high-density grains because they give the highest efficiencies in terms of callus and green plant production, the reason for which may be the optimum kernel development required for in vitro culture studies.

Protoplast culture. The factors significant in the isolation, culture, cell division, callus induction, and plant regeneration of rice protoplasts were assessed to establish a more or less standard procedure for successful protoplast culture. In this respect, cell suspension cultures of japonica, indica, and wild rice species were established. To date, a number of protoplast-derived calli and sustained cell division have been obtained from two genotypes each of japonica and indica varieties. Regeneration from protoplast-derived calli has been possible.

Production of homozygous lines through anther culture. Anther culture for the production of homozygous lines from crosses made for tolerance for adverse conditions has been fully implemented. Because soil and environmental stresses are site-specific, this part of our research has been primarily in collaboration with national programs.

Table 18. Green plant regeneration from grain-derived callus of Nona Bokra in Linsmaier and Skoog culture medium containing 5.0 *μM* benzylaminopurine and 2.5 *μM* naphthaleneacetic acid. IRRI, 1987.

Grain classification[a]	Plant regeneration efficiency[b] (%)	Av number of plants per callus inoculated
Ungraded	36.11 ± 12.48	1.22 ± 0.60
Graded		
1.1>SG>1.0	5.56 ± 3.51	0.14 ± 0.09
1.2>SG>1.1	33.33 ± 7.45	0.81 ± 0.19
SG>1.2	61.11 ± 5.56	2.11 ± 0.23

[a]SG = specific gravity.

[b]% efficiency = $\frac{\text{no. of plant-producing calli}}{\text{total no. of calli inoculated}}$ X 100 ± standard deviation of the mean.

Table 17. Effect of 2,4-D concentration in Linsmaier and Skoog culture medium on percent callus production.[a] IRRI, 1987.

Grain classification[b]	Callus production (%) in 2,4-D concentration			
	0	2.5 μM	5.0 μM	10.0 μM
		Nona Bokra		
Ungraded	36.11 ± 13.17	52.78 ± 10.00	66.67 ± 11.38	63.89 ± 9.04
Graded				
1.1>SG>1.0	5.56 ± 2.87	19.45 ± 3.69	22.22 ± 3.51	19.45 ± 2.78
1.2>SG>1.1	63.89 ± 2.78	72.22 ± 3.51	75.00 ± 3.72	72.22 ± 3.51
SG>1.2	72.22 ± 3.51	83.33 ± 4.30	88.80 ± 3.51	77.78 ± 3.51
		IR28		
Ungraded	5.56 ± 2.87	16.67 ± 8.61	19.44 ± 14.72	25.00 ± 10.97
Graded				
1.1>SG>1.0	0	2.78 ± 2.54	8.34 ± 2.63	8.34 ± 4.81
1.2>SG>1.1	5.56 ± 2.87	11.11 ± 4.30	16.67 ± 3.04	13.89 ± 3.66
SG>1.2	11.11 ± 2.03	16.67 ± 3.04	19.45 ± 3.69	25.00 ± 5.69

[a]% callus production = $\frac{\text{no. of callus-producing grains}}{\text{total no. of grains inoculated}}$ X 100 ± standard deviation of the mean. [b]SG = specific gravity.

The number of crosses and green plants so far regenerated through anther culture in various collaborative projects is summarized in Table 19. The homozygous lines developed from the F_1 hybrids were sent back to the collaborating country or scientist for screening and selection. Informal collaboration has also been established with Pakistan, Dominican Republic, Indonesia, and Japan.

One out of three lines tested for cold tolerance in different locations by the International Rice Testing Program (International Rice Cold Tolerance Nursery) was comparable to the resistant check Stejaree 45. This line, which was derived from Taipei 309 and Tatsumi mochi, was also cold tolerant under field conditions in Chuncheon, Korea, in 1984.

In our collaboration with plant breeders for obtaining salt-tolerant lines through anther culture from F_1 crosses, 14 lines were identified to be salt tolerant under field conditions. Three of them were given to the Plant Physiology Department for salt tolerance screening. These lines, derived from indica/japonica F_1 crosses of IR4630-22-2-5-1-3/Pokkali and IR5657-33-2/IR4630-22-2-5-1-3, showed salt tolerance and, though not as tolerant as the check Pokkali, had better plant type. Furthermore, the anther culture-derived lines were more tolerant than most of the IR varieties simultaneously tested.

Field tests at four sites in Iloilo (San Dionisio, Pili, Lamjagan, and Santo Rosario) during 1987 DS included some of those salt-tolerant materials. Of the 1,544 entries, most of which were obtained through conventional breeding, only those obtained from anther culture survived the highly saline conditions. In addition to salt tolerance, the anther culture-derived plants showed a high degree of homozygosity. Although further testing is needed, the preliminary results are very encouraging and seem to demonstrate the efficiency of generating plants for adverse conditions through anther culture.

Twenty-five F_1 upland crosses were selected for anther culture and out of these crosses, a total of 297 anther culture plants were regenerated and planted in observational plots (Table 20). The 117 anther culture lines selected in 1987 DS were further evaluated during the WS planting. After the evaluation, 53 promising lines were identified for RYTs in different locations. The criteria used in selection included earliness, plant height ≤100 cm, and long panicles with high fertility.

Table 19. Data on green plant regeneration in various collaborative projects on the production, through anther culture, of homozygous lines tolerant of adverse conditions. IRRI, 1987.

Adverse condition	Crosses plated for anther culture (no.)	Calli (no.) producing green plants	Green plants produced (no.)
Cold tolerance	32	1,898	11,450
Resistance to blast and hoja blanca	25	70	781
Upland conditions	107	361	1,988
Salt tolerance	101	119	1,622

Table 20. Selected anther culture-derived lines from F_1 upland crosses. IRRI, 1987 DS.

Cross	Anther culture-derived lines (no.)	Selected lines (no.)	
		1987 DS	1987 WS
IRAT112/IAC47	8	8	6
IAC47/IRAT112	24	10	8
IAC47/Burik	72	33	10
Burik/IAC47	24	0	–
Kinandang Patong/Burik	10	2	0
Burik/Kinandang Patong	1	0	–
UPLRi-5/IAC25	2	0	–
IRAT112/Azucena	4	3	3
Azucena/IRAT112	21	8	6
Chandarhat/IAC47	15	6	0
IAC47/Kinandang Patong	9	9	6
IR976445-2-2/IAC47	1	1	0
UPLRi-5/IAC47	25	4	0
IAC25/GS529	8	1	0
ARC7098/IAC25	1	0	–
IAC25/ARC7098	2	0	–
IR9764-45-2-2/IRAT112	4	1	0
IR9764-45-2-2/Azucena	5	0	–
IAC47/IRAT13	13	13	2
IRAT13/IAC47	11	9	2
Chakula/IAC47	4	0	–
IRAT112/IAC25	27	10	10
UPLRi-5/IRAT13	4	0	–
IRAT13/UPLRi-5	1	0	–
Burik/IRAT112	1	1	0
Total	297	117	53

Table 21. Yields of some breeding lines developed through the modified bulk pedigree method, compared with those of best available check varieties developed through the conventional pedigree method. IRRI, 1987 DS and WS.

Line or variety	Yield (t/ha)						
	1987 DS			1987 WS			General mean
	N_0	N_{120}	Mean	N_0	N_{120}	Mean	
			Short duration				
IR47067-B-B-94	6.8	7.0	5.9	3.8	3.0	3.4	5.2
IR47067-B-B-223	6.1	6.0	6.0	1.9	1.6	1.8	3.9
IR47067-B-B-12	5.5	6.3	5.9	3.8	3.8	3.8	4.8
IR47092-B-B-230	6.0	6.2	6.1	2.1	2.3	2.2[a]	4.2
IR46998-B-B-129	5.3	6.2	5.8	2.5	1.9	2.2	4.0
IR47068-B-P-324	5.1	6.1	5.6	3.1	3.2	3.2	4.4
IR58 (check)	2.5	3.0	2.8	–	–	–	–
IR64	5.6	6.5	6.0	2.1	1.9	2.0[a]	4.0
IR66	5.8	6.1	5.9	3.5	3.0	3.3	4.6
LSD (5%)	1.2	0.6		0.7	0.7		
			Medium duration				
IR51618-B-B-15	5.8	5.9	5.8	2.5	1.4	1.9[a]	3.9
IR51618-B-B-212	5.8	5.4	5.6	3.2	1.8	2.5	4.0
IR47098-B-B-470	5.4	5.8	5.6	2.3	1.5	1.9	3.8
IR51617-B-B-52	5.1	5.4	5.3	1.2	1.1	1.2	3.4
IR47098-B-B-250	5.1	5.1	5.1	3.1	2.1	2.6	3.8
IR64	4.0	4.6	4.3	2.1	1.9	2.0	3.2
IR54	5.3	4.6	5.0			1.6[a]	3.3
IR66	–	–	–	3.5	3.0	3.2	
LSD (5%)	0.8	1.0		0.9	0.9		

[a]Yield unusually low because of severe tungro.

MODIFIED BULK PEDIGREE METHOD TO BREED FOR HIGHER RICE YIELD

Plant Breeding Department

The breeding approach earlier designated as direct selection for yield in early generations (Annual reports for 1985 and 1986) was redesignated as the modified bulk pedigree method. Twenty-seven promising lines developed by this method were evaluated in RYTs under 2 fertility levels (N_0 and N_{120}) in 1987 DS. Eleven lines (6 early and 5 of medium duration) yielded numerically higher in N_0 or N_{120} than the check varieties of corresponding growth durations; these lines were reevaluated in 1987 WS along with newly identified lines from additional crosses. The WS trials were severely affected by tungro. We did not observe striking differences in the yield performance in the N_0 and N_{120} levels, perhaps because the fields were planted to rice for the first time and native fertility was high. Yield data from the two trials (Table 21) indicated yield superiority of two early-maturing lines IR47067-B-B-94 and IR47067-B-B-12 developed through the modified bulk pedigree method. They will be evaluated further by agronomists and physiologists at IRRI to test their yield performance under various fertilizer management and cultural practices.

Encouraged by these results, we have also initiated detailed studies in a set of crosses to compare the relative efficiency of the modified bulk pedigree and conventional pedigree methods in breeding for higher yield potential.

Genetic evaluation and utilization (GEU) program

Computerized data management

Statistics, Plant Breeding, and Communication and Publications Departments, International Rice Germplasm Center, International Rice Testing Program, and Computer Services

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GERMPLASM BANK

Statistics Department and International Rice Germplasm Center

At the end of the year, the germplasm bank (GB) databank contained information on the 45 basic morphoagronomic characters and 35 GEU traits (Annual report for 1983) of 72,482 accessions. During 1987, 7,737 newly registered accessions of *Oryza sativa* and basic morphoagronomic data on 4,725 existing accessions were updated.

Data on 18 GEU traits were added to the GB databank in 1987 (Table 1). The number of accessions per trait averaged 5,082.

Decentralization of GB computerized data processing was accelerated with the following activities:

- increased availability of microcomputers in IRRI research departments and the associated computer proficiency of the staff,
- installation of the SQL/DS-based GEU database management system (DBMS), and
- implementation of Phase I of IRRIGEN (a microcomputer-based system for computerizing International Rice Germplasm Center operations), concerning the management of seed and data that are related to the GB databank such as the processing of incoming seed, the rejuvenation scheme, and the direct encoding of morphoagronomic data.

With decentralized management, the encoding, validation, and update of data for the GB databank as well as information retrieval are done by the concerned GEU scientists themselves (i.e., those who are responsible for the collection and management of data on specific traits). This has resulted in the speedier and more accurate updating of data into the databank and better utilization of data from it.

Table 1. Update of data on GEU traits added to the germplasm bank databank, IRRI, 1987.

GEU trait	Updated records (no.)	Accessions with data (no.)
Bacterial blight	7,980	48,149
Blast	2,521	35,146
Brown planthopper		
Biotype 1	22,517	44,335
Biotype 2	5,598	10,053
Biotype 3	6,817	13,020
Amylose	11,401	29,021
Gelatinization temperature	6,593	26,234
Drought		
Seedling vigor	3,752	27,763
Rate of recovery		
After first stress	3,752	20,767
After second stress	3,752	11,[illegible]
Field resistance		
Early vegetative phase	3,752	25,950
Late vegetative phase	2,590	17,650
Reproductive phase	1,173	10,908
Field tolerance (300-400 kPa)	3,861	4,168
Field tolerance (900-1000 kPa)	3,861	3,650
Rate of recovery after exposure to 900-1000 kPa	3,861	3,651
Flood tolerance	1,218	9,501
Cold tolerance	1,899	6,497

INTERNATIONAL RICE TESTING PROGRAM

International Rice Testing Program

Two new nurseries were incorporated in the computerized systems of the International Rice Testing Program (IRTP):

- IRGQSS—International Rice Grain Quality Screening Set
- IRUSS — International Rice Ufra Screening Set

A system was developed for managing incoming seed and new nomination data. The form completed by the cooperator was revised to facilitate data encoding. Listings of new nominations by country and by nursery were printed to provide information needed for composing nurseries. Nominations to the 1987 and 1988 nurseries were processed. For 1987, 702 entries were nominated by cooperators from 16 countries, and for 1988, 841 entries were nominated by cooperators from 12 countries.

System development continued for the creation of a highlighted or best-performing entries file by nursery. Files were created for 17 nurseries with complete data for all years.

Preliminary and final reports for 1986 were generated for 23 nurseries. Individual nursery and master fieldbooks for 1987 were also generated. Nursery entries for 1987 included 406 from IRRI and 604 from national programs. Seed increase fieldbooks for the 1987 dry and wet seasons were also printed for IRTP entries planted in 2,964 plots.

By the end of the year, the IRTP master entry file had 11,798 entries, 8,969 of which had been tested in nurseries.

EVALUATION OF BREEDING LINES

Plant Breeding Department

In 1987, the International Hybridization Block (IHB) was computerized. The addition of data on this nursery to the system permits automatic retrieval of information on the parentage of IRRI crosses made from IHB materials.

The system now provides frequently retrieved information through reports available from the Plant Breeding Department records room. These include:

- list of all entries ever tested in the hybridization block, replicated yield trials (RYT), observational yield trials (OYT), and elite lines;
- summary data on all entries tested in the hybridization block, RYT, and OYT; and
- summary data on all IRRI released varieties based on tests conducted in the hybridization block, RYT, and OYT.

Fieldbooks and data sheets for plant breeders and other GEU scientists were generated. Information on entries tested in the Plant Breeding Department was provided to IRRI staff and to other agricultural researchers. Data on the entries tested during the year were added to existing computer files; 3,231 new F_1 crosses were added to the history-of-IRRI-crosses file. Some 3,236 advanced generation lines were also tested in the yield trials.

INTERNATIONAL RICE GENETIC SURVEY

Communication and Publications Department

The International Rice Genetic Survey was established in 1978 to build a permanent databank on the genetic ancestry of rice varieties and on hybridizations made by national programs. IRRI now has on file 69,000 crosses made in national programs, plus genealogies of almost 1,000 post-IR8 varieties released by national programs, and 1,600 pre-IR8 varieties that farmers still grow or that rice breeders use as parents in crosses.

"Progenitor cards" are filled out on the parents of all cultivars, and on their parents, down to the ultimate land races. Scientists anywhere can request genealogies of varieties or breeding lines. IRRI can now trace the ancestry of most cultivars back to the land races.

The data are being computerized in a format compatible with the history-of-IRRI-crosses computer program (60,000 IR crosses). When the project is completed, we will have a worldwide computer program on the genealogy of rice varieties and crosses. The information might be made available on CD-ROM (compact disc—read-only memory).

Not only can the computer program be used as a tool to determine sources of genetic resistance, but it can also help measure the degree of genetic diversity in rice. The system could also be useful if rice researchers, like animal scientists, develop measurements of consanguinity.

To make the program effective, IRRI must not only obtain as many of the older breeding records as possible, but must continuously update the system with new crosses and varieties.

Table 2 summarizes current IRGS data. IRRI would appreciate duplicate lists of crosses made at national research centers, and genealogies of both old varieties and those new to the file.

Table 2. Genealogical and hybridization data (no.) gathered through the International Rice Genetic Survey, IRRI, 1987.

Varieties		
Pre-IR8 varieties	1,587	
Post-IR8 varieties	923	
Elite breeding lines	219	
Progenitors	2,013	
Subtotal		4,742
National crosses		
Argentina	118	
Australia	1,129	
Bangladesh	4,483	
Brazil	176	
Burma	1,318	
Dominican Republic	283	
India	11,775	
Indonesia	5,792	
International Institute of Tropical Agriculture	2,118	
Iran	288	
Japan	311	
Korea	23,143	
Nepal	817	
Pakistan	2,555	
Philippines	154	
Sri Lanka	1,617	
Thailand	11,196	
United States	2,409	
Subtotal		69,682
Total		74,424

COMPUTER SERVICES FOR DATA MANAGEMENT

Computer Services

Mainframe computer resources were used mainly for inventory, characterization, and information handling in the GEU program. Because of that, the demand for central computer facilities continued to grow throughout 1987. Central processing unit (CPU) utilization was 44%. The major growth area was in data storage and data processing (data management), particularly with the introduction of the GEU-SQL databases. The move toward DBMSs resulted in an increased need for disk space, which is now at a critically high utilization level of 96%.

A corresponding rise in CPU and main storage usage indicates that the additional data are also being manipulated on the system.

Genetic evaluation and utilization (GEU) program

Seed science and technology

International Rice Testing Program, International Rice Germplasm Center, and Plant Breeding, Entomology, and Cereal Chemistry Departments

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SEED DORMANCY

International Rice Testing Program

Lipids extracted from hulls of dormant seed of variety Nagina 22 inhibited the germination of weakly dormant or nondormant seed of IR8, IR64, China 1039, and Barkat. The amounts of four short-chain saturated fatty acids (SCSFAs)—hexanoic (C_6), heptanoic (C_7), octanoic (C_8), and nonanoic (C_9) acids—were found to be much higher in the seeds of N22 than in Barkat and IR8. There was a sharp decrease in the amount of these SCSFAs, falling below the levels detectable by gas liquid chromatography, after subjecting the seeds to dormancy breaking treatment at 50 °C for 5 d (Table 1). Nonanoic acid alone or in synergistic combinations with other SCSFAs imposes dormancy that can be overcome by heat treatment.

TOLERANCE FOR ACCELERATED AGING

International Rice Testing Program

Sixty-eight rice genotypes, when screened for tolerance for accelerated aging (43 °C, 100% relative humidity [RH] for 8 d) showed genotypic differences (Table 2). Moisture uptake during aging did not correlate with tolerance, whereas lipid content and percent leachates in seed subjected to 4 d of accelerated aging showed highly significant negative association with the germination following the aging treatment (Table 3). The germination rate under low temperature (15 °C) exhibited a significant but negative correlation ($r = -0.28$), whereas germination under moisture stress (−10 bars using PEG 8000) and amylose content did not correlate with aging tolerance. Preliminary studies suggest a relationship of the esterase isozyme patterns, at the Est-2 locus, with tolerance for accelerated aging (Fig. 1). Certain genotypes with a faster mobility band allele (Est-2^2) were less tolerant compared with the ones with a slower mobility band allele (Est-2^1). Further investigations on this relationship are in progress.

Table 2. Varieties with superior[a] and inferior[b] germination after accelerated aging (43 °C, 100% relative humidity, 8 d). IRRI, 1987.

Variety	Germination (%) after accelerated aging	
	Seed from field	Seed from the phytotron
Superior		
BKNLR75091-CNT-B3-RST-40-1-3	68	58
TNAU9039-14	78	63
IR25884-94-3-2	67	63
IR39379-90-2-2-2-2	77	68
Chianung sen yu 13	63	67
MTU5410-14	75	75
TNAU658	83	72
Inferior		
Laxmi	3	0
Chechon-chun-shun	3	0
Giza 159	5	2
IR54	10	7
IR9782-111-2-1-2	12	8
Mean of 68 genotypes	34.0	36.4
Range	3-83	0-75
SD	21.7	20.4

[a]Values exceeding the mean by more than 1 standard deviation. [b]Values less than the mean by more than 1 standard deviation.

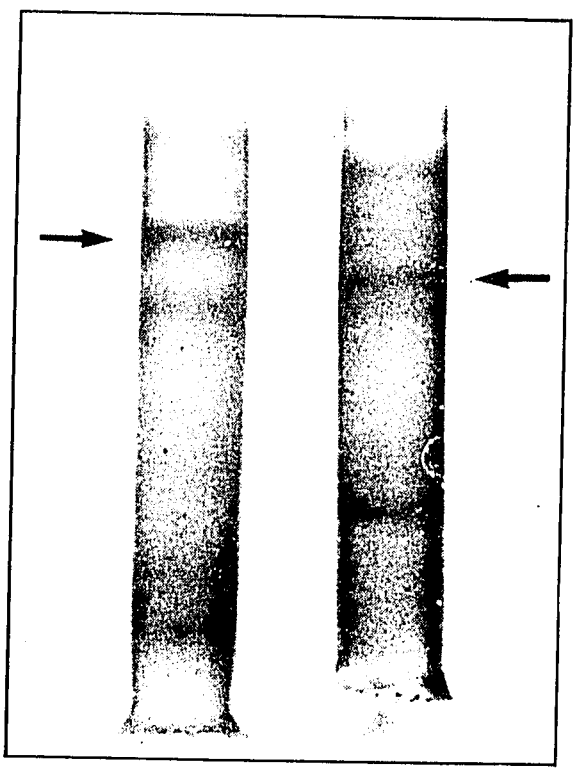
Table 1. Amounts of 4 short-chain saturated fatty acids (SCSFA) in hull and pericarp of 3 rice genotypes before and after heat treatment (50 °C for 5 d) for breaking seed dormancy. IRRI, 1987.

SCSFA	Treatment	SCSFA (μg/g of material)					
		N22		Barkat		IR8	
		Hull	Pericarp	Hull	Pericarp	Hull	Pericarp
Hexanoic (C_6)	Before[a]	567	6759	799	5713	872	4458
Heptanoic (C_7)	Before[a]	689	628	592	775	296	220
Octanoic (C_8)	Before[a]	2586	796	985	865	466	302
Nonanoic (C_9)	Before	16302	2527	1103	1017	445	419
	After	615	182	332	222	82	85

[a]Values after treatment are zero.

Table 3. Correlations (*r* values) between the traits associated with germination following accelerated aging treatment (43 °C, 100% relative humidity, 8 d). IRRI, 1987.

Trait	Leachates (%) in 4-d treated seeds	Lipid content	Germination (%) after 8-d of aging
Moisture content in 4-d treated seeds	0.21	0.48**	-0.36
Leachates (%) in 4-d treated seeds		0.78**	-0.87**
Lipid content			-0.83**



1. Isozyme patterns of esterase in rice genotypes with good and poor seed storability, IRRI, 1987. Left = Est 2^1 slower mobility band (good storer). Right = Est 2^2 faster mobility band (poor storer).

Two genotypes—IR39379-90-2-2-2-2 and IR9782-111-2-1-2—representing good and poor tolerance for accelerated aging were subjected to 4, 8, and 12 d of aging, and their cross sections were stained with tetrazolium trichloride. The sequence of embryo deterioration was the same in both genotypes, except that deterioration was delayed in the more tolerant one. The coleoptile was the first tissue to become senescent, followed by the epiblast, lateral and ventral scales, coleorhiza, plumule, radicle, mesocotyl, and scutellum. A close association was observed between the percentage of seed showing positive reaction to tetrazolium at the coleoptile and the germination percentage (Table 4).

GERMINATION RATE

International Rice Testing Program

Evaluation of 68 genotypes for germination rate revealed genotypic differences (Table 5). Germination rate associated negatively with 100-seed weight (r = -0.26*), root growth rate (r = -0.85**), and shoot growth rate (r = -0.93**), whereas it was associated positively with oxygen uptake (r = 0.50**), total dehydrogenase activity (r = 0.42**), and free amino acid content (r = 0.82**). Genotypic interactions were evident for germination rate under low temperatures (15 and 20 °C), moisture stress (-5 bars using PEG 8000), and post-aging germination. Presence or absence of hull did not influence the germination rate.

Path analysis indicated high direct and positive effects of free amino acid content, followed by total dehydrogenase activity, on germination rate. One hundred-seed weight and O_2 uptake influenced germination rate by their high indirect effects through free amino acid content (Table 6).

Genotypes with higher germination rate showed high α-amylase activity, which associated negatively with 100-seed weight (r = -0.60**), root growth rate (r = -0.65**), shoot growth rate (r = -0.63**), and seedling dry weight (r = -0.42*). A higher mobility band of α-amylase isozyme appeared on the third day of germination in genotypes with faster germination rates; their appearance was delayed up to the fourth or fifth day of germination in the slowly germinating genotypes (Fig. 2).

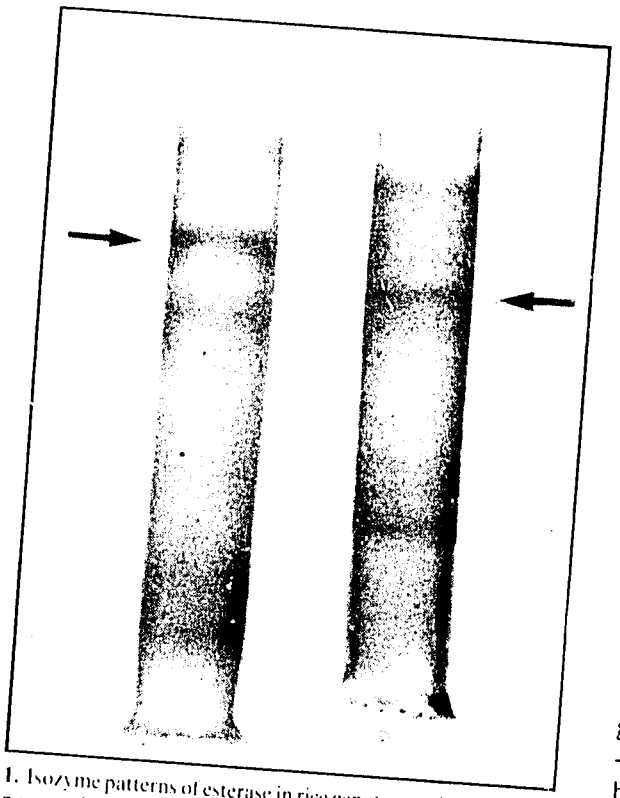
SEED TREATMENT

International Rice Testing Program

Seeds of 27 indica genotypes were fumigated with phosphine at 2 doses (3 and 6 g aluminum phosphide/m^3) for 3 d and evaluated for germination and vigor initially and after 3 mo of storage.

Table 3. Correlations (*r* values) between the traits associated with germination following accelerated aging treatment (43 °C, 100% relative humidity, 8 d). IRRI, 1987.

Trait	Leachates (%) in 4-d treated seeds	Lipid content	Germination (%) after 8-d of aging
Moisture content in 4-d treated seeds	0.21	0.48**	−0.36
Leachates (%) in 4-d treated seeds		0.73**	−0.87**
Lipid content			−0.83**



1. Isozyme patterns of esterase in rice genotypes with good and poor seed storability. IRRI, 1987. Left = Est 2[1] slower mobility band (good storer). Right = Est 2[2] faster mobility band (poor storer).

Two genotypes—IR39379-90-2-2-2-2 and IR9782-111-2-1-2—representing good and poor tolerance for accelerated aging were subjected to 4, 8, and 12 d of aging, and their cross sections were stained with tetrazolium trichloride. The sequence of embryo deterioration was the same in both genotypes, except that deterioration was delayed in the more tolerant one. The coleoptile was the first tissue to become senescent, followed by the epiblast, lateral and ventral scales, coleorhiza, plumule, radicle, mesocotyl, and scutellum. A close association was observed between the percentage of seed showing positive reaction to tetrazolium at the coleoptile and the germination percentage (Table 4).

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SEED TREATMENT

International Rice Testing Program

Seeds of 27 indica genotypes were fumigated with phosphine at 2 doses (3 and 6 g aluminum phosphide/m^3) for 3 d and evaluated for germination and vigor initially and after 3 mo of storage.

With the recommended dose of 3 g/m^3, fumigation did not affect germination or vigor. With 6 g/m^3, vigor decreased perceptibly after 3 mo of storage, as evidenced by increased electrical conductivity of the seed leachate and decreased total dehydrogenase activity (Table 7).

Seeds of four varieties were used to evaluate the effect of fumigation for different durations (3 and 6 d) and at different levels of seed moisture (11 and 15%). Six days of exposure showed deleterious effects. Seeds fumigated at 15% moisture content maintained higher levels of vigor and viability during 3 mo of storage than those at 11% moisture content (Table 8). This was probably because of the beneficial hydration-dehydration effects, as the seeds were hydrated to 15%, fumigated, and then dried back to their original moisture content before storage. Seed treatment with benomyl or mancozeb after fumigation did not show any interaction with the fumigation effects.

COMPARISON OF SEED CONTAINERS UNDER DIFFERENT STORAGE CONDITIONS

International Rice Germplasm Center

In the spring of 1979, an experiment evaluated the suitability of 3 containers under 6 storage conditions for rice seed dried to 6% and 12% moisture content. Significant changes in seed viability detected during 1987 are described below.

- In a subexperiment, where seed was stored in polyethylene bottles in a household refrigerator (5-6 °C, seed initially dried to 6% moisture content retained 95% germinability after 102 mo of storage, whereas in seed of 12%

Table 7. Rice seed germination and vigor initially and 3 mo after storage as influenced by fumigation with phosphine (3 d, 11% seed moisture) at 2 dosage levels (3 and 6 g/m^3).[a] IRRI, 1987.

Phosphine dosage (g/m^3)	Germination (%)	Shoot length (mm)	Root length (mm)	Dry weight (mg) of 10 normal seedlings	Electrical conductivity (dS/m per 25 seeds in 25 ml water)	Total dehydrogenase activity (O.D.)[b]
			Initial			
0	97 a	108.7 a	238.0 a	0.100 a	44.2 c	0.084 a
3	98 a	108.2 a	238.2 a	0.101 a	44.3 c	0.085 a
6	96 a	108.7 a	237.6 a	0.100 a	47.8 b	0.080 b
			3 mo after			
0	93 b	107.0 b	235.0 b	0.095 b	48.0 b	0.075 c
3	92 bc	107.0 b	234.9 b	0.094 b	48.6 b	0.072 c
6	90 c	105.4 c	230.7 c	0.091 c	54.0 a	0.064 d

[a]Mean of 27 varieties. [b]Optical density.

Table 8. Rice seed germination and vigor initially and 3 mo after storage as influenced by fumigation with phosphine (3 g/m^3, 3 d) at 2 levels of seed moisture.[a] IRRI, 1987.

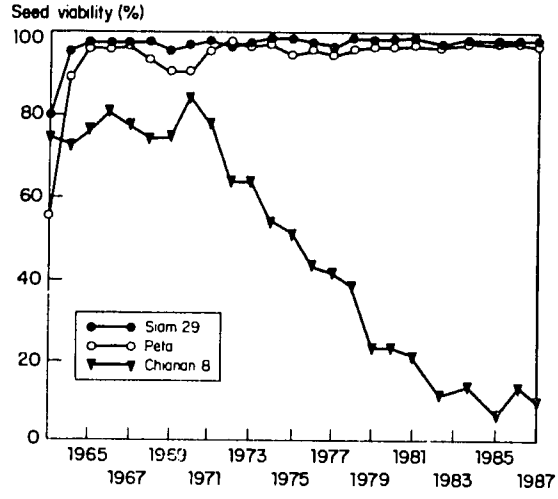
Seed moisture content (%)	Germination (%)	Shoot length (mm)	Root length (mm)	Dry weight (mg)	Electrical conductivity (dS/m per 25 seeds in 25 ml water)	Total dehydrogenase activity (O.D.)[b]
			Initial			
11	95 a	115.0 a	229.2 a	0.104 a	47.6 b	0.080 a
15	95 a	116.1 a	231.5 a	0.103 a	47.3 b	0.080 a
			3 mo after			
11	90 a	114.7 a	221.8 b	0.099 a	52.4 a	0.073 a
15	95 a	115.8 a	230.7 a	0.102 a	48.0 b	0.076 a

[a]Mean of 4 varieties. [b]Optical density.

moisture content it dropped to 42%. In the latter case, the seed moisture content equilibrated at 8.3%, while in the 6% lot the moisture content increased to 8%, indicating that the bottles were not airtight.

- Seed of 6% moisture content stored in plastic jars in a laboratory freezer at -20 °C maintained 98% viability after 96 mo of storage. The viability of seed packaged in porous paper bags declined to 8% at 96 mo.
- No significant change in germinability was found after 96 mo for seed stored under the following conditions: 1) seed at 6% initial moisture content kept in paper bags and plastic bottles in the refrigerator, in the medium-term (2 °C, 40% RH) storeroom, and in the long-term (-10 °C, 37% RH) storeroom; 2) seed of 6% moisture content kept inside plastic bottles in the laboratory freezer; 3) seed of 12% initial moisture content kept in plastic bottles and aluminum foil envelopes inside a laboratory freezer; and 4) seed of 12% initial moisture content kept in all 3 packaging materials under medium-term and long-term conditions.

In another long-term storage experiment set up in April 1963, seed at 8.5% moisture content was stored together with ample amounts of a dehydrating agent (silica gel) in an airtight glass jar and in a 2 °C storeroom. This practice was used in the International Rice Germplasm Center's medium-term storage system until its gradual conversion to vacuum canning in aluminum cans since mid-1981. Two tropical varieties having grain dormancy (Peta and Siam 29) have kept their viability above the 90% level (Fig. 3), whereas a nondormant variety from Taiwan (Chianan 8) has dropped to about 10%. The seed longevity data show the effectiveness of the earlier storage method in one of the longest continually monitored seed storage experiments on record.



3. Seed viability pattern of 3 rice varieties stored in the medium-term room (2 °C, 50% relative humidity, 8.5% moisture content). IRRI, 1963-87.

EFFECT OF SEED QUALITY ON THE PERFORMANCE OF AN F_1 RICE HYBRID

Plant Breeding Department

Hybrid seed produced in bulk using natural outcrossing on male sterile lines was found to fall into various categories, viz., filled, half-filled, lightweight, and unfilled. The filled seeds were either clean or discolored. The latter were sorted out by an electronic color sorting machine (Model GB 104). During the 1987 dry season, we studied the effect of three categories of seed (clean and filled, filled but discolored, and half-filled) of the experimental rice hybrid IR54752A/IR54R on its field performance. The 3 treatments were replicated 6 times in a field trial (gross plot 55 m^2 and net plot 40 m^2). We monitored germination percentage before seeding; seedling dry weight, height, and leaf

Table 9. Effect of seed quality on the agronomic performance of the F_1 rice hybrid IR54752A/IR54R. IRRI, 1987.

Trait[a]	Mean value			LSD (0.05)
	Clean and filled	Discolored but filled	Half-filled	
Germination (%)	98	95	83	–
Seedling height (cm)	31	28	27	ns
Seedling leaf no.	3.1	3.3	3.5	ns
Seedling dry weight (g)	0.09	0.08	0.09	ns
Plant height at 28 DT (cm)	43	43	42	ns
Tiller number at 28 DT	19	18	18	ns
Plant height at maturity (cm)	111	109	112	ns
Panicle number per hill	14	11	12	1.5
Panicle length (cm)	26	26	27	ns
Spikelet fertility (%)	76	72	72	ns
Grain yield (t/ha)	6.9	6.4	6.4	0.3

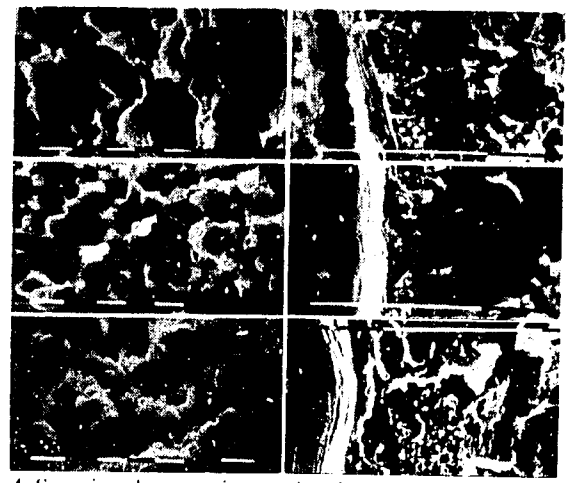
[a]DT = days after transplanting.

number 1 d before transplanting; plant height and tiller count on the 28th day after transplanting; and panicle number per hill; filled grain percentage; and grain yield at maturity. Results (Table 9) indicated that half-filled seeds reduced germination percentage, and half-filled and discolored seeds reduced panicle number per hill and grain yield. Seed quality had no effect on the other traits monitored in the experiment. Seed quality of the hybrid is thus important for realizing its potential yield advantage, and attention must be paid to postharvest seed handling in hybrid rice seed production programs.

VARIETAL RESISTANCE TO STORAGE PESTS

Entomology Department

We evaluated 22 rice varieties obtained from the International Rice Testing Program for resistance to 2 primary and major storage pests—the lesser grain borer *Rhizopertha dominica* and the rice weevil *Sitophilus oryzae*. China 1039 and Eiko were resistant; Azucena and IRAT144 were susceptible; and IR50, TN1, and others were intermediate. The compactness of the starch granules in the endosperm and the thickness of the aleurone layer (Fig. 4) apparently contributed to resistance by incapacitating the reproduction and development of insects in the grains.

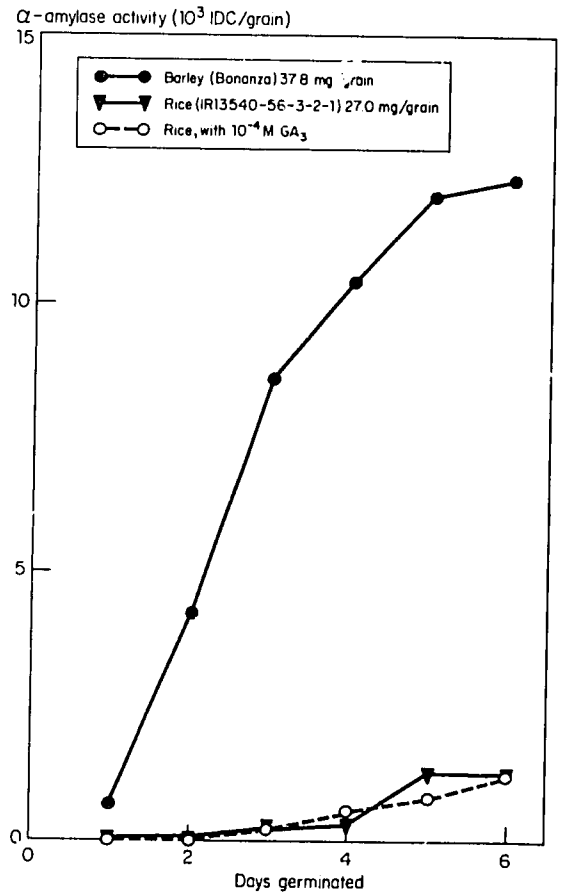


4. Scanning electron micrographs of starch granules and the aleurone layer in resistant Eiko and China 1039 (top left, top right), intermediate IR50 and TN1 (middle left, middle right), and susceptible Azucena (bottom left, bottom right) rice varieties, IRRI, 1987. Note compact starch grains and thick aleurone layer in the resistant varieties.

α-AMYLASES IN GERMINATING RICE AND BARLEY

Cereal Chemistry Department

In a cooperative study with scientists at the Grain Research Laboratory, Canadian Grain Commission, Winnipeg, α-amylase production during germination on moist sand at 25 °C was compared for rice (IR13540-56-3-2-1) and a 6-rowed high-enzyme and high-quality Canadian malting barley (Bonanza). Germinated rice grain had only about 10% of the α-amylase activity of germinated barley grain, or 14% on a weight basis (Fig. 5). GA_3 (10^{-4}M) did not significantly enhance α-amylase production in germinating rice. Isoelectric focusing and chromatofocusing showed that barley α-amylases had isoelectric points between pH 5.4 and 6.5 (α-amylase 2 and 3), whereas rice α-amylases had lower isoelectric points, and 2 major bands had isoelectric points close to pH 4.5 (α-amylase 1).



5. Production of α-amylase by germinating barley and rice grains and by rice grains treated with GA_3, IRRI, 1987.

Genetic evaluation and utilization (GEU) program

Integrated GEU program

Plant Breeding, Agronomy, Plant Physiology, Entomology, Plant Pathology, Statistics and Soils Departments, and International Rice Germplasm Center

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We made 3,231 crosses in 1987, grew F_2 populations from 1987 crosses, evaluated 122,380 pedigree nursery rows, tested 996 breeding lines in replicated yield trials (RYTs), and sent 75,820 seed packets of IRRI breeding lines abroad—23,837 seed packets filled 392 seed requests and 51,983 packets went through International Rice Testing Program (IRTP) nurseries.

IRRIGATED RICE

Plant Breeding, Plant Pathology, Entomology, Soils, Statistics, and Agronomy Departments

Of the 648 crosses made for irrigated rice in 1987, 399 were single crosses and 249 were multiple crosses. F_2 populations from 382 cross combinations were grown, and 68,195 pedigree nursery rows were evaluated. We also evaluated 800 advanced generation entries in RYTs.

In lowland rice performance trials of the Rice Varietal Improvement Group of the Philippine Seed Board at 12 sites, 34 elite breeding lines were evaluated. About 200 elite breeding lines were evaluated internationally in IRTP nurseries. National rice improvement programs evaluated many other promising lines.

IRRI lines named varieties (*Plant Breeding, Plant Pathology, Entomology, and Agronomy*). In 1987, 23 IRRI lines from the irrigated breeding program were named varieties in 9 countries, bringing to 178 the number of IRRI breeding lines named as varieties worldwide.

- IR1626-203 was released as Giza 181 in Egypt. Outyields most varieties and lines in Egypt. Excellent grain quality with intermediate amylose content (AC) and high milling recovery.
- IR1820-210-2 was recommended as IR1820 in Vietnam. Highly resistant to blast (Bl) and yellow stem borer. Released earlier as Tamale 1 in Ghana.
- IR1846-284-1 was released as V L Dhan for irrigated transplanted production in the lower hills of Uttar Pradesh, India. Excellent long slender grains.
- IR2151-196-3-1-3 was released as IR2151, and IR2153-26-3-5-6 was recommended as IR2153, both for acid sulfate soils of Vietnam. Both highly tolerant of salinity and toxicity.
- IR7151-60-3-3 was released as Chaite 1 and IR9729-67-3 as Chaite 3 in Nepal. Early-maturing selections fit the late sowing conditions in the Terai region.
- IR8192-200-3-3-1 was recommended as Lemayan for irrigated and rainfed lowland conditions in Sabah, Malaysia. High-yielding and tolerant of Fe toxicity.
- IR9129-102-2 was recommended as Guojiyouzhan in Guangdong Province, China. Early-maturing and high-yielding. Excellent grain quality with intermediate AC.
- IR9965-48-2 was released as Waiyin 35 in Guangdong Province, China. Early-maturing, with high yield potential and multiple resistance to diseases and insects.
- IR13240-10-1 was recommended as NN9A in Vietnam. Resists all brown planthopper (BPH) biotypes.
- IR15853-89-7 was released as N90 in Guangxi Province, China. High yield potential and good grain quality.
- IR18348-36-3-3 was released as IR64 in Indonesia and Vietnam. (Named IR64 by the Philippine Seed Board in 1985.) Superior grain quality conditioned by intermediate AC and intermediate gelatinization temperature (GT). Excellent lodging resistance and high yield potential.
- IR19661-150-2-2-1 was recommended as HKR120 in Haryana State, India. High-yielding. Long, slender, translucent grains. Resists local races of bacterial blight (BB) and tolerates whitebacked planthopper.
- IR19743-46-2-3-3-2 was released as Jangkok in Indonesia. Early-maturing with excellent grain quality. Recommended for Lombok Island's short rainy season.
- IR19746-11-3-3 was recommended as CN2 in Vietnam. Very early-maturing. Fits the Red River Delta's high cropping intensity.
- IR21015-80-3-3-1-2 was released as N304 in Guangxi Province, China. Very high yield potential, short growth duration, and multiple resistance to diseases and insects.
- IR21015-196-3-1-3 was recommended as IR65

in Indonesia. (Released as IR65 in the Philippines in 1985.) Glutinous grains.

- IR21820-154-3-2-2-3 was released as ADT38 in Tamil Nadu State, India. Very high-yielding. Resists local races of tungro (RTV), BB, and BPH. Excellent grain quality.
- IR21848-65-3-2 was recommended as Sin Ekari-4 in Burma. High-yielding. Extra-long, translucent grains with intermediate AC.
- IR21929-12-3-3 was released as Minkang 108 in Fujian Province, China. Early-maturing. Resists stem borer. High yield potential.
- IR28128-45-3-3-2 was recommended as Dodokan in Indonesia. Very short growth duration fits Lombok Island's short rainy season. Excellent grain quality with intermediate AC and intermediate GT.
- IR32307-107-3-2-2 was released as IR66 by the Philippine Seed Board. High-yielding. Matures in 110 d. Resists major diseases and insects. Has *bph-4* gene for resistance to BPH and high level of resistance to RTV.

Elite breeding lines (*Plant Breeding, Plant Pathology, Entomology, and Agronomy*). Elite breeding lines were evaluated in RYTs during the dry (DS) and wet (WS) seasons. They were also evaluated for grain quality, disease and insect resistance, and tolerance for soil problems such as salinity and alkalinity. Eighteen most advanced lines were yield tested in N response trials at Bureau of Plant Industry stations in the Philippines. Nine elite lines are described:

- IR28224-3-2-3-2. High yield potential. Matures in 130 d. Long, slender, translucent grains with high milling recovery. High AC and low GT. Tolerant of RTV. Resistant to Bl, BB, BPH biotypes, and green leafhopper (GLH). Performed well in Philippine Seed Board lowland rice trials.
- IR28228-12-3-1-1-2. Performed very well in Philippine Seed Board lowland rice trials. Matures in 130 d. Medium-long translucent grains with high AC and intermediate GT. Resists Bl and tolerates RTV. Resists GLH and BPH biotypes.
- IR32453-20-3-2-2. Medium-maturing. Outyielded most selections in multilocation yield trials. High field tolerance for RTV and resistance to Bl and grassy stunt. Resists GLH and BPH biotypes. Long, slender grains with high AC and low GT.
- IR34686-179-1-2-1. Very high-yielding. Matures in 135 d. Long, slender grains with intermediate AC and low GT. Resists Bl and BB, and tolerates RTV. Resists GLH and BPH biotypes.
- IR31802-48-2-2-2. Matures in 105 d. Excellent yield potential. Long, slender, translucent grains with intermediate AC and intermediate GT. Resists Bl and BB and has field tolerance for RTV. Resists GLH and BPH biotypes 1 and 2.
- IR32429-47-3-2-2. Matures in 107 d. Consistently yields well. Excellent grain quality conditioned by intermediate AC and intermediate GT. Resists Bl and BB and has field tolerance for RTV. Resists GLH and BPH biotypes.
- IR35366-90-3-2-1-2. Matures in 110 d. Outyielded other early-maturing selections in RYTs. Highly resistant to RTV in the field. Resists BB, Bl, GLH, and BPH biotypes. Long, slender grains with high AC and intermediate GT.
- IR42000-211-1-2-2-3. Matures in 105 d. Excellent yield potential. Excellent grain quality conditioned by intermediate AC and intermediate GT. Excellent field tolerance for RTV and resistant to Bl, BB, GLH, and BPH biotypes 1 and 2.
- IR41996-50-2-1-3. Matures in 100 d. Consistently yields well. High field tolerance for RTV and resistance to Bl, BB, GLH, and BPH biotypes. Excellent, long, slender grains with intermediate AC and intermediate GT.

Interactions of physical, nutritional, and biological stresses in irrigated transplanted wet season rice (*Soils, Agronomy, Entomology, Plant Pathology, and Statistics*). When rice simultaneously suffers more than one growth-limiting stress, the stresses may interact. The rice would then suffer growth and yield decreases larger than the sum of the decreases caused by the individual stresses acting alone. Management that alleviates one particular stress might therefore give an added benefit of also lessening the decrease in growth

caused by the associated interactions. To test this hypothesis for transplanted rice under realistic field conditions, a multidisciplinary team of agronomists, entomologists, plant pathologists, statisticians, and soil scientists, initiated multifactor interaction experiments both to determine the magnitude of such interactions and to make supporting measurements to understand their mechanisms.

Five stresses were imposed — water, nutritional (Zn), insect (stem borer [SB]), pathogen, and weeds — each at two levels: no stress as far as practicable, and a realistic field stress. All 32 combinations of stresses were tested, each with 5 replications. Water stress was imposed through a scheduled withholding of irrigation; nonstressed plots were fully irrigated. SB damage was simulated by artificial defoliation of 30% of the tillers. Zn stress occurs naturally at the test site, and was relieved for nonstressed plants by dipping seedlings in ZnO. Weed and pathogen stresses were generated by natural infestations and infections; nonstressed plants were hand weeded or treated with fungicides.

In a first trial, using IR62, nonstressed plants yielded 5.9 t/ha. Water stress and simulated SBs each lessened yield by 55% (more than was intended); Zn and weed stresses lowered yield by 5% (expectedly low for this first use of a field that had been nonsubmerged during several preceding months; effects should be larger in the second and subsequent trials); and pathogens lessened yield by 14%. The combination of all stresses decreased yield by 84%. The effects of water stress, simulated SBs, and pathogens were each large enough to detect interactions. Thus

- The proportional effect of irrigation was to increase the yield of detillered (SB simulation) plants by 109 ± 10%, and of normal plants by 133 ± 10%, a differential effect of 24 ± 14%, suggesting that if SBs are controlled, plants make more effective use of irrigation.
- The proportional effect of not detillering (i.e., simulation of SB control) was to increase the yield of water-stressed plants by 91 ± 10%, and that of irrigated plants by 112 ± 8%, a differential effect of 21 ± 13%, suggesting that if plants are adequately irrigated, they derive greater benefit from SB control.
- The proportional effect of pathogen control was to increase the yield of nondetillered plants (simulation of SB control) by 13 ± 5%, and of detillered plants by 23 ± 10%, a nonsignificant difference of 10 ± 12%.
- The proportional effect of pathogen control was to increase the yield of irrigated plants by 9 ± 5% and of water-stressed plants by 24 ± 8%, a differential effect of 15 ± 9%, suggesting that water-stressed plants derive proportionately more benefit from pathogen control.

COLD-TOLERANT RICE

Plant Breeding Department

We restructured the cold tolerance breeding program in 1987. In previous years, segregating populations were evaluated in Banaue, Philippines (about 1000 m elevation), where rice is cultivated only during DS (January to June). In DS evaluations, we could select for seedling tolerance but not for reproductive phase tolerance because temperatures are not low enough to be adverse to rice. Although rice is not cultivated in Banaue in WS (July to November) because of adverse climate, we were compelled to evaluate in WS and evidently discarded valuable genotypes.

We will continue DS evaluations to select materials for seedling tolerance and develop improved cold-tolerant varieties for the Philippines, but will not evaluate breeding materials in WS. Instead, we will use varietal screening in Tublay, Benguet Province (about 1100 m elevation), where climate, except low temperature, is not as severe as in Banaue. We will advance generations during WS. As before, pest and disease evaluation will be done at IRRI.

In Banaue or Tublay, tolerance during the reproductive phase can be detected if flowering begins in mid-December. To verify this, we composed a nursery of three varietal types: sensitive, moderately tolerant, and highly tolerant of low temperature. Indica and japonica varieties were seeded in late September 1986 in Banaue and transplanted in late october. Flowering ranged from late December to mid-February, with minimum temperature around 14 °C. Reproductive phase tolerance was easily determined by leaf

color, panicle exsertion, and grain sterility, showing clear differences among the three types of varieties. Considering this success, we will continue to use September seeding to evaluate segregating populations and advanced lines for tolerance during the reproductive phase.

In Banaue and Tublay in 1987 DS, we evaluated 42 F_2, 30 F_3, 34 F_4, and 24 F_5 hybrids, all from earlier breeding work. Of these, 19 F_3s were specifically for the Philippines to improve popular bulu varieties.

Popular Philippine varieties Pinidua and Madduli are bulu types. From 600 bulus in the International Rice Germplasm Center (IRGC) collection, the Plant Breeding Department selected 24 for hybridization. These and some common Philippine varieties were evaluated in an unreplicated yield trial in DS in Banaue and Tublay. All entries showed acceptable seedling tolerance. Although all introductions were superior to local types in vigor during the vegetative phase, only local types had the growth duration to fit climatic needs. Introductions flowered about 5 wk later than locals, extending into WS. Later, damage from rain and wind prevented harvest of the introductions. Local types matured successfully. Evidently, farmers in these areas have grown a range of bulus and over time have selected the best adapted ones.

In WS, 19 F_4 bulks from DS and 7 new F_2s involving bulus were evaluated in Tublay for Philippine use. Selections emphasized bulu characteristics with modern plant type.

To explore growing rice in Banaue during WS, short-duration varieties with some cold tolerance were tested in a RYT. Variety Barkat was the check. All entries performed well until flowering, but only Barkat was free of grain discoloration, which appeared during the soft dough stage. Advanced lines IR8866-30-3-1-4-2, IR29824-B-84-1-1, IR32843-92-2-2-3, and IR40085-6-1-2 discolored less than others. Although a typhoon destroyed the experiment, we concluded that indica varieties with Barkat's characters would permit rice cultivation in Banaue during WS.

We used September seeding to select for reproductive phase tolerance. Materials included 49 F_2 populations and 32 F_3, 4 F_4, 26 F_5, and 21 F_6 bulks.

We made 167 single crosses and 82 multiple crosses in 1987, 60% requested by collaborating breeders from Bhutan, India, Korea, Madagascar, and Nepal.

We began an indica/japonica hybridization program to transfer salt tolerance from indicas to japonicas and to combine agronomic traits. We selected three varieties having the wide compatibility gene: BPI 76 (indica), N22 (aus), and Moroberekan (japonica). In the first phase, these were crossed with several salt-tolerant indicas, and with high-yielding, pest- and disease-resistant indicas and japonicas. We made 88 single crosses.

We provided breeding materials ranging from F_2s to advanced lines to India, Madagascar, Nepal, Philippines, and the West Africa Rice Development Association (WARDA). We began a shuttle breeding program with Bhutan, primarily for cold tolerance. See details in the Cooperative Country Projects section under Country Reports.

RAINFED LOWLAND RICE

Plant Breeding, Agronomy, Plant Physiology, and Multiple Cropping Departments

The rainfed lowland rice improvement program formulates breeding objectives for rainfed ecologies, develops improved germplasm for unfavorable environments, uses alternative breeding methods, and collaborates with national research programs. Improved rainfed lowland rices should resist drought, flooding, diseases, and insects, and should yield higher than traditional rices under low-cost technologies. They must maintain the yield stability of traditional rices.

Breeding operations (*Plant Breeding*). Breeding nurseries for drought-prone conditions in 1987 consisted of 127 F_2 populations and 14,551 pedigree rows. For medium deep conditions, 217 F_2 populations and 16,171 pedigree rows were grown. The observational yield trial was composed of 1,879 entries from IRRI and various countries, including 420 for drought-prone and 282 for medium deepwater areas. The RYT evaluated 100 entries under irrigation, 46 in drought-prone areas, and 50 in medium deep conditions.

More than 5,000 seed samples were distributed to breeders in Bangladesh, Brunei, Burma, Colom-

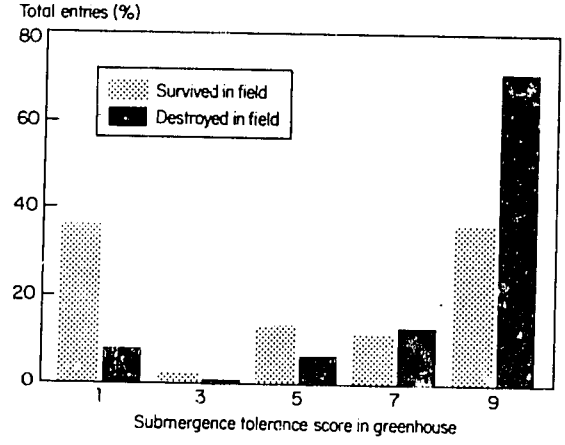
bia, Ecuador, Fiji, India, Indonesia, Kampuchea, Laos, Malaysia, Nepal, Nigeria, Sierra Leone, Thailand, and Vietnam. The samples included advanced breeding lines, donors for various traits, and F_2 populations.

Drought resistance (*Plant Breeding and Agronomy*). Selection for drought resistance is done at all breeding stages. Early generations are grown under water stress, and best survivors are selected. Later generations are screened in drought nurseries during DS. Advanced lines are evaluated either transplanted or direct seeded in a range of drought-prone environments.

Drought-prone areas require rice cultivars with a range of growth durations, and with drought resistance at different growth stages. Selection for resistance during the vegetative phase is easier than during the reproductive phase, although the latter is more sensitive to drought. In 1987, seven rainfed lowland breeding lines that showed good drought recovery and good phenotypes under field conditions were identified (Table 1). Of all rainfed lowland lines screened in the drought nursery in 1987, 4% had a tolerance score of 4 or better, and 5% had a recovery score of 1.

Flood tolerance (*Plant Breeding and Plant Physiology*). Excess water can hurt rice growth by short-term (flash floods) or long-term (stagnant) flooding. The two often go together. Several hundred breeding lines with improved plant type were evaluated in different flooding regimes. All lines were also tested in greenhouse tanks for submergence tolerance at the seedling stage. The breeding lines performing best under mild submergence stress in the field were often not the best under more severe stress. In a field completely submerged for 12 d, 85% of the entries tested were killed. Those with scores of 1 (same as the tolerant check FR13A) in the greenhouse tanks survived better in the field (Fig. 1). Six lines with submergence tolerance and good agronomic characteristics were identified (Table 2). All have traditional submergence-tolerant cultivars in their pedigrees.

Photoperiod sensitivity (*Plant Breeding*). In many rainfed areas, the onset of the rainy season determines seeding and transplanting dates. The harvest date depends on the time when rainfall decreases and the floodwater recedes, the onset of



1. Entries with different submergence tolerance scores (greenhouse) that showed some survival or were completely destroyed under severe flooding of the medium deep observational yield trial, IRRI, 1987. Submergence scores are percentage of comparative survival relative to the tolerant check FR13A: 1 = 100%, 3 = 95-99%, 5 = 75-94%, 7 = 50-74%, 9 = 0-49%.

Table 1. Characteristics of rainfed lowland breeding lines with good drought resistance. IRRI, 1987.

Designation	Maturity (d)	Height (cm)	Resistance to blast[a]	Amylose (%)	Grain[b]			Drought[c]	
					L	S	C	Tolerance	Recovery
IR33355-39-1-1-3	120	100	9	27	3	1	0	4	1
IR41431-68-1-2-3	125	110	6	23	3	1	0	4	3
IR42221-14-1-3-1-2	135	125	9	25	3	1	3	3	1
IR43040-25-1-2-3	125	100	9	23	3	1	1	5	1
IR43072-PMI-B-24-3	140	110	9	25	3	1	0	5	1
IR43088-89-2-3-1	120	100	3	26	1	1	5	5	1
IR43552-80-3-1-3	140	130	8	26	5	5	0	5	1

[a]By *Standard evaluation system for rice* (SES) 0-9 scale: 0 = no lesions, 9 = all leaves dead. [b]L = length, S = shape, C = chalkiness, SES scale. [c]Drought tolerance at 10 bars soil moisture tension and recovery after rewatering. Average scores of the resistant checks (Salumpikit and IR442) were 6 for tolerance and 3 for recovery.

Table 2. Rainfed lowland breeding lines with submergence tolerance and good phenotypic acceptability. IRRI, 1987.

Designation	Ultimate source of tolerance	Maturity (d)	Height (cm)	Grain[a]			Submergence tolerance[b]
				L	S	C	
IR40931-26-3-3-5	FR13A	135	105	4	4	8	1
IR40931-33-1-3-2	FR13A	130	105	4	2	2	1
IR42207-93-22-2-1-2	FR13A	130	110	3	5	5	1
IR42243-80-3-2-1-3	Nam Sagui 19	130	95	3	1	1	1
IR43439-99-23-1-1	64-117	135	100	3	1	4	2
IR46292-24-2-2-1-2	64-117	130	90	3	5	9	1
IR42 (check)							9
IR46 (check)							8

[a]L = length, S = shape, C = chalkiness, SES scale. [b]Submergence tolerance scored in the greenhouse tanks at the seedling stage. Scores are in comparison with the tolerant check FR13A.

low temperature (in higher latitudes), and the seeding date of the DS crop, if any. Therefore, photoperiod sensitivity is an important breeding objective. Improved lines with strong sensitivity are being evaluated for use in rainfed lowland environments (Table 3).

The preferred flowering date varies from place to place. Within a region, it can depend on a field's position in the toposequence. Later varieties are sown on the low-lying fields, where the water recedes last. The critical daylength of a variety determines its usual flowering date; varieties with shorter critical daylength flower later. Many areas need weakly sensitive varieties with longer critical daylength; these usually flower in September or October. Other areas need late-flowering varieties with very short critical daylength; these often flower in December. Because most improved IRRI photoperiod sensitive lines flower in October, we are developing lines with later flowering dates. Photoperiod sensitivity is controlled by a few major genes, so we can easily combine it with other desired characteristics, but critical daylength appears to be affected by both major genes and modifier or minor genes.

Thai-IRRI collaborative breeding (*Plant Breeding*). The Thai-IRRI project to develop rainfed lowland rices for Northeast Thailand continued for the fifth year. Plant selections, including 294 from the pedigree nurseries and 1,322 from the F_2 populations, were taken to IRRI for off-season generation advance and screening. Several breeding lines performed well for 2 consecutive years in the observation trial planted at 6 research stations in Thailand (Table 4). F_2 populations have also been sent to other countries. See Country Reports under Cooperative Country Projects for additional information.

Drought-prone yield trials (*Agronomy, Multiple Cropping, and Plant Breeding*). Rainfed lowland

Table 3. Characteristics of photoperiod-sensitive, rainfed lowland breeding lines with improved plant type. IRRI, 1987.

Designation	Flowering period	Height (cm)	Amylose (%)	Grain[a]		
				L	S	C
IR43446-7-3-2-1	mid-Oct	105	27	3	1	1
IR43491-140-1-2-3	mid-Oct	110	25	5	5	9
IR43505-571-1-1-3	late-Oct	115	26	3	1	1
IR43522-37-3-3-3	mid-Oct	125	26	3	1	5
IR43526-523-1-1-1	early-Nov	140	26	3	5	9
IR43552-19-2-1-2	late-Oct	130	25	5	5	1
IR43552-80-3-1-3	mid-Oct	130	26	5	5	0
IR46376-CPA-8-3-1-1	mid-Oct	140	24	1	1	5
IR48069-24-3-3-2	late-Oct	120	24	3	1	5

[a]L = length, S = shape, C = chalkiness, SES scale.

Table 4. Characteristics of rainfed lowland breeding lines that performed well for 2 consecutive years in the observation nursery at 6 stations in Northeast Thailand, 1987.

Designation[a]	Photoperiod sensitivity[b]	Height (cm)	Resistance[c] to			Amylose (%)	Gelatinization temp[d]	Grain[e]		
			Bl	BB1	GLH			L	S	C
IR43049-CPA-509-2-3-1-3	S	135	5	1	3	0	L	1	1	–
IR43070-UBN-507-1-2-2-1	I	130	5	1	5	0	L	3	1	–
IR43506-UBN-520-2-1-1	S	105	3	5	6	0	L	1	1	–
IR43523-SRN-504-2-2-3-2	S	130	7	1	7	25	I	3	1	1
IR46375-CPA-19-3-1	I	130	7	1	7	27	I	3	3	3

[a]CPA = selections from the Chum Phae Rice Experiment Station, UBN = Ubon, SRN = Surin. [b]S = photoperiod sensitive, I = insensitive. [c]Bl = blast, BB1= bacterial blight race 1, GLH = green leafhopper. [d]Gelatinization temperature, L = low, I = intermediate. [e]L = length, S = shape, and C = chalkiness.

yield trials were conducted in Santa Rosa, Laguna; Liloan, Cebu; Solana, Cagayan; and Batac, Ilocos Norte, Philippines. Trials used 20 early and 30 medium- to late-maturing entries.

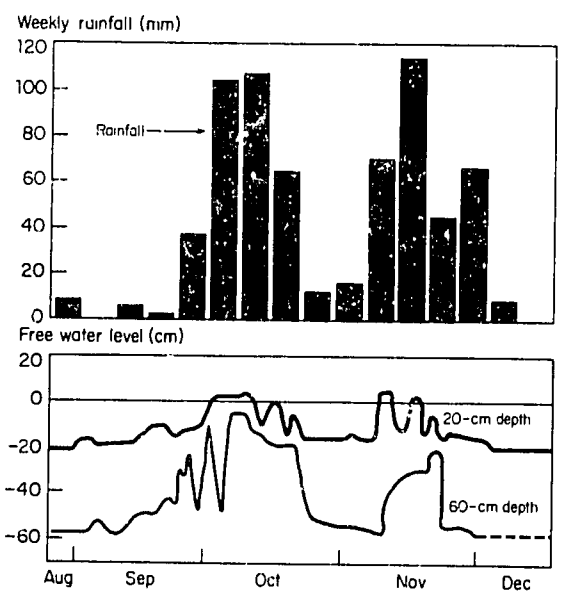
Santa Rosa, Laguna. Low rainfall from 25 Aug to 30 Sep in Santa Rosa caused severe water stress during vegetative growth (Fig. 2). The free water level (20-cm and 60-cm depths) remained below the soil surface for the crop duration.

Liloan, Cebu. Total rainfall in Liloan during crop growth was only 600 mm, barely enough to produce a crop (Fig. 3). Water deficit occurred during vegetative growth from mid-August to mid-September; soils cracked, and rice leaves rolled and dried. After mid-September, however, sparse rainfall was well distributed, resulting in yields up to 2.5 t/ha.

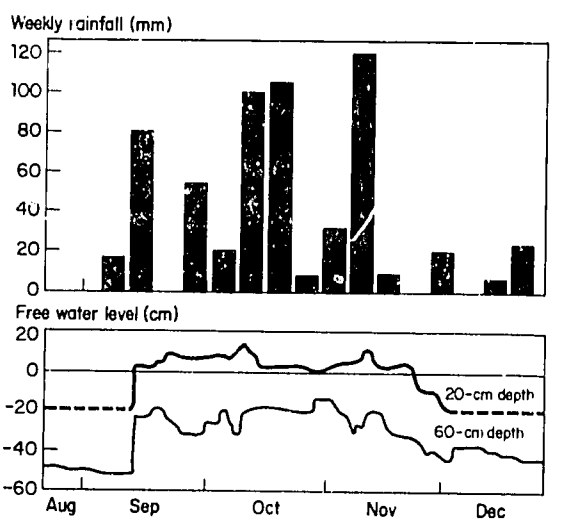
Solana, Cagayan. Only late entries were grown in Solana. Stratum 1 (Fig. 4) experienced mild water deficit from 12 Sep to 4 Oct and from 3 to 12 Dec. Stratum 2 experienced short-term submergence twice.

Batac, Ilocos Norte. The early set was planted on two strata in Batac in collaboration with Mariano Marcos State University. Rainfall and hydrology data were not collected.

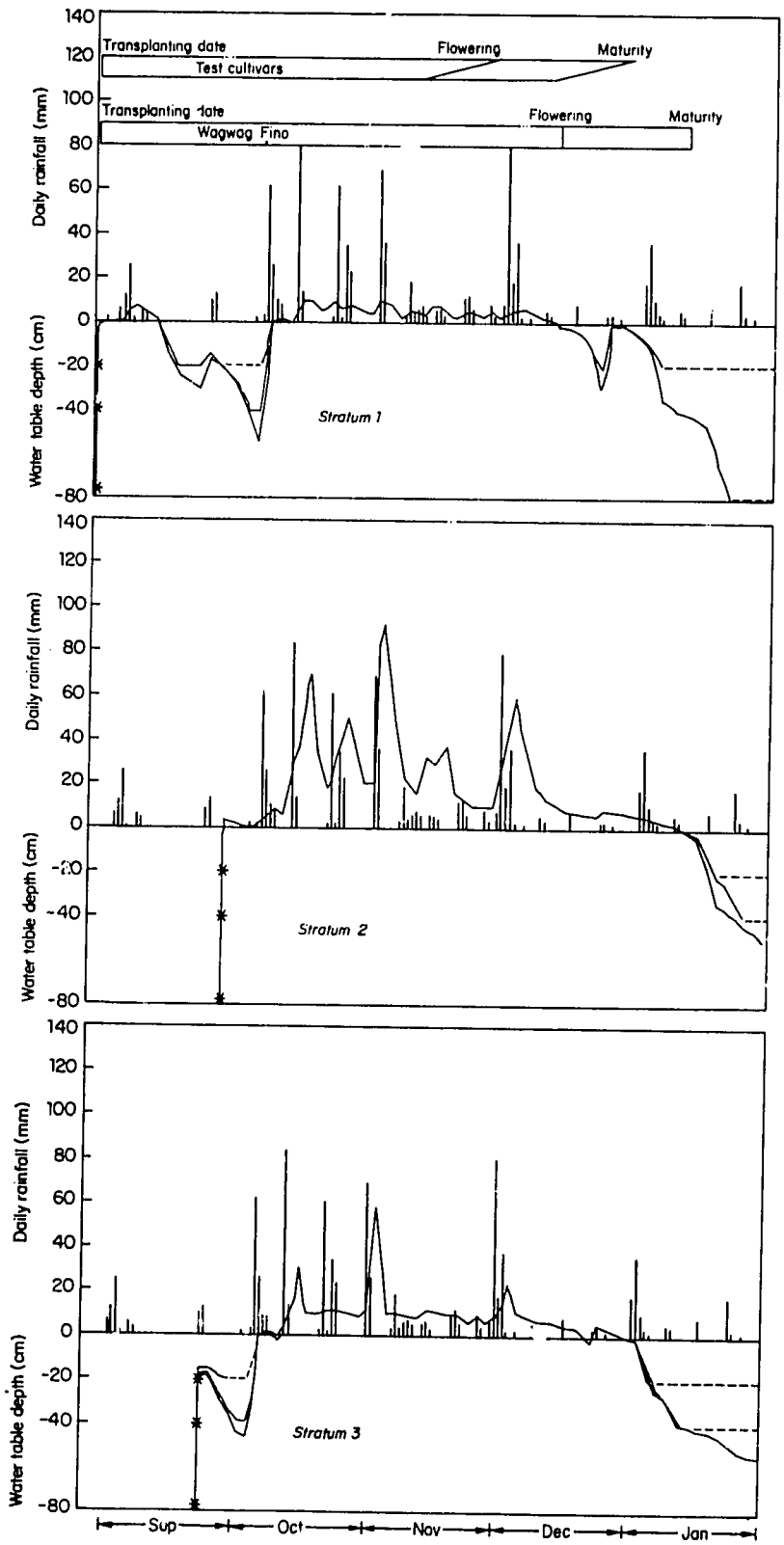
Two of the highest yielding entries in the early group (Table 5), IR21567-9-2-2-3-1-3 and IR13240-108-2-2-3, had been high yielding the previous year. In the late group, IR19431-72-2 had also performed well in previous years. IR28526-44-1-1, the highest yielding entry in Solana, was not planted in Santa Rosa.



2. Water level (piezometer at 20 and 60 cm) and rainfall in Santa Rosa, Laguna, Philippines, 1986 WS.



3. Water level (piezometer at 20 and 60 cm) and rainfall in Liloan, Cebu, Philippines, 1986 WS.



4. Daily rainfall and water table depth (20, 40, and 80 cm) for strata I, II, and III in Solana, Cagayan, Philippines, 1986 WS.

Table 5. Yields and ranks (in parentheses) of the highest yielding entries at 5 Philippine sites in the drought-prone rainfed lowland yield trials, 1986-87.

Designation	Yield (t/ha)					
	Santa Rosa	Liloan	Batac	Solana I	Solana II	Average
			Early			
IR21567-18-3	1.5 (4)	2.3 (2)	3.3 (2)			2.4
IR21567-9-2-2-3-1-3	0.9 (16)	2.5 (1)	3.4 (1)			2.3
IR11418-15-2	1.4 (7)	1.5 (8)	3.0 (3)			2.0
IR64	1.8 (3)	1.5 (8)	2.7 (7)			2.0
IR13240-108-2-2-3	1.9 (2)	1.5 (8)	2.5 (11)			2.0
Mean	1.3	1.5	2.5			
			Medium/late			
IR19319-5-3-3-2-1	2.0 (2)	2.1 (4)		2.9 (10)	2.6 (7)	2.5
IR19319-1-2-1-1-2	1.7 (4)	2.5 (1)		3.0 (7)	2.6 (7)	2.4
IR33380-60-1-2-2	2.1 (1)	2.0 (9)		2.8 (13)	2.3 (16)	2.3
IR37096-49-1-3	1.2 (14)	1.9 (15)		3.1 (3)	2.8 (3)	2.2
IR19431-72-2	1.6 (5)	2.1 (4)		2.5 (20)	2.7 (4)	2.2
IR29341-15-2-1-1	1.9 (3)	1.8 (16)		2.8 (13)	2.3 (16)	2.2
IR36974-13-3-3-3	1.6 (5)	1.2 (29)		3.2 (1)	2.9 (2)	2.2
Mean	1.2	1.9		2.7	2.4	

Farmers' field yield trials, Solana, Cagayan (*Multiple Cropping and Plant Breeding*). Cultivars and breeding lines were tested for yield in three unfavorable environments in Solana, Cagayan, in 1986-87. Conditions were drought-prone for stratum 1, drought- and submergence- prone for stratum 2, and submergence- prone for stratum 3 (Fig. 4). In a yield trial of 20 improved lines and 4 local checks grown on all strata, several promising breeding lines outyielded the local checks (Table 6). Yields were low in stratum 3, where flooding was severe. Breeding lines IR28930-5T, IR26724-246-1-1, and BR118-3-17 yielded particularly high at this site.

A drought- and submergence- prone yield trial was grown on strata 2 and 3. Several improved breeding lines with submergence tolerance gave higher yields than the checks in both strata (Table 7).

In rainfed lowland areas, farmers often rely on higher grain quality as a compensation for lower yields. Several lines with improved grain quality gave yields more than twice those of local checks in stratum 1 (Table 8). These lines are from crosses with the Thai aromatic rainfed lowland cultivar Khao Dawk Mali 105. IR43523-56-2-3-2 yielded highest of all Solana entries in 1986-87.

Medium deepwater yield trials (*Multiple Cropping and Plant Breeding*). The medium deepwater RYT, composed of 48 entries, was evaluated at the medium deepwater research site in Bay, Laguna. The materials were exposed to three flooding regimes (Fig. 5) varying in sustained water depth and in timing and severity of submergence. Rice was submerged four times during the vegetative phase in regimes A and B at phase 25-30 cm depth. The flooding subsided more rapidly during the reproductive phase in regime B. Depth in regime C was about 40 cm for most of the growing season.

The materials were replicated twice in each water regime within a randomized complete block design. Mean grain yields were highest (2.1 t/ha) in regime C, which had deeper water but no severe submergence (Table 9). Submergence levels greater than 90 cm killed several entries in regimes A and B.

The yield of IR19319-5-3-3-2-1 was particularly high and stable across water regimes (Table 9). Five entries yielded more than 3.0 t/ha across the regimes. The local check Wagwag Faire performed well as in previous tests at this site. Four advanced breeding lines that had performed consistently well in medium deepwater tests in previous years were among the better yielding cultivars in this test: IR24705-11-3-2-3-3, IR13149-43-2-P1, IR13149-71-3-2-3, and IR26760-27-1-3-2-1.

The medium deepwater observational trial consisted of 274 entries. These were evaluated as

Table 6. Grain yields and ranks (in parentheses) of the highest yielding entries and the checks in a yield trial grown on 3 strata in Solana, Cagayan, Philippines, 1986-87.

Designation	Grain yield (t/ha)			
	Stratum 1	Stratum 2	Stratum 3	Average
BR118-3B-17	2.8 (6)	2.6 (2)	1.5 (3)	2.3 (1)
IR28930-5T	2.0 (22)	2.7 (1)	1.9 (1)	2.2 (2)
IR33238-25-2-3-2	2.9 (3)	2.6 (2)	1.0 (6)	2.2 (2)
IR19319-5-3-3-2-1	2.8 (6)	2.6 (2)	1.1 (4)	2.2 (2)
IR26724-246-1-1	2.4 (15)	2.2 (12)	1.8 (2)	2.1 (5)
Wagwag Java (check)	2.0 (20)	1.8 (16)	1.1 (4)	1.6 (11)
Wagwag Saigon (check)	2.1 (17)	1.8 (16)	0.7 (11)	1.5 (16)
Wagwag Tawataw (check)	1.9 (23)	1.8 (16)	0.8 (8)	1.5 (16)
Wagwag Fino (check)	1.7 (24)	1.6 (22)	0.6 (12)	1.3 (19)
Mean	2.5	2.1	0.7	

Table 7. Days to flowering, plant heights, grain yields, and ranks of the highest yielding entries and checks in the drought- and submergence-prone yield trial, Solana, Cagayan, Philippines, 1986-87.

Designation	Stratum 2				Stratum 3				Average	
	Days to flowering	Plant height (cm)	Yield (t/ha)	Rank	Days to flowering	Plant height (cm)	Yield (t/ha)	Rank	Yield (t/ha)	Rank
IR43559-159-3-3-1	101	94	3.0	3	122	72	0.8	7	1.9	1
IR43559-39-2-6-3	101	94	2.6	7	122	72	1.2	3	1.9	1
IR43563-5-1-3-5	115	93	2.4	15	133	75	1.4	1	1.9	1
IR42243-34-1-2-3	108	98	2.5	10	123	72	1.2	3	1.9	1
IR31239-31-6-3-P5	120	109	2.9	4	133	76	0.7	10	1.8	5
IR29012-2-1-3	121	105	2.1	20	140	76	1.4	1	1.8	5
Wagwag Saigon (check)	136	140	2.0	21	133	78	0.8	8	1.4	12
Wagwag Tawataw (check)	138	150	1.6	23	136	69	0.7	10	1.1	13
Mean	113	103	2.5		126	74	0.8			

Table 8. Grain yields, and agronomic and grain quality characteristics of the highest-yielding, high quality rainfed lowland breeding lines in a yield trial in stratum 1 in Solana, Cagayan, Philippines, 1986-87.

Designation	Days to flowering	Plant height (cm)	Yield (t/ha)	Grain[a]			Amylose content (%)	Comments
				L	S	C		
IR43523-56-2-3-2	106	98	4.6	2	1	0	26	
IR43485-22-2-2-2	105	98	3.3	3	1	1	26	Slight aroma, photoperiod sensitive
IR43568-14-1-1-2	105	82	3.2	3	1	0	18	Strong aroma, photoperiod sensitive
IR43483-7-2-1-2	111	106	2.8	3	5	2	26	Strong aroma
IR43586-13-3-2-2	108	83	2.8	3	1	0	17	Strong aroma
Wagwag Fino (check)	136	140	1.9					
Wagwag Saigon (check)	136	138	1.7					
Wagwag Java (check)	141	131	1.6					
Wagwag Tawataw (check)	132	143	1.5					
Mean	115	108	2.5					

[a]Grain quality data were collected only for the breeding lines.

Table 9. Mean grain yields (t/ha) of the best entries from the medium deep replicated yield trial tested in 3 (A, B, C) medium deepwater conditions. Bay, Laguna, Philippines, 1986 WS.

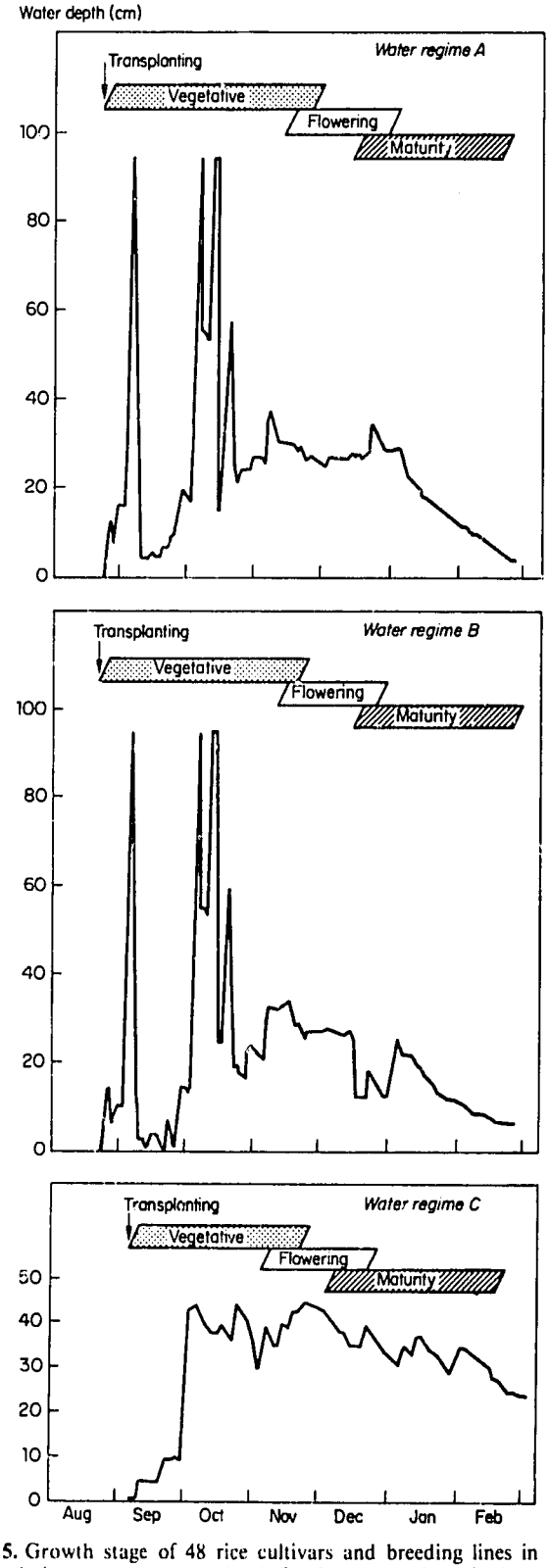
Designation	Grain yield (t/ha)				Rank
	A	B	C	Grand mean	
IR19319-5-3-3-2-1	4.6	3.1	4.6	4.1	1
IR24705-11-3-2-3-3	1.6	4.6	3.8	3.3	2
IR36974-13-3-3-3	3.4	2.9	3.4	3.2	3
IR33461-39-3	3.9	1.7	3.8	3.1	4
Wagwag Faire	2.5	3.6	3.1	3.0	5
B4259-39-2-3	3.4	1.6	3.6	2.8	6
IR33380-7-2-1-3	2.2	2.9	2.8	2.6	7
IR21567-9-2-2-2-1	2.1	2.8	2.6	2.5	8
IR37094-31-2-3-2	2.5	1.3	2.8	2.2	9
IR13149-43-2-P1	2.1	2.1	2.4	2.2	9
IR38380-31-1-1-3	2.0	2.4	2.2	2.2	9
IR13149-71-3-2-3	3.1	1.5	3.3	2.2	9
IR26760-27-1-3-2-1	2.6	1.2	2.6	2.1	13
IR43485-22-2-2-2	2.0	1.7	1.8	1.8	14
IR26760-76-2-1-2-3	2.5	0.5	2.4	1.8	14
Pankaj	2.1	1.2	1.9	1.7	16
IR19431-72-2	2.1	1.1	1.8	1.7	16
Checks					
CR1009	1.6	0.4	2.7	1.6	22
IR46	1.6	0.6	2.3	1.5	23
IR42	1.5	0.5	2.1	1.4	28
IR43	1.0	0.7	1.9	1.2	33
IR64	1.1	0.7	1.5	1.1	36
Grand mean[a]	1.9	1.3	2.1		
LSD (0.05)	1.6	1.4	0.4		

[a]Mean of all entries.

unreplicated plots in flooding regimes A and B (Fig. 5). Nine cultivars exceeded 5 t/ha in grain yield (Table 10) in at least 1 regime. Severe submergence seriously delayed flowering of many entries.

Elite cultivar evaluation on rainfed landforms (*Multiple Cropping*). Two sets of elite improved rainfed lowland cultivars were evaluated at a range of rainfed rice-growing locations in the Cagayan Valley, Philippines.

The first set, composed of medium-maturing, intermediate-height entries, had superior performance in the drought-prone areas RYT on strata 1 and 2 of the alluvial terrace of the Cagayan River in Solana. This group included a photoperiod-sensitive cultivar from Bangladesh (BR236-10-2-2-1). The set was planted under researcher management on landforms dominated by traditional late-maturing, photoperiod-sensitive cultivars. The cooperating farmers' cultivars were included as checks.



5. Growth stage of 48 rice cultivars and breeding lines in relation to water table depth for 3 water regimes in Bay, Laguna, Philippines, 1986-87.

The second set of entries included two early-maturing, shorter-statured cultivars suited to favorable rainfed lowland hydrologies (IR36 and IR64), and three first set cultivars (IR19431-72-2, IR33238-25-2-3-2, and IR46). This trial was conducted on landforms currently planted predominantly to modern varieties (MVs). In the randomized complete block design, each location represented one replication.

The mean yields of the cultivars tested at 5 sites on 3 landforms where traditional varieties (TVs) are grown ranged from 2.1 to 2.6 t/ha. IR19431-72-2 was the top cultivar, but yields did not differ significantly among entries. The farmers' varieties in these trials averaged 2.4 t/ha. The site mean yields ranged from 1.6 to 3.0 t/ha.

At 4 sites on landforms dominated by MVs, yields averaged 4.4 t/ha (Table 11), nearly double those on TV-dominated landforms. The top-ranked entry was also IR19431-72-2, averaging 5.4 t/ha across sites. MV yields were 1.9 t/ha higher than those of farmers' varieties. IR46, IR36, and IR64 yielded between 4.1 and 4.8 t/ha, statistically on par with IR19431-72-2. The medium maturity, intermediate height, and tolerance for late transplanting of IR19431-72-2 are important characters for rainfed rice adaptation to most landforms in this region.

Table 10. Entries with mean grain yield greater than 3 t/ha from 274 entries tested in the medium-deepwater observational trial under 2 water regimes.[a] Bay, Laguna, Philippines, 1986 WS.

Designation	Grain yield (t/ha)	Days to flowering
Water Regime A		
IR41111-46-2-3-1	3.8	142
CR1009	3.6	121
IR15810-260-1-3-1-3	3.6	129
IR38499-C0-209-3-3-2	3.6	141
IR33225-21-3-1-3	3.4	127
IR10232-17-2-1E-P1	3.1	127
IR43511-3-1-1-3-1	3.0	126
IR54	3.0	126
Water Regime B		
IR43552-80-3-1-3	3.0	147

[a]Water regimes are shown in Figure 5.

Table 11. Mean grain yields of a set of cultivars tested in 4 farmers' fields across 2 rainfed rice-growing landforms grown mainly to modern varieties. Cagayan, Philippines, 1986 WS.

Cultivars	Grain yield[a] (t/ha)				
	1	2	3	4	Mean
IR36	4.7	–	5.0	–	4.8
IR46	4.6	3.7	4.4	3.8	4.1
IR64	4.2	–	4.2	5.2	4.5
IR33238-25-2-3-2	5.6	3.6	3.2	4.6	4.3
IR19431-72-2	5.6	4.0	6.3	5.6	5.4
Farmers' variety[b]	4.5	2.8	3.3	3.1	3.4
X	4.9	3.6	4.4	4.0	4.4
LSD (0.05)					1.1
(0.01)					1.6
CV					15%

[a]Sites 1 and 2 = Talinganay (interhill miniplain), 3 and 4 = Maguirig (alluvial fan). – = no data. [b]Farmers' variety: IR23, IR36, BLM.

UPLAND RICE

International Rice Germplasm Center and Plant Breeding Department

Breeding operations. *International Rice Germplasm Center.* In 1987, IRGC incorporated grain quality and weed competitiveness into advanced breeding lines that already had Bl and drought resistance, tolerance for acid upland soil, and adaptation to low P supply. About 220 single crosses, topcrosses, double crosses, and backcrosses were made. Most traditional upland varieties compete well with weeds because of their tall heights and long and droopy leaves, which also make them lodging susceptible. Selection aimed for a plant type that combines intermediate plant height, droopy lower leaves, and erect upper leaves. Most grain quality traits came from upland rices of the Philippines, Thailand, and USA. Grain shape has progressed from bold grains to more slender ones. An additional selection criterion is translucent and clear endosperm.

IRGC continued to provide national programs with seed from specified cross combinations. A total of 128 F_2 and F_3 bulk populations were sent to national centers in India, Mexico, Senegal, and Zanzibar, and to WARDA. The crosses aimed to combine early maturity, gall midge resistance, resistance to drought and Bl, adaptation to acid upland soils, and improved grain quality.

One hundred thirty F_2 and F_3 bulk populations were grown and carried through the F_4. From 140

F_4 and F_5 bulk populations, IRGC continued to select for deep and thick roots in DS prior to transplanting. Selection for the desired morpho-agronomic traits was made before maturity. About 2,000 progenies were selected and carried into the F_5 and F_6. Lines with early maturity, intermediate height, long and heavy grains, field resistance to Bl, and detectable aroma were recovered in WS.

Plant Breeding Department. In 1987, the Plant Breeding Department made 42 crosses. Table 12 shows the parents used in crosses made according to their electrophoretic groups. Fewer crosses were made in order to

- use only the best parents for drought tolerance, Bl resistance, and tolerance for acidic poor soils;
- focus on group 6 parents that are best under adverse environments; and
- have more F_2 studies to get more transgressive recombinations between the parents.

The crosses numbered 1 for 1/6 groups, 21 for 6/1 groups, 1 for 6/2 groups, 18 for 6/6 groups, and 1 for unknown/6 groups. The only unknown group parent was IR30716-B-1-B-1-2, a RP825-70-7-1/LAC23//LAC23 cross, therefore having a strong group 6 background.

Group 2 is seldom used because it recombines poorly with group 6. Group 2/group 6 crosses can recombine group 2's earliness, grain quality, and very good early standing vigor with group 6's very good adaptation to poor acidic soils. Unfortunately, good phenotypes in the F_2 are extremely rare.

Many group 6/group 1 crosses are needed to combine the best traits from both groups, especially group 6's good adaptation to adverse conditions and group 1's very good yield potential under good conditions and managed cultivation practices.

As of December 1987, under study were 17 F_1 progenies and 27 F_2 progenies (13 are 6/6 crosses and 14 are 6/1 crosses; all female parents were from group 6).

Six hundred seven F_3 lines from 19 crosses (Table 13) were under study.

Table 12. Parents used in crosses made by the IRRI Plant Breeding Department in 1987 for upland rice breeding.

Parent name	Group	Times (no.) used as		Type[a]	Country of origin
		Female	Male		
AUS196	2	0	1	T	Bangladesh
Azucena (C)	6	6	4	T	Philippines
BPI 9-33	6	2	1	I	Philippines
BR319-1	1	0	3	I	Bangladesh
CNA4102	6	2	2	I	Brazil
CNA4120	6	4	1	I	Brazil
CNA4143	6	2	1	I	Brazil
CT6516-21-4-4	6	1	2	I	Colombia
Gogo Gundil	6	2	0	T	Indonesia
IR30716-B-1-B-1-2		0	6	I	Philippines
IR47686-B-4-3	6	2	1	I	Philippines
IR47686-13-1-1	6	2	0	I	Philippines
IRAT104	6	0	1	I	Ivory Coast
IRAT104 (D)	6	1	0	I	Ivory Coast
IRAT104 (E)	6	4	1	I	Ivory Coast
IRAT115	6	0	3	I	Ivory Coast
IRAT144 (A)	6	2	0	I	Burkina Faso
IRAT177	6	2	0	I	French Guyana
IRAT288	6	2	0	I	French Guyana-Brazil
ITA130	6	2	0	I	Nigeria
LAC23	6	4	0	T	Liberia
Milyang 26	6	0	2	T	Korea
Palawan (A)	6	2	0	T	Philippines
UPLRi-5 (B)	1	0	2	I	Philippines
UPLRi-5 (C)	1	0	7	I	Philippines
UPLRi-7	1	0	4	I	Philippines

[a]T = traditional cultivar, I = improved variety.

Table 13. F_3 progenies under study in 1987, IRRI Plant Breeding Department.

Female parent		Male parent		F_2 plants
Designation	Group	Designation	Group	(no.)
Chianan 8	6	IRAT104	6	94
CNA4121	6	IRAT104	6	76
BR319-1	1	IRAT104	6	64
UPLRi-5	1	BR319-1	1	58
Milyang 26	6	Moroberekan	6	57
BPI 9-33	6	ARC7046	2	45
IRAT140	6	Aus 196	2	42
CNA4130	6	Kinandang Patong	6	33
IRAT104	6	Aus 454	2	31
CNA4120	6	B2997C-TB-60-3-3	1	21
IRAT140	6	M55	6	18
Aus 454	2	Moroberekan	6	15
UPLRi-5	1	IRAT144	6	15
UPLRi-5	1	CNA4121	6	12
Dinorado	6	BR319-1	1	9
UPLRi-5	1	IRAT177	6	8
BR319-1	1	CNA4130	6	5
Carreon	1	IAC25	6	2
GS529	2	IAC25	6	2

Tables 12 and 13 reflect the strategy:

- Focus on group 6/group 6 crosses, widely using the best materials adapted to adverse environments, emphasizing breeding for earliness, using CNA lines; drought and Bl tolerance, using IRAT104, IRAT144, Moroberekan, Dinorado, and others.
- Emphasis on group 6/group 1 crosses more than on group 6/group 2, but using a few selected parents from groups 1 and 2—UPLRi-5 and Aus 196 because of their yield potential under moderately adverse environments.
- Progressive move from IRAT104 and other group 6 entries as donors toward IR47686 top lines (from IRAT104/Palawan cross) developed by the project and the best CT lines developed by CIAT.

Five hundred nine F_4 families were under study, composed of 70 early families from 4 crosses, 343 medium-duration families from 44 crosses, and 96 late families from 11 crosses. The most promising crosses were IRAT140/Milyang 26, IR12979-24-1/IRAT140, UPLRi-5/IRAT140, UPLRi-5/IRAT140, Palawan/Milyang 26, B2997C-TB-4-2-1/UPLRi-5, and IR12979-24-1/LAC23.

There were 261 F_5 families, composed of 225 short-duration lines from 5 crosses and 36 medium-duration lines from 5 crosses. The most promising crosses were ITA235/IAC25, IAC47/IRAT112, IRAT112/Azucena, IAC47/IRAT13, and Azucena/IAC47. All parents are from group 6.

Twenty-three F_6 families from 4 crosses were under study, the most promising cross being LAC23/IRAT134, with both parents from group 6.

Yield performance. *Farmer's field.* We continued to evaluate breeding lines in a farmer's field in Santo Tomas, Batangas. WS rainfall was below average—1,065 mm. Mild water stress at panicle initiation in late August did not seriously affect yield. Leaf and neck Bl were prevalent, but most lines showed scores between 2 and 3. The yields ranged from 1.2 to 4.1 t/ha. The highest yielders (3-4 t/ha) were IR10147-113-5-1-1-5, the IR13754 lines, IR27078 lines, and IR27095 lines. These lines also performed well in 1986.

IRRI. WS rainfall was only 987 mm. Water stress was mild during the vegetative phase and the early reproductive phase in the UZ area. Yields ranged from 0.3 to 2.2 t/ha. Root nematodes continually lowered yields, even without drought. Lines best adapting to this condition were IR13754-6-4 and -7-3, IR26957-86-2, IR27069-B-53-B-B-1-4-3, IR27112-B-43-B-B-2-2-2 and -2-1-2, averaging at least 2.0 t/ha.

In the IRRI rainfed area, entries were more vigorous. A few showed leaf Bl infection during the early vegetative phase. Severe lodging, however, occurred during the reproductive phase. Yields ranged from 0.5 to 2.9 t/ha. The highest yielders (2.8-2.9 t/ha) were IR13754-6-4, IR44712-B-B-5, and IR26957-86-2.

Across the three favorable environments (Santo Tomas and 2 IRRI fields), 4 lines were comparable to IR43 (highest average yield 2.6 t/ha) in yield performance: IR13754-6-3 (2.7 t/ha), IR26957-86-2 (2.7 t/ha), IR13754-6-4 (2.9 t/ha), and IR13754-5-10 (2.6 t/ha). The results agreed with previous performance.

The line IR44716-B-B-B-6-2, which performed fairly well at the new rainfed site on the IRRI farm but poorly in Santo Tomas, Batangas, also performed well (2.2 t/ha) at a low-fertility site in Bohol, which has a soil pH of 7.0. This shows the location-specific nature of upland rice production.

Acid upland site. About 64 entries were included in the yield trial in Cavinte, Laguna. The fertilizer

applied was 60-20-20 kg NPK/ha. A serious leaf Bl infection during the early vegetative phase wiped out most good performers of 1986. The yields ranged from 0.1 to 1.7 t/ha. The highest yielder, IR10120-7-2-1-4, has the African variety E425 in its background. It showed moderate Bl resistance (score 3-4). Bl appeared more severe at low P levels. The best performers included IR29429 lines (1.3 to 1.6 t/ha), IR23261-23-2-2 (1.5 t/ha) and -2-3 (1.4 t/ha), IR10147-113-5-11-1-5 (1.5 t/ha), B2406B-SM24TB-2-1-MR-5 (1.5 t/ha), and IR43 (1.4 t/ha). IR29429 lines and IR23261 lines have the weed competitive plant type. IR10147-113-5-1-1-5 also performed well at an acid upland site in Claveria.

Evaluation of field germplasm for adverse environments (*Plant Breeding*). After 4 yr of screening 3,765 entries under adverse conditions, 105 (2.7%) were selected. Along with 35 CT lines of 389 received from the Centro Internacional de Agricultura Tropical (CIAT), 11 mutants and 39 progenies developed by the IRRI-Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT) upland rice project, and 51 entries recently received from various sources, a field germplasm of 241 entries was under observational trials and seed increase as of December 1987.

Most of this germplasm belongs to group 6, which includes such traditional upland cultivars as Azucena, Dinorado, and Kinandang Patong from the Philippines; Makouta from Africa; and Arroz Dos Indios from Brazil. Most of 100 traditional upland rices from Japan and 20 from Korea were very susceptible to Bl in 1987, but a few resistant entries, such as Gaisen Mochi, Gose Yowkoku, Hideri Shirazu, and Okka Modoshi, were kept for their earliness, very good standing vigor, and response to low N inputs.

The most promising lines from Brazil are CNA4120 and CNA4164 for adverse conditions and low management; CNA4136 and CNA5164 look better under moderately adverse stresses. These CNA entries are very early, drought tolerant, and moderately resistant to Bl.

The very promising CT lines from CIAT have in their parentage an IRAT entry from Madagascar, and either a Tox line from the International Institute of Tropical Agriculture (IITA) or M312A from the Ivory Coast, or both.

The IRAT entries provided useful materials, such as IRAT104 and 216. All IRAT entries belong to group 6. IRAT216, widely used as a donor by CIAT, is a cross between Colombia 1 and M312A.

Very few group 1 and group 2 entries are included in the germplasm. Group 1 is not adapted to adverse environments, where it is frequently too Bl susceptible. All group 1 entries are medium to long in duration. Most group 2 entries are Bl susceptible. Of those that are not, Aus 196, Aus 454, and Surjamkuhi are very early, well adapted to adverse soils, and high yielding, apparently with durable Bl resistance, but they lodge before maturity.

Better materials are listed in Table 14. Other CNA, CT, and IRAT lines are good performers in severe environments. In 1987, a severe leaf Bl incidence during the early vegetative phase completely destroyed susceptible materials. In addition to entries in Table 14, the following entries have good Bl resistance: 119B, Catetao Precoce, CNA4164, CNA4749, CT6510-19-2-1, CT6514-31-5-2, CT6516-1-2-2, CT6516-23-1-2, CT6516-23-1-5, CT6516-6-4-1, CT6660-2-6-5, Dinorado (E), EEPG369, Gose Yonkoku, H.D. 1.4, IRAT108, IRAT134 (A), IRAT142, IRAT144 (B), IRAT146 (B), IRAT164, IRAT166, IRAT169F 10/6, IRAT177 (A), IRAT215, IRAT226, IRAT257, IRAT258, IRAT260, and IRAT267. All these entries can be used as donors for Bl resistance.

Advanced progeny studies (*Plant Breeding*). One hundred fifteen advanced (F_8) progenies were studied in nonreplicated observational plots under adverse conditions during 1987 WS.

The characters studied were early vegetative vigor (EVV), leaf Bl during early vegetative phase (LBl), glume discoloration (GlD), brown spot (BS), leaf scald (LSc), phenotypic acceptability (Pacp), yield (t/ha), and seed-to-seed duration in days (Mat). The observations are rated according to the *Standard evaluation system for rice* (1 = best, 9 = the poorest).

Table 15 gives the correlation matrix for yield and the seven other characters.

There are negative relationships between yield and Pacp and between yield and EVV. BS and LSc

Table 14. Top germplasm entries for adverse upland conditions at Mahipon, Philippines, 1987.[a]

Variety or line	Origin	Seed-to-seed duration (d)	EG	EVV	LBI	Pacp	BS	LSc	GID	Amylose (%)
CNA4102	Brazil	Less than 95	6	3	4	5	2	3	4	21.4
CNA4120	Brazil		6	3	1 (3-4)	3	3	5	3	14.3
CNA4127	Brazil		6	2	1 (3-4)	4	2	7	4	23.4
CNA4136	Brazil		6	1	1 (4)	3	2	4	2	22.4
CNA5164	Brazil	95-105	6	5	1 (3-4)	5	4	4	5	12.5
IRAT115	Ivory Coast		6	3	1 (3-4)	3	4	4	5	21.3
IRAT284	Guyana-Brazil		6	3	1 (3-4)	3	2	2	3	21.4
IRAT288	Guyana-Brazil		6	1	4	3	4	2	3	22.4
Surjamkuhi	India	106-119	2	1	3 (4)	4	2	5	3	26.0
Arroz dos Indios	Brazil		6	1	4	3	1	1	3	
Azucena (C)	Philippines		6	1	4	3	2	4	3	22.0
CT6510-24-1-3	Colombia		6	1	1 (3-4)	5	2	5	4	15.8
CT6516-1-2-2	Colombia		6	3	1 (3-4)	4	2	3	4	14.6
CT6516-21-4-4	Colombia		6	1	4	4	2	5	3	20.6
IRAT104 (E)	Ivory Coast		6	1	1 (3-4)	5	3	5	5	9.6
IRAT211	Ivory Coast		6	3	4	4	2	4	2	20.7
IRAT212	Ivory Coast		6	1	3-4	4	4	2	5	23.4
IRAT216	Ivory Coast		6	4	4	5	3	4	5	14.2
ITA130	Nigeria		6	1	1 (3-4)	6	3	5	4	9.6
KU115	Thailand		6	3	1	6	1	3	4	9.7
Makouta	Ivory Coast	120-130	6	1	1	4	3	5	4	
Moroberekan (A)	Guinea		6	3	1 (3-4)	4	3	5	3	21.8

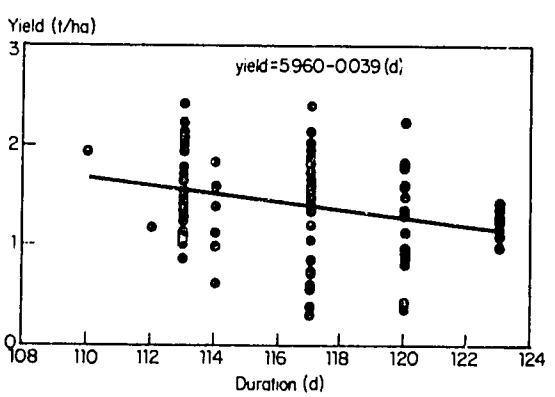
[a]EG = electrophoretic group, EVV = early vegetative vigor, LBI = leaf blast, Pacp = phenotypic acceptability, BS = brown spot, LSc = leaf scald, GID = glume discoloration.

Table 15. Data correlation matrix for yield and 7 other characters. IRRI, 1987.

Yield (t/ha)	1.000	-0.586	-0.529	-0.218	-0.107	0.414	0.199	-0.290
Pacp	-0.586	1.000	0.512	0.278	0.191	-0.193	-0.166	-0.048
EVV	-0.529	0.512	1.000	0.467	0.048	-0.157	-0.282	0.052
LBI	-0.218	0.278	0.467	1.000	-0.066	-0.103	-0.167	-0.175
GID	-0.107	0.191	0.048	-0.066	1.000	-0.072	0.219	0.162
BS	0.414	-0.193	-0.157	-0.103	-0.072	1.000	0.191	-0.188
LSc	0.199	-0.166	-0.282	-0.167	0.219	0.191	1.000	0.262
Mat	-0.290	-0.048	0.052	-0.175	0.162	-0.188	0.262	1.000

have low incidence, if any, and apparently have a positive relationship to yield. Mat shows a negative correlation with yield, with the best duration being about 113 d, about 85 d from sowing to flowering (Fig. 6). Leaf Bl incidence is low in the early vegetative phase, but most entries are tolerant. Incidence is reported if the score is 5 or higher during early growth stages. As expected, GID has a minor effect on yield, but a serious one on grain appearance at harvest.

The percentages for the 11 groups of best progenies according to yield and the 4 diseases scored are given in Table 16. The acceptability level



6. Relationship between yield and duration. IRRI, 1987.

Table 16. Number and percentage of 11 groups according to top yielders and lower number of diseased entries. IRRI, 1987.

Designation	Cross	Progenies		Top entries for									
				Yield		Leaf blast		Glume discoloration		Brown spot		Leaf scald	
		no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
IR47684	IRAT104/Kinandang Patong	1 =	0.87	1 =	5.0								
IR47686	IRAT104/Palawan	69 =	60.0	15 =	75.0	23 =	88.5	6 =	40.0	8 =	40.0	8 =	42.1
IR47690	IRAT140/Kinandang Patong	1 =	0.87										
IR47691	IRAT140/Palawan	19 =	16.52	1 =	5.0			2 =	13.3	3 =	15.0	4 =	21.0
IR47697	ITA235/IR9669 selection	2 =	1.74	1 =	5.0					1 =	5	1 =	5.3
IR47699	ITA235/Palawan	9 =	7.82	1 =	5.0			1 =	6.7			2 =	10.6
IR47701	ITA235/UPLRi-7	8 =	6.96	1 =	5.0			6 =	40.0	5 =	25.0	4 =	21.0
IR47704	Moroberekan/Kinandang Patong	1 =	0.87			1 =	3.8						
IR47719	IRAT117/IRAT177	3 =	2.61			2 =	7.7			2 =	10.0		
IR47722	IRAT177/Apura	1 =	0.87							1 =	5.0		
IR47728	IRAT112/Papayo	1 =	0.87										
	Total	115	100	20	100.0	26	100.0	15	100.0	20	100.0	19	100.0

for Bl is 0.1, 1-2-3 for GID, and 1-2 for BS and LSc. The table shows that IRAT104 is a good parent for yield potential and Bl; UPLRi-7 is good for GID, BS, and LSc; while both IRAT117 and IRAT177 are promising for Bl and BS.

In conclusion, the best progenies are given in Table 17 and are compared with selected entries, including their parents.

- Most top entries are from IRAT104/Palawan, both group 6 entries.

Table 17. Top entries and their main adaptive characters under adverse environments. IRRI, 1987.

Progeny	Main adaptive characters	Yield (t/ha)	Duration (d)
IR47686-18-4-1	Yield	2.4	117
IR47686-30-2-1	Yield	2.4	113
IR47699-64-1-1	Yield, leaf scald	2.3	113
IR47686-13-1-1[a]	Yield, blast	2.2	120
IR47686-9-1-B-1[b]	Yield, blast, early vegetative vigor	2.1	113
IR47686-31-1-1[c]	Yield, glume discoloration, leaf scald	2.1	113
IR47686-6-2-2-1[d]	Yield, drought	2.0	117
IR47686-18-1-1	Yield, brown spot	1.9	117
Mean of 115 progenies		1.4	117
	Selected entries (for comparison from same trial)		
CT6510-21-5-3 (top yielder)	CIAT, Colombia	3.0	117
CNA4120	EMBRAPA, Brazil	2.7	113
IRAT144	IRAT, Burkina Faso	2.6	106
IRAT104	IRAT, Ivory Coast	1.6	120
ITA235	IITA, Nigeria	1.5	114
Palawan	Local check	1.2	123
UPLRi-5	Local check	0.9	129
Kinandang Patong	Local check	0.8	119

[a]Ranking 4th out of 52 entries, yield = 3.3 t/ha in Acid Upland Yield Trial, Claveria, 1987 (Multiple Cropping Department). Ranking 3rd out of 100 entries, yield = 3.9 t/ha in Acid Upland Observational Trial (AUOT). [b]Ranking 7th out of 500 entries, yield = 2.4 t/ha in AUOT, Cavinti, 1986 (Multiple Cropping). [c]Ranking 1st out of 500 entries, yield = 5.9 t/ha in AUOT, Claveria, 1987 (Multiple Cropping). [d]Top entry for drought resistance in 1987 DS evaluation (Agronomy Department). Ranking 1st out of 52 entries, yield = 3.3 t/ha in AUYT, Cavinti, 1987 (Multiple Cropping). Ranking 5th out of 100 entries, yield = 3.8 t/ha in AUOT, Cavinti, 1986 (Multiple Cropping).

- The top yielder is CT6510-21-5-3 from Colombia; IR47686-18-4-1 ranks 9 among 252 entries.
- The yield potential of these best entries is more than 5 t/ha under moderately favorable conditions; IR47686-31-1-1 yielded 5.9 t/ha in 1987.
- The goal is to recombine the best IR47686 progenies with the top CT, CNA, and IRAT entries. An example is CT6510-21-5-3/IRAT 144//CNA4120/IR47686-6-2-2-1.

The parents are

- CT6510-21-5-3 = IRAT120/Khao Lo//IR8///Col 1/M312A
- IR47686-6-2-2-1 = IRAT104/Palawan
- CNA4120 = IAC47/63-83
- IRAT144 = IRAT10/IRAT13

The first step for such crosses will be made in 1988.

DEEPWATER RICE

Plant Breeding Department

Hybridization. We made 524 single crosses and 655 multiple crosses for deepwater rice (DWR). The aim was to recombine improved plant and grain types with tolerance for deepwater conditions. Donor parents included traditional and released DWRs, deepwater breeding lines, and breeding lines for other desirable traits (Table 18).

Preliminary yield testing at IRRI. We harvested DWRs in a seed increase plot in shallow water. Table 19 lists the best-yielding lines that also had acceptable elongation ability in a parallel test in 1-m-deep water.

In an observation trial with seed increase, we planted advanced DWRs in 1-m-deep water at IRRI. The best-yielding lines are given in Table 20.

Field testing. We field-tested advanced DWRs in these facilities:

- Huntra Rice Experiment Station, Thailand. Natural water supply, subjected in 1987 to severe drought followed by rapid flooding.
- Prachinburi Rice Experiment Station, Thailand. Lines planted in observation nurseries in natural water regimes; maximum water depth of 1 m.
- Tamisac, near San Dionisio, Iloilo, Philippines. Deep stagnant water, with repeated flooding in 1987 starting 2 wk after transplanting.
- IRRI's DS drought screening facility.
- Caliraya, Laguna, Philippines at a Bl screening site used for upland rices.
- IRRI's Bl nursery.

Table 18. Parents used in 30 or more F_1 crosses planted in the deepwater rice (DWR) breeding program, 1987.

Parent	Times (no.) used in crosses	Remarks
FRRS43-3	111	West African popular floating rice with good elongation ability and some submergence tolerance; drought tolerant and photoperiod sensitive
Karijawa	57	DWR from the "diarra" lands in Bihar; good elongation ability
LMN111 mutant	133	Improved plant type, mutant of floating rice Leb Mue Nahng 111 from Thailand; good elongation ability
Rayada 16-6	31	Traditional floating rice from Bangladesh with resistance to the ufra nematode and blast (Bl); cold tolerant
IR11141-6-1-4	267	DWR with improved plant type; released in South Kalimantan; drought tolerant; very good elongation ability; resistant to brown planthopper (BPH) biotypes 1 and 3
IR11288-B-B-118-1	67	Floating rice released in South Kalimantan; good elongation ability; photoperiod sensitive; resistant to Bl, bacterial blight (BB) race 1, and BPH biotypes 1, 2, and 3; good grain appearance
BR311-B-5-4	30	Floating rice, photoperiod sensitive, with good elongation ability; promising line in Bangladesh

Continued on next page

Table 18 continued

Parent	Times (no.) used in crosses	Remarks
BR118-3B-17	57	Medium tall DWR; resistant to BI, green leafhopper (GLH), and BB races 1 and 2; photoperiod sensitive with some elongation ability and submergence tolerance; drought tolerant
HTAFR77022-14-157-6	39	DWR with improved plant type and good elongation ability
IR11288-B-B-69-1	111	Photoperiod-sensitive DWR; improved plant type; good elongation ability; resistant to BB race 1, BPH biotypes 1, 2, and 3, and GLH
IR20992-7-2-2-2-2-3	40	DWR resistant to BB race 1, BPH biotypes 1, 2, and 3, and GLH; drought tolerant with high yield
IR31406-333-1	52	Improved plant type with resistance to salinity, tolerance for drought, and very good submergence tolerance; resistant to BPH biotypes 1 and 3, and BB race 1
IR32429-47-3-2-2	32	Drought-tolerant line with high yield in deep water; resistant to BPH biotypes 1, 2, and 3, and to GLH, BI, and BB race 1
IR38784-100-1-3-6-3	169	Improved plant type with very good elongation ability; resistant to BB race 1, BPH biotypes 1, 2, and 3, and GLH; good grain appearance and intermediate gelatinization temperature
SPR7274-0-0-1	10	Improved plant type DWR; strongly photoperiod sensitive and resistant to GLH; cold tolerant
IR4563-52-1-3-6	33	Improved plant type with tolerance for Fe toxic problem soils
IR64	116	Modern variety with good grain appearance, intermediate gelatinization temperature, and soft gel consistency
IR9782-111-2-1-2	41	Breeding line with improved plant type, very good drought tolerance, and resistance to BI and BPH biotypes 1, 2, and 3
B4259-48-1-1-1-2-2-2-1-3	189	Improved plant type resistant to 3 BPH biotypes, GLH, and BI; good grain appearance and intermediate gelatinization temperature

Table 19. Best-performing lines in an observational trial in shallow water. IRRI, 1987 WS.

Designation	Elongation in 1 m water[a]	Height (cm)	Flowering date	Yield (t/ha)
IR39564-81-B-B-1	4	160	28 Sep	2.2
IR38684-8-3-3-6-1-2-2-2	2	175	1 Oct	2.2
IR41430-502-3-2-2	2	170	1 Oct	2.5
IR42506-531-1-2-3	4	150	3 Oct	2.9
IR38684-8-3-1-2-2-3-1-3	2	160	3 Oct	2.9
IR37449-13-HM-1-1-3-3-2	4	153	3 Oct	3.1
IR42506-531-1-2-1	5	118	6 Oct	3.3
IR40905-11-3-1-5-2-24	1	154	10 Oct	3.5
IR42506-531-1-2-2	5	160	10 Oct	3.0
IR42529-104-2-3-3	4	165	10 Oct	2.2
IR40905-11-3-1-6-3-21	1	170	10 Oct	2.4
IR41405-16-1-3-2-3-3	3	140	10 Oct	2.2
IR40905-11-3-1-5-2-22	1	160	12 Oct	3.0
IR40905-11-3-1-5-2-21	1	161	12 Oct	3.8
IR40905-11-3-3-4-1-21	1	165	15 Oct	2.1
IR41405-16-1-3-2-3-2	3	135	15 Oct	2.2
IR38685-23-1-3-6-3-2-2-1	4	147	15 Oct	3.6
IR40905-11-3-1-5-2-23	1	150	15 Oct	3.6

[a]By SES.

Table 20. Best performing lines in an observational trial in deep water, IRRI, 1987 WS.

Designation	Height (cm)	Days to flowering	Yield (t/ha)
IR42569-329-5-2-1	111	158	2.0
IR33226-15-1-3-3-2	120	175	1.9
IR33225-45-3-1-1-2-3-1	117	177	2.0
BKNFR76010-108-2	159	180	2.2
IR38692-33-3-3-6-22	120	180	2.3
IR42479-85-2-1-3-3	120	180	1.9
IR33225-45-3-1-1-3-2-3	120	180	1.5
IR38692-33-3-3-6-21	120	180	1.8
IR33225-45-3-1-1-2-1-3	115	180	1.8
IR38787-50-5-3-2	159	185	2.2
IR38692-33-3-3-6	120	185	1.9
IR42580-23-2-1-1-1	120	185	2.0
IR38692-33-[illegible]-3-5	120	185	1.8
IR33225-45-[illegible]-1-2	115	190	1.9
IR40905-11-3-1-5-3-3	130	230	2.8

Table 21 lists the best lines from among the 400 lines tested.

We continued exchanging bulk F_2 and F_3 populations with DWR breeders. Breeders usually request crosses with a parent of proven acceptability in the site concerned.

Table 22 lists F_2 and F_3 bulks performing best in at least two locations.

TIDAL WETLAND AND PROBLEM SOILS RICE

Plant Breeding and Soils Departments

In 1987, all breeding for tidal wetland problem soils was linked to the newly established regional (South and Southeast Asia) Cooperative for Research on Problem Soils. The Cooperative aims to strengthen

Table 21. Promising deepwater lines from field observations on deepwater survival in Thailand and in Iloilo, and drought and blast tests in the Philippines, 1987.

Designation	Acceptability[a]			Drought tolerance[b]	Blast	
	HTA	PCR	ILO		Caliraya	IRRI
RD19/IR54						
IR37026-R-3-1-1	3.3	–	7.0	4.0	5.0	4.5
BKN7022-6-4/IR25861-31-1-3						
IR40555-33-2-3-1-1-1		3	7.0	3.4	6.0	5.5
Badal 613/IR11288-B-B-118-1						
IR40905-11-3-3-5-2-3		3	6.1	3.2	5.5	8.0
NSPT/IR7732-RGA-B-A96-1						
IR41271-76-1-1-2-1-1	5.2	–	5.6	4.7	6.0	5.0
IR41271-80-1-2-1-3-2	7.5	–	5.8	1.9	3.5	4.0
IR8234-OT-9-2/Nam Sagui 19						
IR41425-112-23-1-2	4.5	–	–	3.1	4.0	2.0
IR41425-58-22-2-3	5.8	–	–	4.2	2.5	2.0
IR41425-65-25-1-3	5.2	–	–	4.2	4.0	1.0
IR8234-OT-9-2/IR4630-22-2-17						
IR41427-195-22-1-3	5.3	–	–	2.1	4.5	3.5
IR41427-22-24-3-2	5.6	–	–	3.6	4.5	5.0
IR41427-221-1-4-2-1-3	3.6	–	–	1.9	5.5	4.0
IR8234-OT-9-2/IR13146-45-2-3						
IR41430-117-2-2-2-3	4.5	–	–	2.2	6.0	4.5
IR41430-118-8-2-1-1	5.2	–	–	2.9	2.5	3.5
64-117/IR19661-131-1-3-1-3//IR13259153-5E-P2-2/IR8234-OT-9-2						
IR42531-39-3-2-2	5.8	–	5.6	3.0	4.5	2.0
IR42531-84-1-1-1	2.6	–	7.0	4.7	4.0	7.0
Nam Sagui 19/IR11288-B-B-288-1//RD19/IR11288-B-B-445-1						
IR42555-72-2-2-2-1	3.9	–	3.6	6.2	3.0	1.0
IR42555-72-2-2-2-2	4.7	–	5.5	5.3	4.0	0.5
RD19/Murungkayan 101B//Nam Sagui 19/IR19661-131-1-3-1-3						
IR42566-62-2-1-2-2	5.8	–	6.4	6.5	4.0	4.0
IR42566-62-2-2-1-3	4.4	–	7.0	5.0	4.0	3.5
RD19/IR19661-131-1-2//RD19/IR50						
IR42577-21-1-2-2-2	2.8	–	3.6	5.0	5.5	4.5

Continued on next page

Table 21 continued

Designation	Acceptability[a]			Drought tolerance[b]	Blast	
	HTA	PCR	ILO		Caliraya	IRRI
RD19/IR19661-131-1-2//RD19/IR15314-43-2-3-3						
IR42579-8-1-1-2-1	6.0	–	6.4	3.5	2.5	1.0
RD19/Murungkayan 101B//BIET1048/DWCT156-1						
IR42583-12-6-1-2-3	–	3	5.0	1.8	4.0	1.0
HTA7406-111-0-0-2/SPR7282-2-0-5-2//IR13423-10-2-3/IR11288-B-B-118-1						
IR43946-45-2-1-2	2.1	–	6.4	3.1	7.0	5.5
IR43946-45-3-3-3	3.8	--	5.0	3.5	7.5	6.0
HTA7406-111-0-0-2/SPR7292-151-2-1//KDM105/IR11288-B-B-69-1						
IR43947-46-3-1-1	4.2	–	6.2	2.1	5.0	5.5
IR43947-50-3-2-1	3.3	–	4.2	3.5	6.5	5.0
IR43947-98-2-3-1	3.0	–	6.1	3.3	4.0	4.5
HTA7406-111-0-0-2/SPR7292-151-2-1//RD19/IR17494-32-3-1-1-3						
IR43950-3-3-1-1	2.2	–	3.6	3.4	5.5	6.5
IR43950-40-2-1-1	4.3	–	4.5	3.6	5.5	4.5

[a]Huntra Rice Experiment Station, Thailand (HTA): drought followed by fast flooding. Prachinburi Rice Experiment Station (PCR): 1 m stagnant water. Tamisac, Iloilo, Philippines (ILO): flash flooding during early vegetative growth. [b]Field test for drought tolerance at IRRI, av of scores.

Table 22. F_2 and F_3 bulks with outstanding acceptability in at least 2 off-station deepwater locations. 1987.

Cross	Sites[a]	Parentage
IR47587	TSC, HTA	IR17491-5-4-3-3/ IR11288-B-B-118-1
IR48166	TSC, NVN	CN540/IR56//CN540/IR9764-45-2-2
IR48194	TSC, HTA	HTA7205-11/HTAFR77043-2// HTAFR77022-14-157-1
IR48280	TSC, HTA	BKNFR76106-13-2/IR46// Tilockachari 33-754/ IR18348-36-3-3
IR49953	TSC, HTA	IR21037-2-1-2E-P3-6// IR13149-19-1/IR11141-6-1-4
IR49965	SVN, HTA	IR21037-2-1-2E-P3-6// IR31432-2-3/RD19
IR49966	SVN, HTA	IR21037-2-1-2E-P3-6// RD19/TCA177
IR49971	TSC, HTA	BR516-48-3/HTAFR77022-14-157-1//IR21037-2-1-2E-P3-6
IR49998	TSC, HTA	IR6023-10-1-1/TOx 896-R-R-R-102//IR21037-2-1-2E-P3-6
IR49999	TSC, HTA	IR6023-10-1-1/TOx 896-R-R-R-102//IR21178-43-1-2-2-2
IR50064	TSC, HTA	IR13419-113-1/HTAFR77022-14-157-6-1//IR17494-32-3-1-1-3/IR11288-B-B-65-8-3
IR51193	NVN, KDP	IR21567-9-2-2-2-1-2-2-2/ IR27527-CPA12-501-1-3// IR21567-16-2-2/IR31406-333-1

[a]Tamisac (TSC): rapid flooding. North Vietnam (NVN): flash flooding. South Vietnam (SVN): rapid flooding. Huntra (HTA): flooding 1 m deep. Kakdwip (KDP): flash flooding and salinity.

one national breeding program for each problem soil type, including tidal wetland.

For salinity, collaborative breeding began with the Central Soil Salinity Research Institute (CSSRI), India: coastal salinity at its regional research station in Canning, West Bengal; and inland salinity at the Karnal headquarters. The Saline Agriculture Research Station, Sadhoke, Pakistan, initiated breeding work on alkaline or saline soils.

The Banjarbaru Agricultural Research Institute for Food Crops (BARIF), South Kalimantan, Indonesia, is developing improved varieties for tidal swamps with peat soil. Collaborative research with Thailand at the Rice Research Center, Pathum Thani, emphasizes acid-sulfate soils. In Sri Lanka, the Regional Agricultural Research Center, Bombuwela, is breeding for Fe toxic soils.

In 1987, we made 220 single crosses and 165 multiple crosses, mostly in collaboration with breeders. Traditional varieties were widely used. A special hybridization block was established at IRRI to include highly photoperiod-sensitive varieties from Thailand, Indonesia, Sri Lanka, and the Philippines.

Breeding materials were advanced at IRRI, with selection restricted to resistance to lodging, pests, and diseases. Of 108 bulk populations evaluated, ranging from the F_2 to the F_5, 78 were advanced.

Many discarded crosses were highly susceptible to BB and RTV.

In WS, breeding materials were evaluated at target sites. Because many national program sites were not yet developed, we used six sites in the Philippines (Santo Tomas, Castuli, Lanjagan, Santo Rosario, and artificial saline and alkaline fields at IRRI). Of 50 bulk populations evaluated in Santo Tomas, Pampanga (coastal, acid saline), 1 F_2 and 5 F_3 were mass-selected, and single plant selections were made from 28 F_4 and 3 F_5 populations. At the coastal saline site in Castuli, Pampanga, 29 of the 30 F_3 bulks planted were mass-selected. All other bulks, 11 F_4 and 17 F_5 were single plant selected. Of the 26 F_2s planted in Lanjagan, Iloilo (coastal acid sulfate saline), 17 were mass-selected. In Santo Rosario, Iloilo (acid sulfate), all 26 F_2 populations evaluated were mass-selected. Soil stresses in these locations were moderate, but climate hazards such as flash floods were severe. The saline field at IRRI was used to evaluate and select 5 F_2, 17 F_3, and 2 F_4 bulks. In the alkaline field, 1 F_3 and 3 F_4 bulks were advanced.

In Thailand, selections made in previous years and 11 F_2 populations were evaluated in Ongkharak. Acidity was severe during the vegetative phase because of drought followed by several flash floods. Deepwater condition existed from flowering to ripening.

Ten F_2 bulk populations were evaluated in West Bengal, India, in coastal salinity and tidal swamp conditions. Because of prolonged waterlogging, few segregants survived. No selections were made because survivors did not express agronomic traits better than those of local checks such as SR26B.

F_2 bulks of crosses made with varieties tolerant of peat soil conditions were established at the Cooperative's site in South Kalimantan, Indonesia.

In Pakistan, 16 segregating populations were evaluated, ranging from the F_3 to the F_6, all previously advanced under artificial alkaline soil conditions at IRRI. These crosses adapted well to saline-alkaline soil conditions. Short-duration types were selected for further testing.

Segregating populations could not be evaluated at the Fe-toxic soil site in Sri Lanka.

We composed 4 nurseries: 1) with 50 advanced IR lines tolerant of salinity, P deficiency, and Zn deficiency; 2) with 20 traditional varieties cultivated in coastal acid-saline soils of West Africa; 3) with 15 traditional varieties from South Kalimantan, Indonesia, with soil problems associated with peatiness; and 4) with F_1 anther culture derivatives of IR crosses involving highly salt-tolerant varieties. These nurseries were distributed among Cooperative members for isolating suitable parents for hybridization work.

In West Bengal, India, IR lines, and West African and Indonesian varieties were tested. Four IR lines — IR4630-22-2-5-1-3, IR37257-41-3-2-3, IR39558-48-1-2-2, and IR40578-13-2-2-3-2-2— performed well. Many West African and Indonesian varieties appeared promising during the vegetative phase but had high photoperiod sensitivity. One of each group expressed correct duration. Nurseries tested in Thailand were similar to those of West Bengal. Anther culture derivatives were tested in alkaline soils in Karnal, India, and on alkaline-saline soils in Sadhoke, Pakistan. All lines showed tolerance for soil stresses, but their growth durations were too long.

In Sri Lanka IR advanced lines were tested for Fe toxicity tolerance, but the stress condition was too low to detect differences. Results from Indonesia will be available next year.

These tests have identified varieties and breeding lines adaptable to a range of soil stresses. To develop commercial varieties, however, breeding materials with higher genetic variability such as early or advanced bulks need to be evaluated and selected at each site.

On request, we supplied early generation bulk populations, advanced breeding lines, and varieties to Bangladesh, Fiji, Jamaica, Madagascar, China, Sierra Leone, and Vietnam.

Moreover, we initiated, in collaboration with the Republic of Korea, a breeding program to incorporate salt tolerance of some indicas into japonicas. Salt-tolerant japonicas are increasingly needed for saline ricelands in the Middle East and in the Korean peninsula. See details in the section on Adverse Temperature Tolerance.

Management of rice pests

Diseases

Plant Pathology, Entomology, and Agronomy Departments

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BIOLOGICAL CONTROL

Plant Pathology Department

Bacterial isolates. We continued to screen and test bacterial isolates for their efficacy as biological control agents against rice pathogens.

In the laboratory, bacteria were tested in vitro for inhibition of mycelial growth and sclerotia germination or infectivity. We used a detached-leaf technique to measure how well these bacteria infect target pathogens. A seed germination test (untreated seed with fungicide used as a check) further assessed the effect of bacterization.

Twenty-three isolates representing the genera or species identified last year (Annual report for 1986) were tested in seed germination of four rice cultivars—IR36, IR42, IR58, and IR64. Untreated seeds of each cultivar were soaked for 10 min in a suspension (10^8 colony-forming units [CFU]/ml) of each bacterial isolate. Using blotter germination for 5 d, we measured germination, plus hypocotyl and radicle length.

Germination of IR58 increased from 78 to 93%; that of IR64, from 89 to 97% (Table 1). No effect was observed on IR42 and IR36. IR58 and IR64 seeds bacterized with *Bacillus* spp. and Enterobacteriaceae germinated best.

Bacteria also enhanced radicle and hypocotyl development. *Bacillus* spp. enhanced the radicle and hypocotyl development of all cultivars except IR42. The three isolates of *Pseudomonas fluorescens* inhibited the radicle and hypocotyl of IR36, IR42, and IR58. The two isolates of *P. rubrisubalbicans* inhibited the radicle and hypocotyl of IR42, IR58, and IR64 but enhanced those of IR36. Seed treatment with *P. aeruginosa* promoted the radicle and hypocotyl of IR36, IR42, and IR64 but not those of IR58.

Rice fungal diseases. In 1986, many bacterial strains isolated from the rice system inhibited mycelial growth in vitro. These isolates were tested against sheath blight (ShB), blast (Bl), and bakanae (Bak) in the greenhouse and in Korean fields.

In the greenhouse, seeds of Cheong-cheong-byeo were coated with individual bacteria from 16 isolates and sown in seedboxes previously infested with *Rhizoctonia solani* (ShB) and *Fusarium moniliforme* (Bak). Seeds soaked in sterile water served as checks. Disease incidence was measured at 21 d after seeding (DAS). A spore suspension of *Pyricularia oryzae* was sprayed on plants at 20 DAS, and lesions were counted at 10 d after treatment.

Some of the 16 isolates tested effectively reduced

Table 1. Effect of seed bacterization[a] on germination[b], hypocotyl length, and radicle length of 4 rice cultivars. IRRI, 1987.

Parameter	*Bacillus* species (5)	Enterobacteriaceae (6)	*Pseudomonas fluorescens* (3)	*Pseudomonas rubrisubalbicans* (2)	*Pseudomonas aeruginosa* (7)	Check
			IR36			
Germination (%)	96 ± 2.15	97 ± 1.95	87 ± 1.25	99 ± 0.50	98 ± 1.59	96 ± 6.93
Height (mm)	46 ± 2.28	38 ± 3.06	25 ± 15.50	34 ± 0	41 ± 2.13	25 ± 2.28
Radicle length (mm)	51 ± 8.80	45 ± 10.45	36 ± 11.80	35 ± 10.0	61 ± 1.25	31 ± 1.50
			IR42			
Germination (%)	94 ± 6.49	96 ± 2.06	84 ± 8.22	95 ± 1.50	98 ± 1.36	96 ± 0.50
Height (mm)	40 ± 4.95	34 ± 1.81	36 ± 3.72	25 ± 2.50	32 ± 4.05	28 ± 9.91
Radicle length (mm)	44 ± 15.84	53 ± 1.05	48 ± 18.97	27 ± 12.00	52 ± 7.07	50 ± 6.69
			IR58			
Germination (%)	93 ± 1.94	91 ± 3.30	70 ± 17.91	93 ± 0.50	88 ± 3.16	78 ± 6.22
Height (mm)	54 ± 5.80	40 ± 4.60	30 ± 3.90	45 ± 1.75	43 ± 16.88	51 ± 3.45
Radicle length (mm)	65 ± 15.40	56 ± 7.39	55 ± 18.65	48 ± 12.12	59 ± 24	65 ± 2.68
			IR64			
Germination (%)	95 ± 2.32	97 ± 3.02	86 ± 7.90	97 ± 0.50	95 ± 3.60	89 ± 7.68
Height (mm)	47 ± 1.70	38 ± 3.60	37 ± 3.40	40 ± 2.50	40 ± 3.10	37 ± 1.87
Radicle length (mm)	60 ± 4.9	58 ± 10.50	63 ± 15.80	53 ± 2.50	57 ± 10.8	56 ± 11.72

[a]Figures in parentheses indicate number of isolates. [b]At 5 d after seeding.

Bak incidence. The bacterized seed had 1.6 to 67% Bak, compared with the check with 74%. Isolates 45, 55, 145, 97, and 165, which produced fluorescent pigments on King's medium B, appeared most effective (Table 2).

On ShB, isolate 55 was most effective, followed by isolate 125.

Many isolates did not reduce Bl infection. However, the lesions per hill on seeds coated with isolates 55, 22, and 91 were 53.2, 65.4, and 66.7, respectively, while the check produced 244.2.

Bacterization on Bl was also field-tested, with lesions counted at 50 DAS. Although the planting was 2 mo later than farmers' plantings, Bl developed enough for assessment of bacterial control. Isolates 41, 55, and 127 were comparable to fungicide treatments with validamycin. Moreover, leaf imprints on King's medium B detected the bacteria.

These results suggest great potential for using antagonistic bacteria isolated from ricefields to manage rice fungal diseases caused by *P. oryzae*, *R. solani*, and *F. moniliforme*. Few isolates, however, are effective against all three diseases.

***Trichoderma* spp.** In earlier studies (Annual report for 1986), 13 *Trichoderma* spp. were isolated from Philippine ricefields. The isolates varied in their cellulolysis adequacy index (CAI). We selected isolates having high CAI and mycoparasitism and determined their ability to control damping-off of mungbean caused by *R. solani* in the greenhouse.

A higher percentage of mungbean emerged with *T. glaucum*, *T. reesei*, and *T. viride* inoculations (Table 3). CAIs of different species of *Trichoderma* positively correlated with the number of seedlings that emerged in *Trichoderma*- and pathogen-treated soil. Isolates with high CAI had high saprophytic activity, reducing disease incidence.

T. reesei, *T. glaucum*, and *T. viride*—all high in disease control—were tested for survival ability in natural soil and for their effect on plant growth. Soil and *Trichoderma* were mixed 10:10, 10:0.5, and 10:0.01. Fifty mungbean seeds were sown, and emergence was recorded at 10 DAS. One month after mungbean harvest, 25 IR58 rice seeds were directly seeded in the same soil. *Trichoderma* populations in nonrhizosphere and rhizosphere soils were estimated by dilution plating using *Trichoderma* selective medium. All three *Trichoderma* spp. survived until crop maturity and colonized the rhizosphere of mungbean. Nonrhi-

Table 2. Effect of antagonistic bacteria on rice diseases in the greenhouse.[a] Korea, 1987.

Treatment	Disease incidence (%)		Blast lesions (no./hill)
	Bakanae	Sheath blight	
Control	73.9 g	46.0 de	244.2 f
Isolate 22	66.9 g	31.3 a-d	65.4 ab
Isolate 53	45.1 f	43.8 de	112.6 abc
Isolate 137	40.5 ef	33.4 a-e	229.4 ef
Isolate 125	36.8 ef	19.8 ab	102.6 ab
Isolate 91	32.0 def	44.8 de	66.7 ab
Isolate 167	28.0 c-f	41.7 cde	193.4 def
Isolate 72	24.9 b-e	27.1 a-d	166.6 cde
Isolate 127	23.4 b-e	40.1 b-e	85.4 ab
Isolate 162	16.4 a-d	27.1 a-d	172.8 cde
Isolate 166	15.2 a-d	31.3 a-d	208.5 ef
Isolate 41	11.5 abc	21.1 abc	101.9 ab
Isolate 165	7.4 ab	39.6 b-e	223.2 ef
Isolate 97	6.7 ab	52.6 e	130.6 bcd
Isolate 145	3.9 a	41.7 cde	99.8 ab
Isolate 55	2.2 a	17.7 a	53.2 a
Isolate 45	1.6 a	31.3 a-d	174.1 cde
Validamycin	–	28.4 a-d	–

[a]Av of 4 replications. In each replication, 3 fully expanded leaves/tiller in all of the plants were scored.

Table 3. Emergence of mungbean seedlings inoculated with 2 levels[a] of *Trichoderma* spp. in soil with *Rhizoctonia solani* inoculum. IRRI, 1987.

Trichoderma species	Germination (%) of mungbean	
	1	2
T. aureoviride	12.3	5.3
T. glaucum	39.6	17.3
T. hamatum	0	0
T. harzianum	6.7	0.67
T. koningii	3.3	0
T. longibrachiatum	9.3	2.7
T. polysporum	0	0
T. piluliferum	5.3	0
T. pseudokoningii	0	0
T. reesei	34.8	14.3
T. viride	37.7	12.6
Trichoderma sp. I	0	0
Trichoderma sp. II	0	0
No *Trichoderma* (control)	0	0

[a]*R. solani: Trichoderma* substrate: 1 = 1:1, 2 = 1:0.25.

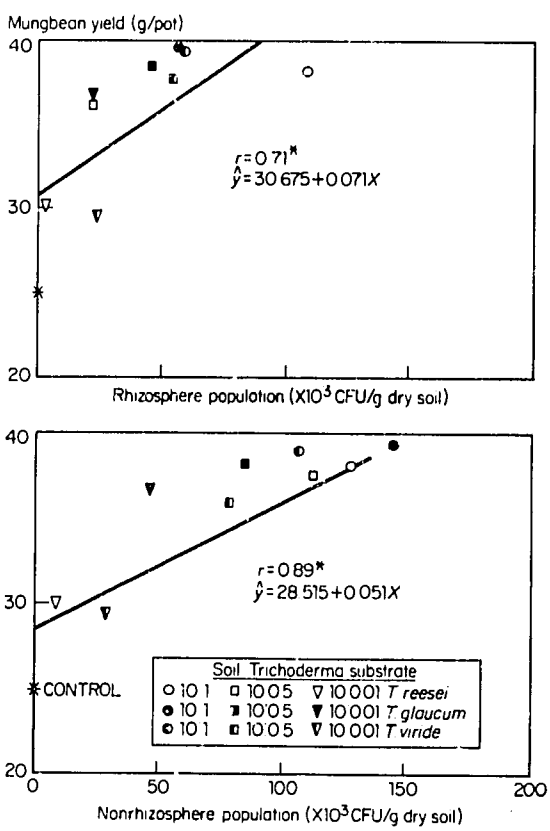
zosphere and rhizosphere *Trichoderma* populations at 10 DAS significantly correlated with the number and dry weight of mungbean seedlings that emerged. Furthermore, both populations at 20 and 90 DAS (Fig. 1) correlated significantly with mungbean yields. In rice grown after mungbean, rhizosphere populations of *Trichoderma* spp. increased (Fig. 2).

Changes in the population of infective mycorrhizal fungi. In 1985 and 1986, we reported mycorrhizal population changes at different stages in the rice-based cropping systems in Nueva Ecija, Philippines, and ShB reductions in rice and maize from adding mycorrhizal fungi to soil. We continued to determine the infectious vesicular-arbuscular mycorrhizal (VAM) fungi in one rainfed ricefield in Manaoag, Pangasinan, Philippines.

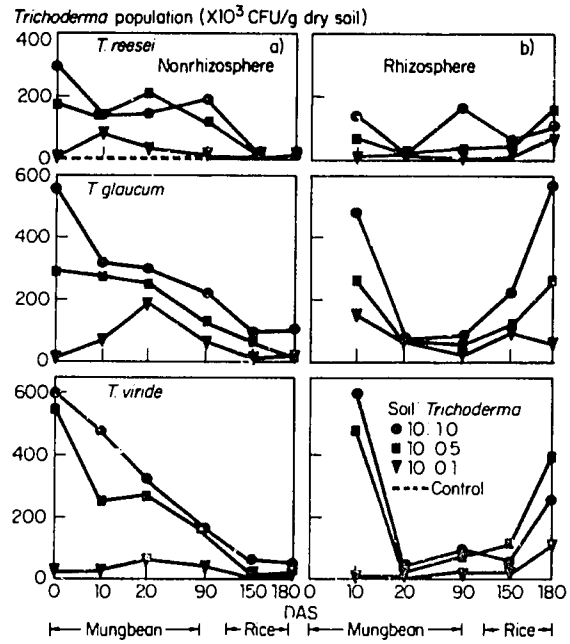
The inoculum potential was lowest in soil sampled after land preparation, and highest at upland crop maturity (Fig. 3). The VAM fungal population plummeted after harvest, when soil was plowed under, increased at early crop stages, and peaked at maturity.

Comparing the endomycorrhizal inoculum potential of rhizosphere and nonrhizosphere soils from the same field showed that the soil associated with roots had more infective VAM propagules than the soil some distance from the roots (Table 4).

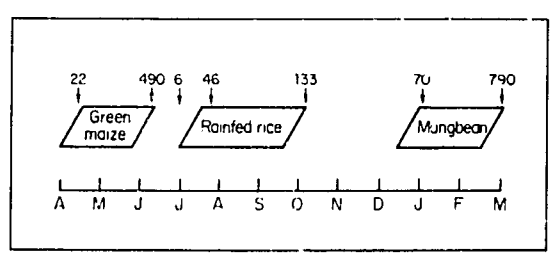
Weeds in fallow fields were all mycorrhizal except for *Saccharum spontaneum* sampled from lungog after harvest of irrigated rice (Table 5). However, *S. spontaneum* roots from Manaoag



1. Relation between mungbean yield and rhizosphere and nonrhizosphere populations of 3 *Trichoderma* spp. at 90 d after seeding. IRRI, 1987.



2. Rhizosphere and nonrhizosphere populations of 3 *Trichoderma* spp. at different growth stages of mungbean and rice, IRRI, 1987. DAS = days after seeding.



3. Endomycorrhizal fungal populations at various stages of the cropping pattern in a rainfed ricefield in Manaoag, Pangasinan, Philippines, 1987.

Table 4. Most probable number (MPN) of VAM fungal propagules per 100 g air-dried soil in the rhizosphere and nonrhizosphere areas sampled from a rainfed ricefield in Manaoag, Pangasinan, Philippines, 1987.

Area sampled	Rhizosphere		Nonrhizosphere	
	MPN	Range[a]	MPN	Range[a]
A	350	106-1155	23	7-76
B	110	38- 363	22	7-73
C	268	81- 884	25	8-83

[a]95% confidence limits.

collected after harvest of rainfed rice were colonized by VAM fungi.

In a pot experiment with weeds allowed to grow with rice in field soil, all weeds were mycorrhizal in soil watered to field capacity until the rice matured and in soil flooded for 3 wk after transplanting, then drained and watered to field capacity until the crop matured (Table 6).

SEED PATHOLOGY

Plant Pathology Department

Pseudomonad pathogen. Grain and sheath discoloration is becoming a serious problem in the tropics. Scientists at the Centro Internacional de Agricultura Tropical identified *Pseudomonas fuscovaginae*, causing bacterial sheath brown rot, as the major cause. They also reported that the pathogen had been isolated from Philippine seeds. In 1987, we started to explore the relationship of sheath and grain discoloration on rice at IRRI.

We isolated fluorescent and nonfluorescent bacteria from apparently infected seedlings, dark brown sheaths, and partially or completely discolored grains. The seedlings were taken from blotter tests and nursery beds, while the sheaths and grains were collected from the IRRI farm. The fluorescent bacteria showing greenish or bluish fluorescence on King's medium B by tissue plating were isolated more often from grains than from sheaths and seedlings. To determine pathogenicity, cultivar Cica 8 was inoculated at the early tillering stage. Because reports showed that a high concentration of these pseudomonads generally cause browning on sheaths, we tested the inoculation method and the inoculum concentration. We used a concentration of 0.30 O.D. at 420 nm by injection, in KB cabinets (25/25 °C day and night temperature, 98% relative humidity (RH)) or in the greenhouse.

Of 135 isolates tested, 73 showed dark brown to purplish brown discoloration on sheaths, extending linearly from infections. Lesions appeared water-soaked with undefined margins under low temperature and high RH. Greenhouse tests showed a similar but restricted discoloration and no water-soaked appearance. The inoculated plants grown until maturity yielded partially or completely discolored grains.

Table 5. Mycorrhizal weeds in Philippine ricefields, 1987.

Weed	Location[a]	Mycorrhizal rating[b]	Sampling stage
Saccharum spontaneum L.	Manaoag, Pangasinan	3	After harvest of rainfed lowland rice
S. spontaneum L.	Lungog, Guimba, Nueva Ecija	0	After harvest of irrigated rice
Commelina sp.	Manaoag, Pangasinan	1	After harvest of rainfed lowland rice
Cyperus sp.	Turod, Guimba, Nueva Ecija	1	Fallow period before the wet season rice crop
Echinochloa colona (L.) Link	Turod, Guimba, Nueva Ecija	2	Fallow period
Paspalum distichum L.	Lungog, Guimba, Nueva Ecija	2	Fallow period

[a]Lungog = low-lying stratum, turod = upper stratum. [b]Mycorrhizal rating, qualitative and descriptive: 0 = no mycorrhiza formed, 1 = 1 to 5% of roots colonized, 2 = 6 to 26% of roots colonized, 3 = 27 to 50% of roots colonized. All those rated above 0 showed larger, more uniformly distributed colonization sites.

Table 6. Mycorrhizal weeds growing with rice in pots under varying moisture conditions. IRRI, 1987.

Moisture condition of soil	Weed species	Mycorrhizal rating[a]
Soil flooded up to maturity	*Monochoria vaginalis* (Burm. f.) Presl.	0
Soil flooded for 3 wk after transplanting, then drained and watered to field capacity until maturity	*Cynodon dactylon* (L.) Pers.	1 s
	Cyperus difformis L.	2 s
	C. iria L.	1 l
	Eclipta zippeliana Bl.	3 s
	Lindernia anagallis (Burm. f.) Pennel	1 s
	Ludwigia hyssopifolia (G. Don.) Excell	2 l
	Mimosa pudica L.	3 l
	Rotala catholica (C. & S.) B. Van Leeuwen	1 s
Soil watered to field capacity until maturity	*Cleome rutidosperma* DC.	3 l
	Cyperus difformis L.	1 l
	C. iria L.	1 s
	Eleusine indica (L.) Gaertn.	1 s
	Eragrostis tenella L. Beauv. ex R. & S.	1 s
	Lindernia anagallis (Burm. f.) Pennel	1 s
	Rotala catholica (C. & S.) B. Van Leeuwen	1 s
	Scoparia dulcis L.	2 l
	Vernonia cinerea (L.) Less.	1 s

[a]Mycorrhizal rating: 0 = no mycorrhiza, 1 = 1 to 5% of roots colonized, 2 = 6 to 26% of roots colonized, 3 = 27 to 50% of roots colonized. s = small, widely scattered colonization sites, l = larger, more uniformly distributed colonization sites.

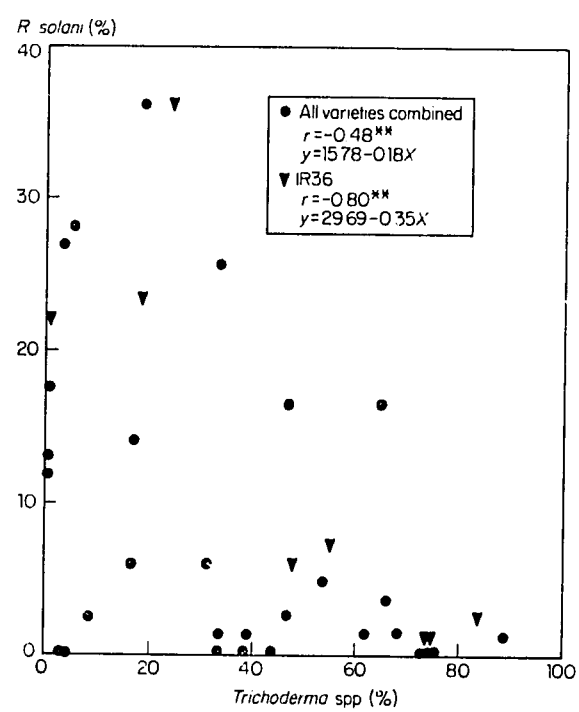
ECOLOGY AND EPIDEMIOLOGY

Plant Pathology, Entomology, and Agronomy Departments

Saprophytic survival of *Rhizoctonia solani* (*Plant Pathology*). We studied the survival of *R. solani*, the ShB pathogen, from infected varieties differing in resistance: IR64, IR62, IR36, and IR58. IR64 and IR62 are moderately resistant to ShB, while IR36 and IR58 are susceptible. Straw pieces 2.5 cm long were buried in upland soil at 50 pieces/treatment. At 2-wk intervals for 8 wk, the straws were sampled and plated in acidified potato dextrose agar. Recovered *R. solani* and *Trichoderma* were counted.

The recovery of *R. solani* was negatively correlated (r = -0.48**) with increase in *Trichoderma* (Fig. 4), especially with IR36 (r = -0.80**). Apparently, IR36 straw decomposed faster. Therefore IR36, although more susceptible than other varieties to *R. solani*, may not be an important source of inoculum. In contrast, IR64 and IR62, though less susceptible than IR36, decompose slower, and so may serve as an important source of inoculum. The *Trichoderma* in the soil will affect the inoculum potential through its ability to decompose the straw.

Sheath blight and inoculum dynamics (*Plant Pathology*). To determine the varietal differences in ShB severity, inoculum dynamics, and the role of *Trichoderma* population, the same four varieties were planted for five continuous upland croppings starting in 1985 DS (January-May) and ending in 1987 DS (February-June). Each variety was direct seeded in hills 0.20 cm apart in plots measuring 3.6 × 2.8 m. Each treatment was replicated four times. The first crop was initially inoculated with LR-1 isolate of *R. solani* in rice



4. General relation between the recovery of *R. solani* and recovery of *Trichoderma* spp. from infected tissues of IR64, IR62, IR58, and IR36 buried under upland soil. IRRI, 1987

grain-rice hull medium. Disease severity, based on relative lesion height of ShB, was obtained at flowering and at 15-20 d after flowering.

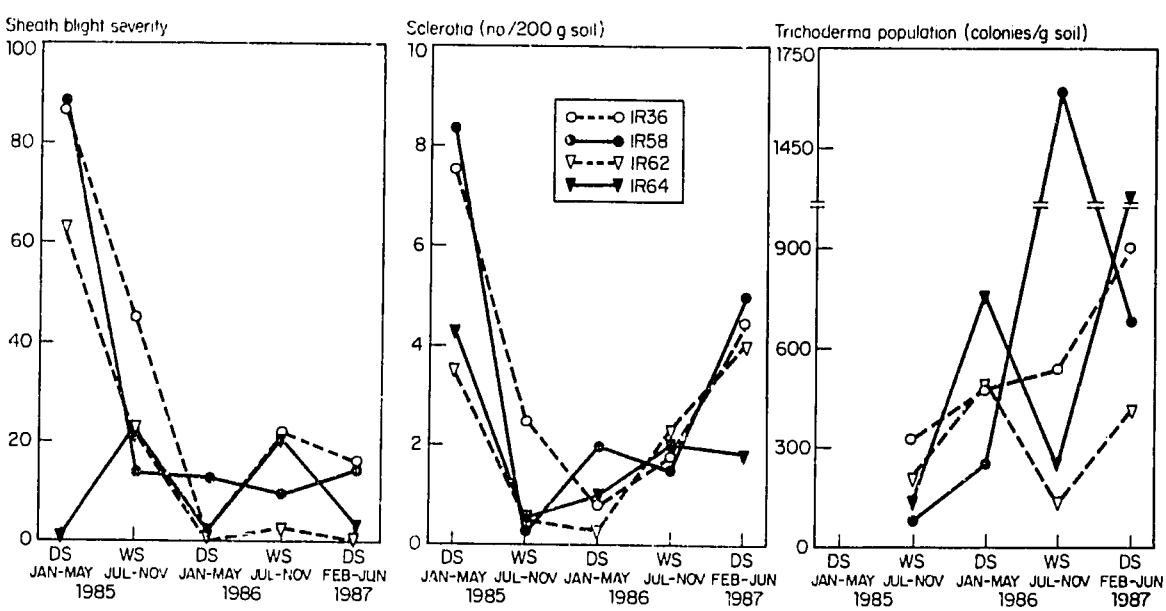
Although the inoculum level was low, results indicate a positive relationship between ShB severity and inoculum production (Fig. 5) except when disease was low. The low disease level was apparently due to environment. Further study will focus on varietal resistance, disease severity, inoculum dynamics, and influence of environment.

Trichoderma population was high when the disease was low. Hence, *Trichoderma* and varietal resistance both affect disease level and, ultimately, inoculum production.

Serology of *Xanthomonas campestris* pv. *oryzae* (*Plant Pathology*). Plant quarantine services and epidemiologists need a tool to rapidly detect and identify *Xanthomonas campestris* pv. *oryzae* (Xco). To monitor and identify Xco races now requires 65 d. With a specific antiserum, the pathogen could be identified in several hours.

The serological groupings of the Philippine isolates of Xco were investigated using antisera to glutaraldehyde-fixed cells and extracellular glycoproteins of PXO 86, using Ouchterlony double diffusion tests (Table 7). Within Serovar 1, two subgroups were recognized: Serovar 1a with two, and Serovar 1b with three precipitin bands, representing 60 and 35% of the 139 isolates examined, respectively. Isolates (2%) not reacting with the antiserum were temporarily designated Serovar 2. The antiserum did not cross-react with antigens of 14 other pathovars of *X. campestris* and 13 other bacteria belonging to 8 genera.

The one serogroup observed using extracellular glycoprotein antiserum (Table 8), Serovar A, had two major and two minor subgroups. The major subgroups Serovar A1 and Serovar A2, characterized by 2 and 3 precipitin bands, respectively, constituted 58 and 40% of the 90 isolates tested. The minor subgroups Serovar A3 and Serovar A4, with only one isolate each, were variants of Serovar A2 and Serovar A1, respectively. The antisera cross-reacted with other *X. campestris* pathovars when nontreated antigens were used. With heated antigens, only the Xco precipitin band was noted. Certain races clustered to their serovars or subgroups, but without clear-cut specificity.



5. Dynamics of sheath blight, sclerotial count, and *Trichoderma* populations in 5 successive croppings of selected rice varieties, IRRI, 1987. The first crop was artificially inoculated with *R. solani* in rice grain-rice hull medium. No data on *Trichoderma* population were taken at first cropping. DS = dry season, WS = wet season.

Table 7. Groupings of Philippine strains of *Xanthomonas campestris* pv. *oryzae* based on Ouchterlony double diffusion tests using antiserum to glutaraldehyde-fixed cells of Xco isolate PXO 86, race 2, IRRI, 1987.

Antigen	Isolate distribution among 3 groups[a]			Total isolates (no.)
	Serovar 1a	Serovar 1b	Serovar 2	
Race 1	PXO: 5, 39, 48, 61, 62, 68, 77, 102 IRN: 201, 207, 455, 874, 950, 961, 974, 997, 1005, 1009, 1017	PXO: 66B	PXO: 35 IRN: 955	22
Race 2	PXO: 63, 82, 86 IRN: 144, 166, 260, 340, 404, 409, 436 449, 511, 514, 522, 643, 644, 670, 673, 695, 738, 781, 783, 795, 890, 900, 944, 951, 975, 976	PXO: 78, 134, 139 IRN: 169A, 209, 250, 403, 435, 611, 687, 712, 719, 760, 772 779, 780, 825, 927, 940, 944, 956, 959, 978, 985, 1008, 1010, 1020	IRN: 543	57
Race 3	PXO: 79, 87, 81, 143 IRN: 136, 224, 281, 458, 463, 534, 702, 830, 858, 920, 924, 928, 929, 933, 953, 962, 994, 1019	0	0	22
Race 4	PXO: 69, 71, 125	PXO: 70	0	4
Race 5	PXO: 45, 80, 105, 111, 144 IRN: 243, 394, 753	PXO: 108, 110, 112 IRN: 758, 759, 963 966, 968	PXO: 145	17
Race 6	PXO: 120, 121	PXO: 99, 114, 115, 116, 117, 118, 119, 122, 123, 124, 127	0	13
Total	83	49	3	135

[a]Serovar 1a = 2-precipitin-band group, Serovar 1b = 3-precipitin-band group, Serovar 2 = no precipitin band group; designation temporary.

The research explored the potential of polyclonal antibodies to detect and identify Xco and its races. Antiserum was produced from PXO 86 of race 2. Xco cells were effectively detected by direct fluorescent-antibody staining (FAS). FAS solution was prepared using antiserum to PXO 86 cells fixed in 2.5% glutaraldehyde and fluorescein-isothiocyanate. It had a high degree of specificity based on tests with 117 isolates representing 6 races of Xco collected from 1972 to 1986 in 54 Philippine provinces; 25 naturally infected rice leaf samples representing 4 races from 15 provinces; 14 other pathovars of *X. campestris*; 13 bacterial cultures from 8 genera; and 80 bacterial contaminants from isolation plates of rice seed washings and ricefield water.

The FAS procedure also detected Xco from young panicles of infected plants, symptomless rice and weed leaves, and necrotic lesions atypical of bacterial blight. In controlled experiments where Xco was mixed with pure cultures of other bacteria or rice seed and leaf washings or ricefield water with a background bacterial count of 10^6 to 10^8 CFU/ml, the practical detection (sensitivity) limit of the FAS procedure was 10^4 CFU Xco/ml. The reactions of the different isolates of the six Xco races to FAS showed that the specificity of antiserum to glutaraldehyde-fixed cells could not be related to race virulence.

GLH abundance and tungro incidence in asynchronous planting (*Plant Pathology and Entomology*). A newly developed ricefield in Carmen, Bohol, Philippines, planted synchronously, and a field in Bilar, Bohol, planted asynchronously, were selected to determine green leafhopper (GLH) abundance and tungro (RTV)

Table 8. Groupings of Philippine strains of *Xanthomonas campestris* pv. *oryzae* based on Ouchterlony double diffusion test using antiserum to extracellular glycoprotein of Xco isolate PXO 86, race 2. IRRI, 1987.

Antigen	Isolate distribution[a]				Total isolates (no.)
	Serovar A1	Serovar A2	Serovar A3	Serovar A4	
Race 1	PXO: 48, 61, 62, 66B IRN: 207, 857, 884, 126, 206, 223, 280, 339, 402, 442, 522, 662, 670, 732, 738, 760	PXO: 1, 10, 26, 29 IRN: 453, 454, 457	PXO: 35 IRN: 730, 735	0 IRN: 525	31
Race 3	PXO: 81, 87 IRN: 140, 146, 269, 290, 405, 650, 681, 686, 702, 827, 840, 920	PXO: 79	0	0	15
Race 4	PXO: 71	PXO: 7, 69, 125, 129	0	0	5
Race 5	PXO: 45, 64, 65B, 80, 105, 112, 161 247, 572, 573, 754, 755, 758, 759				14
Race 6	0	PXO: 99, 114, 115 116, 117, 118, 119, 120, 121, 122, 123, 124, 127, 128	0	0	14
Total	49	26	3	1	79

[a]Serovar A1 = 2-precipitin-band group, Serovar A2 = 3-precipitin-band group, Serovar A3 = 1-precipitin-band group and variant of Serovar A2, Serovar A4 = 1-precipitin-band group and variant of Serovar A1.

incidence during the 1987 wet season (WS). In 0.6-ha fields planted to IR64, GLH abundance was estimated by sweep net and kerosene light trap (KLT) catches, and RTV incidence by visual assessment and by latex serology.

The pattern of GLH collected by sweep net was similar at both sites (Fig. 6). GLH numbers increased in both fields within 1 mo after transplanting. Although the number of GLH caught by KLT fluctuated considerably throughout the cropping season, many were caught before transplanting in both fields. At crop maturity, KLT again caught GLH in Carmen.

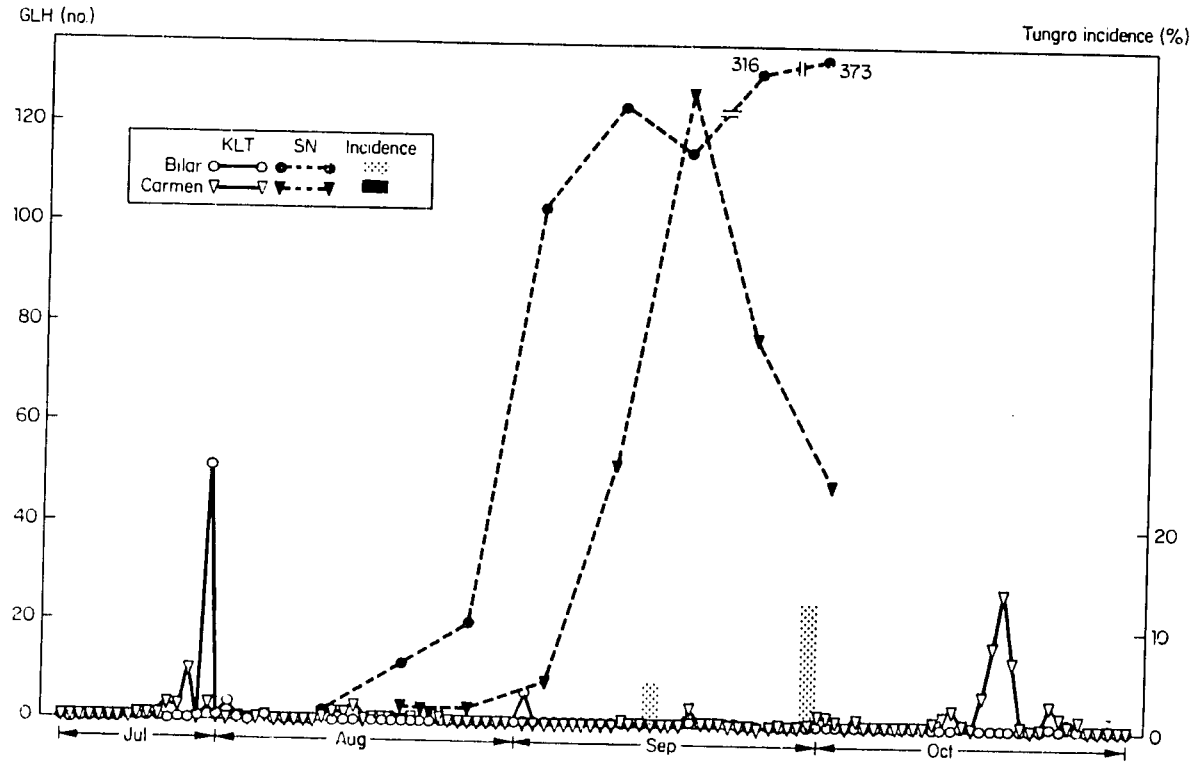
RTV incidence was 4% at Bilar and 0.06% in Carmen (Table 9). In Bilar, rice tungro spherical virus (RTSV) infection was 18.7% at 42 d after transplanting (DT) and 31.8% at 76 DT, while rice tungro bacilliform virus (RTBV) + RTSV infection was 24.0% at 42 DT and 38.3% at 76 DT.

Tungro infection in broadcast and transplanted rice (*Plant Pathology*). In 1986 WS and 1987 dry season, RTV incidence and GLH population density in broadcast and transplanted IR36 and TN1 were compared at 34-46 d after seed soaking. Broadcast seeding rate was 70 kg/ha, and spacing in transplanted fields was 20 × 20 cm.

By symptoms, RTV was more prevalent in transplanted than in broadcast fields of both varieties regardless of cropping season. By sweeping, GLH density was higher in transplanted rice of both varieties (Table 10).

Host range of rice viruses (*Plant Pathology and Agronomy*). *Rice tungro-associated viruses.* Seven accessions of *Oryza* spp. and 19 weed species were tested for susceptibility to RTBV and RTSV. Young seedlings were inoculated by 10 viruliferous GLH fed on RTV-infected plants for 4 d. Inoculated plants were indexed by enzyme-linked immunosorbent assay (ELISA) at 30 d after inoculation (DAI) for RTBV and RTSV. Uninoculated plants served as controls. Inoculated plants having absorbance at 405 nm of 3 times that of healthy plants were considered infected.

All seven accessions of *Oryza* spp. tested were infected with RTBV (Table 11). *O. australiensis*, *O. longistaminata*, and *O. barthii* were also infected



6. Number of green leafhoppers (GLH) caught daily by kerosene light trap (KLT) and weekly by sweep net (SN), and tungro incidence in IR64 grown synchronously (Carmen) and asynchronously (Bilar). Bohol, Philippines, 1987 WS.

Table 9. Rice tungro bacilliform (RTBV) and spherical (RTSV) viruses in synchronous (Carmen) and asynchronous (Bilar) plantings of IR64 at different times after transplanting.[a] Bohol, Philippines, 1987 WS.

Location	Plants infected (%) at 19 DT[b]		Plants infected (%) at 42 DT			Plants infected (%) at 76 DT		
	RTBV+RTSV	RTSV	RTBV+ RTSV	RTBV	RTSV	RTBV+ RTSV	RTBV	RTSV
Bilar	0	0.2	24.0	1.7	18.7	38.3	3.4	31.8
Carmen	0.3	1.0	0.2	0.2	2.0	0.8	0	5.0

[a]DT = days after transplanting. [b]No plant had RTBV alone.

Table 10. Green leafhopper (GLH) collected by sweep net and tungro (RTV) incidence in broadcast and transplanted IR36 and TN1. IRRI, 1986 WS and 1987 DS.

Variety, treatment	1986 wet season		1987 dry season	
	GLH density (no.)	RTV incidence (%)	GLH density (no.)	RTV incidence (%)
IR36				
Broadcast	13 a	5 a	8 a	7 a
Transplanted	43 b	27 b	12 a	20 b
TN1				
Broadcast	11 a	31 a	7 a	14 a
Transplanted	12 a	64 b	71 b	80 b

with RTSV. Weed species infected with both viruses were *Cyperus rotundus* and *Fimbristylis miliacea* (Table 11). Some weeds were infected with either RTBV or RTSV. Weeds not infected by either virus were *Brachiaria distachya, Chloris barbata, Cynodon dactylon, Cyperus brevifolius, Cyperus difformis, Digitaria ciliaris, Echinochloa colona, Eragrostis tenella, Imperata cylindrica, Leptochloa chinensis, Paspalidium flavidum*, and *Paspalum dilatatum*.

Seedlings of 4 *Oryza* spp. and 19 weed species were inoculated by RTSV-viruliferous GLH at

Table 11. Absorbance at 405 nm in ELISA of extracts of plants infected with RTBV or RTSV after inoculation by RTBV + RTSV viruliferous GLH. IRRI, 1987.

Species	Inoculated plants (no.)	RTBV			RTSV		
		Infected plants (no.)	Absorbance at 405 nm		Infected plants (no.)	Absorbance at 405 nm	
			Infected plants	Uninoculated plants		Infected plants	Uninoculated plants
Oryza australiensis							
Acc. 100882	8	4	0.98-1.95	0.00	0	–	0.00
Acc. 101397	12	2	1.20-1.51	0.18	1	0.07	0.00
Acc. 101144	7	4	0.50-1.48	0.00	0	–	0.00
O. barthii							
Acc. 100122	8	8	0.20-0.44	0.00	8	0.48-1.39	0.00
Acc. 100921	5	5	0.15-0.40	0.00	3	1.01-1.11	0.02
O. latifolia	10	2	0.25-0.48	0.00	0	–	0.02
O. longistaminata	10	9	0.57-1.51	0.14	4	0.34-0.89	0.00
Axonopus compressus	12	0	–	0.01	5	0.18-0.46	0.00
Brachiaria mutica	8	0	–	0.02	4	0.06-0.06	0.00
Cyperus rotundus	9	1	0.20	0.05	1	0.36	0.00
Eleusine indica	12	3	0.04-0.14	0.01	0	–	0.00
Fimbristylis miliacea	12	8	0.11-1.47	0.00	1	0.36	0.00
Leersia hexandra	10	2	0.14-0.17	0.04	0	–	0.00
Monochoria vaginalis	12	1	0.33	0.10	0	–	0.11

10/seedling. Inoculated plants were indexed by ELISA at 30 DAI.

Four of 6 accessions of *Oryza* spp. and 13 of 19 weed species were infected with the virus (Table 12). Species not infected were *O. australiensis, O. latifolia Axonopus compressus, B. distachya, Chloris barbata, L. chinensis, Paspalidium flavidum*, and *Paspalum conjugatum*.

Rice grassy stunt virus, strain 2. Seedlings of 6 accessions of 4 *Oryza* spp. and 18 weed species were inoculated by rice grassy stunt virus (GSV-2)-viruliferous BPH at 20/seedling. At 1 mo after

Table 12. Absorbance at 405 nm in ELISA of extracts of plants infected with RTSV. IRRI, 1987.

Species	Inoculated plants (no.)	Infected plants (no.)	Absorbance at 405 nm	
			Infected plants	Uninoculated plants (mean)
Oryza australiensis (Acc. 101144)	7	5	0.11-0.29	0.03
O. australiensis (Acc. 101397)	12	3	0.09-0.14	0.02
O. barthii (Acc. 100117)	3	3	0.89-1.11	0.05
O. longistaminata (Acc. 101196)	9	4	0.12-1.82	0.03
Brachiaria mutica	20	3	0.05-0.09	0.01
Cynodon dactylon	22	10	0.07-0.15	0.02
Cyperus brevifolius	8	1	0.08	0.00
C. difformis	10	5	0.13-0.54	0.04
C. rotundus	12	6	0.04-0.45	0.01
Digitaria ciliaris	10	5	0.10-0.15	0.00
Echinochloa colona	12	3	0.34-0.40	0.10
Eleusine indica	12	4	0.04-0.12	0.01
Eragrostis tenella	10	2	0.18-0.37	0.05
Fimbristylis miliacea	12	5	0.10-0.35	0.00
Imperata cylindrica	10	4	0.36-0.43	0.10
Leersia hexandra	10	2	0.05-0.07	0.00
Monochoria vaginalis	11	2	0.13-0.16	0.02

inoculation, the second youngest leaf of each inoculated plant was indexed by ELISA. All six *Oryza* spp. tested were infected with GSV-2 (Table 13). Of 18 weed species, 5 were infected. Weed species not infected were *Cyperus brevifolius, A. compressus, B. distachya, B. mutica, Chloris barbata, Cyperus rotundus, Digitaria ciliaris, Eleusine indica, Eragrostis tenella, Fimbristylis miliacea, Imperata cylindrica, Leptochloa chinensis, Paspalidium flavidum, Paspalum conjugatum*, and *Pennisetum glaucum*.

Rice ragged stunt virus. Young seedlings of 3 *Oryza* spp. and 15 weed species were inoculated with rice ragged stunt virus-viruliferous BPH. Inoculated plants were indexed by ELISA at 30 DAI. All *Oryza* spp. tested were infected with the virus (Table 14). Six of 15 weed species were infected (Table 14). Weed species not infected were *B. distachya, B. mutica, Chloris barbata, Cyperus brevifolius, Cyperus difformis, Eleusine indica, Imperata cylindrica, Leptochloa chinensis*, and *Paspalum conjugatum*.

Tungro infectivity of field-collected green leafhopper (*Plant Pathology*). GLH collected by aspirator in a field planted to TN1 at different times after transplanting were tested for infectivity on TN1 seedlings. At 1 mo after inoculation, all inoculated TN1 seedlings were scored visually for infection and indexed by ELISA for RTBV and RTSV. RTV incidence in the same field was also determined visually and by ELISA.

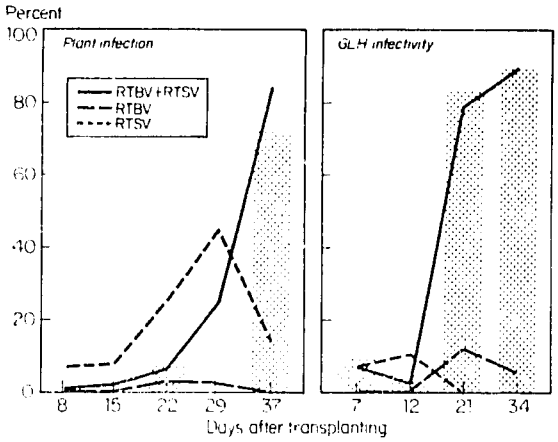
At 15 DT, RTSV infection increased sharply (Fig. 7). At 22 DT, RTBV + RTSV infection increased remarkably. RTV, not observed the first 2 wk after transplanting, steadily increased after 15 DT. RTV-infective GLH collected at 7 and 12 DT

Table 13. Absorbance at 405 nm in ELISA of extracts of plants infected with GSV-2. IRRI, 1987.

Species	Inoculated plants (no.)	Infected plants (no.)	Absorbance at 405 nm	
			Infected plants	Uninoculated plants (mean)
Oryza australiensis (Acc. 100882)	14	6	0.08-1.40	0.00
O. australiensis (Acc. 101144)	9	3	0.16-0.32	0.00
O. australiensis (Acc. 101397)	5	3	0.19-0.99	0.00
O. barthii (Acc. 100117)	3	2	0.68-1.14	0.04
O. latifolia (Acc. 100168)	10	4	0.27-0.70	0.03
O. longistaminata (Acc. 101196)	3	3	0.09-0.33	0.00
Cynodon dactylon	10	4	0.05-0.14	0.01
Cyperus rotundus	9	5	0.24-0.96	0.05
Echinochloa colona	10	2	0.08-0.40	0.02
Monochoria vaginalis	10	1	0.10	0.03

Table 14. Absorbance at 405 nm in ELISA of extracts of plants infected with RSV. IRRI, 1987.

Species	Inoculated plants (no.)	Infected plants (no.)	Absorbance at 405 nm	
			Infected plants	Uninoculated plants (mean)
Oryza australiensis (Acc. 100882)	14	2	0.13-0.48	0.00
O. latifolia (Acc. 100168)	10	3	0.13-0.22	0.01
O. australiensis (Acc. 101397)	12	6	0.07-0.29	0.00
Axonopus compressus	12	1	0.15	0.04
Cynodon dactylon	12	1	0.17	0.03
Cyperus rotundus	16	1	0.25	0.08
Eragrostis tenella	12	3	0.12-0.37	0.04
Fimbristylis miliacea	12	3	0.10-0.28	0.00
Leersia hexandra	28	5	0.06-0.12	0.00



7. Tungro incidence (shading) based on symptoms and on tungro bacilliform virus (RTBV) and tungro spherical virus (RTSV) incidence from ELISA, and infectivity of GLH (shading) in field planted to TN1 at different days after transplanting. IRRI, 1987.

might have been immigrant. Infective GLH increased remarkably when RTV incidence started to increase.

Recovery of rice tungro virus from rice stubble (*Plant Pathology*). Rice stubbles of IR64 and TN1 naturally infected with RTBV and RTSV were used as virus sources at 2 wk after harvest at IRRI in 1987. Virus-free male GLH (colony selected on TN1) introduced on caged and uncaged stubble were collected the following day and tested on TN1 seedlings for infectivity. Likewise, GLH collected by sweep net on 1- and 4-wk-old stubbles were tested.

GLH mortality was higher on IR64 stubble than on TN1 stubble. Most GLH transmitted either RTBV + RTSV or RTBV alone (Table 15). GLH collected in IR64 by sweep net were not infective, and those collected on TN1 had low infectivity.

Effects of tungro on symptoms and yield (*Plant Pathology*). *Symptoms.* Seedlings (5- to 7-d-old) of 7 selected varieties were inoculated by RTV-viruliferous GLH and transplanted in pots. Between 1 and 2 wk after inoculation, plants infected with RTBV + RTSV, RTBV, and RTSV were serologically identified by ELISA or the latex test. Uninoculated seedlings served as controls.

Plants infected with RTSV did not show any clear symptoms (Table 16). RTBV-infected plants had milder symptoms than plants infected with both RTBV and RTSV. Plants infected with both viruses lacked symptoms in Balimau Putih, had very mild symptoms in Utri Rajapan, and had symptoms distinct at the early stages, becoming milder, in Palasithari and Sigadis. In BW272-6B and FK135, RTBV-infected plants showed symptoms as severe as those on plants infected with both viruses.

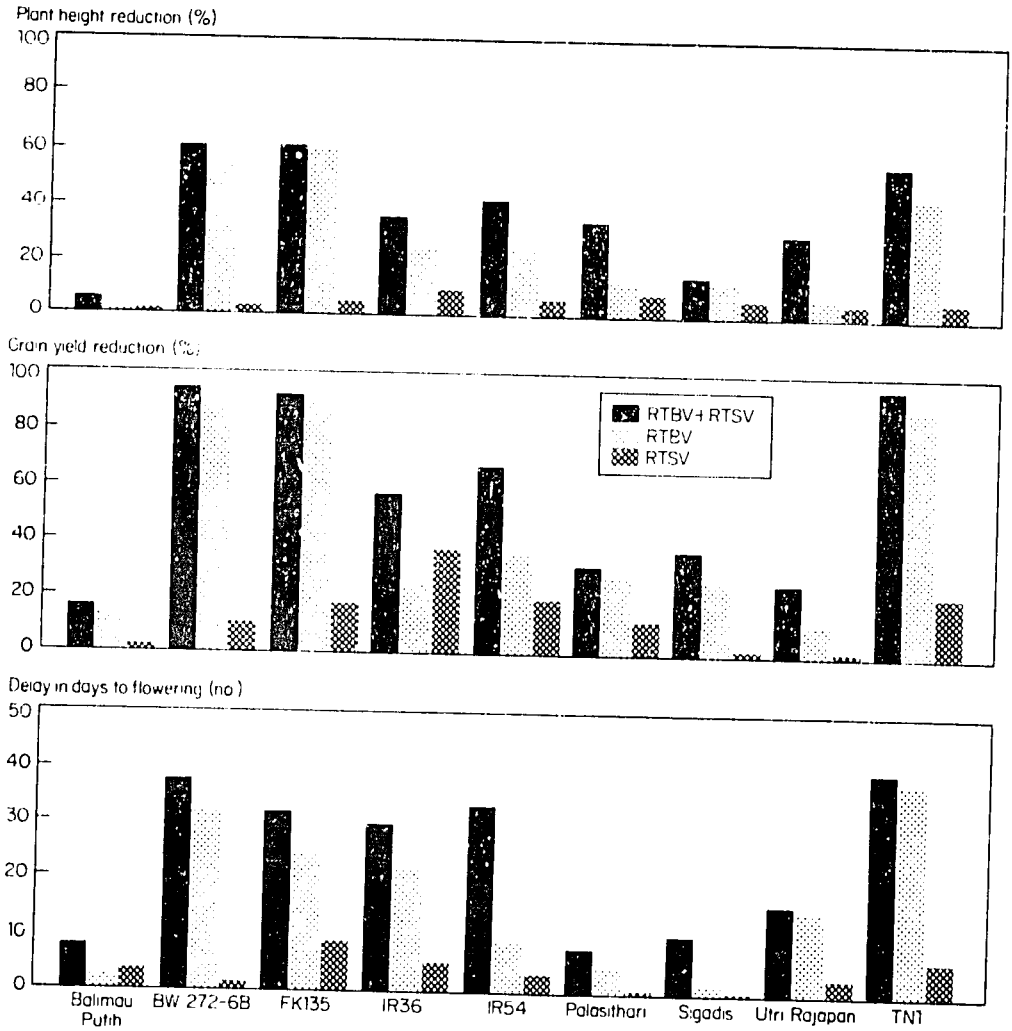
Growth parameters and yield components. RTV infection, studied in two trials at IRRI in 1986-87, had similar effects on plant growth and yield. Balimau Putih, Palasithari, Sigadis, and Utri Rajapan had less reduction in plant height at 9 wk after inoculation (WAI), in effective tiller number, filled grain number, and grain yield, and less delay in days to flowering (Fig. 8). BW272-6B, FK135, IR36, IR54, and TN1 had greater reduction in height and yield components, and more delay in days to flowering. Yield reduction was as high as 40% in IR36 infected with RTSV alone.

Effect of plant age when infected. Seedlings of Balimau Putih, IR54, Sigadis, and TN1 were inoculated with RTV at 1, 3, 5, or 7 wk after

Table 15. Infectivity of GLH exposed for 1 d on caged and uncaged RTV-infected stubble of IR64 and TN1. IRRI, 1987.

Stubble[a]	Caged stubble					Uncaged stubble			
	Av tillers (no.)	GLH recovered and tested (%)	GLH transmitted (%)			Av tillers (no.)	GLH recovered and tested (%)	GLH transmitted[b] (%)	
			RTBV+ RTSV	RTBV	RTSV			RTBV+ RTSV	RTBV
IR64	15 a	34 a	37 a	28 a	9 a	16 a	4 a	15 a	23 a
TN1	29 b	49 b	40 a	41 b	5 a	25 b	13 a	41 a	22 a

[a]Forty stubbles of IR64 and 20 of TN1 were exposed to GLH at 20 GLH/stubble for each treatment. [b]No RTSV was transmitted.



8. Reduction in plant height and grain yield, and delay in days to flowering in plants of 9 varieties infected with RTBV + RTSV, RTBV, or RTSV at 5-7 d after soaking, IRRI, 1986-87. Means of two trials.

soaking, and the growth and yield of plants infected with RTBV or RTSV, or both were recorded. Plant height was measured at 9 wk after soaking. IR54 yields were greatly reduced by infection at 3 or 5 wk after soaking (Fig. 9). Sigadis yields were greatly reduced with infection at 3 wk, but less so when infected at 5 or 7 wk. TN1 yields were low with infection at 1 wk, but better when infected at 7 wk.

Correlation between virus concentration and symptom severity in tungro-infected rice (*Plant Pathology*). Seedlings (5- to 7-d-old) were inoculated by RTV-viruliferous GLH and transplanted in pots. At 1, 3, 5, and 7 WAI, at least 5 plants infected with RTBV + RTSV, and 4 uninoculated plants of each variety were harvested (excluding roots) and separately homogenized in buffer solution. Homogenate at 1:10 dilution was directly tested by ELISA.

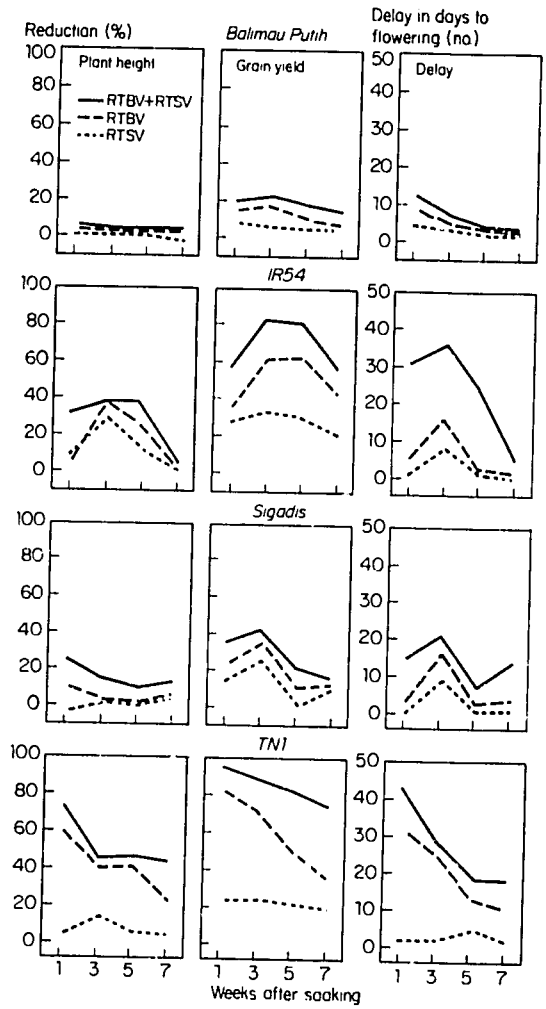
RTBV concentration was generally high at 1 or 3 WAI and declined thereafter (Fig. 10). The concentration was especially low at 5 and 7 WAI in Balimau Putih, Utri Rajapan, Jingasail, and FK135, but high in BW272-6B, IR54, IR36, and TN1.

Virus concentration in doubly infected plants of RTV- tolerant and -intolerant varieties at 3 WAI was compared. RTBV concentration in tolerant

Table 16. Symptoms expressed at 1, 3, 5, and 7 wk after infection on plants infected with RTBV + RTSV, RTBV, or RTSV at 5-7 d after soaking. IRRI, 1986.

Variety	Time after infection (wk)	Symptoms[a] of plants infected with	
		RTBV+ RTSV	RTBV
Balimau Putih	1	NS	NS
	3	NS	NS
	5	NS	NS
	7	NS	NS
BW272-6B	1	S, DC, DL	S, dc
	3	S, DC, DL	S, dc
	5	S, DC, DL	S, dc
	7	S, dc, DL, TR	S, dc, TR
FK135	1	S, DC	S, dc
	3	S, dc, ly, DL	D, dc, ly, DL
	5	S, dc, ly, DL	S, dc, ly, DL
	7	S, dc, ly, DL, TR	S, dc, ly, DL, TR
Palasithari	1	s, dc	s, dc
	3	S, DC, lc	S, DC
	5	s, dc	NS
	7	s, TR	NS
Sigadis	1	s, dc	NS
	3	S, dc, lc	NS
	5	s, dc	NS
	7	s, TR	NS
Utri Rajapan	1	S	NS
	3	sDC	NS
	5	s	NS
	7	TR	NS
TN1	1	S, DC	s, lc
	3	S, DC, lc	S, dc, lc
	5	S, DC, lc	S, dc, lc
	7	S, dc, lc, TR	S, TR

[a]NS = no clear symptoms, s = mild stunting, S = severe stunting (50%), dc = mild discoloration (mild yellowing), DC = severe discoloration (yellow to orange), lc = interveinal chlorosis, ly = interveinal yellowing striping, DL = drooping leaves, TR = tiller reduced. All plants infected with RTSV were rated NS.

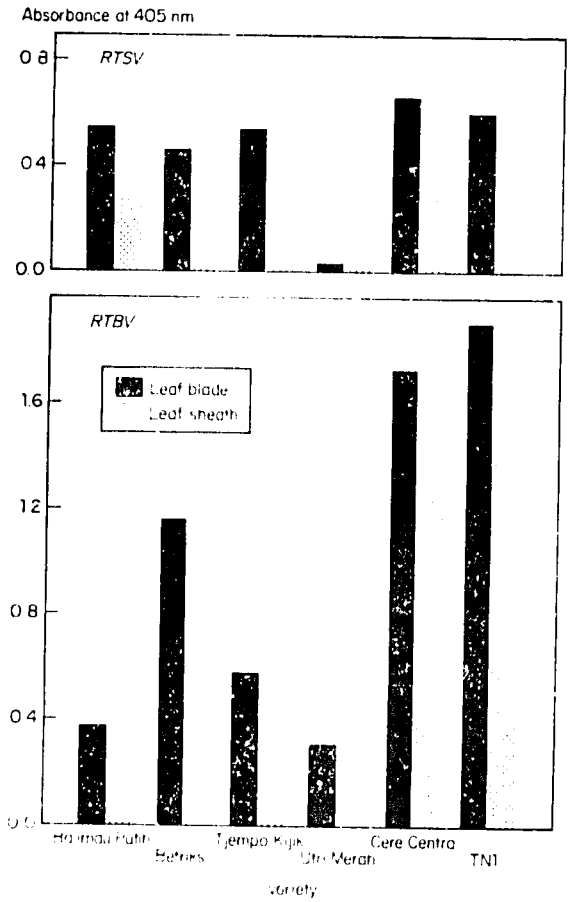


9. Reduction in plant height and grain yield, and delay in days to flowering in plants of 4 varieties infected with RTBV + RTSV, RTBV, or RTSV or both at 1, 3, 5, and 7 wk after soaking. IRRI, 1986.

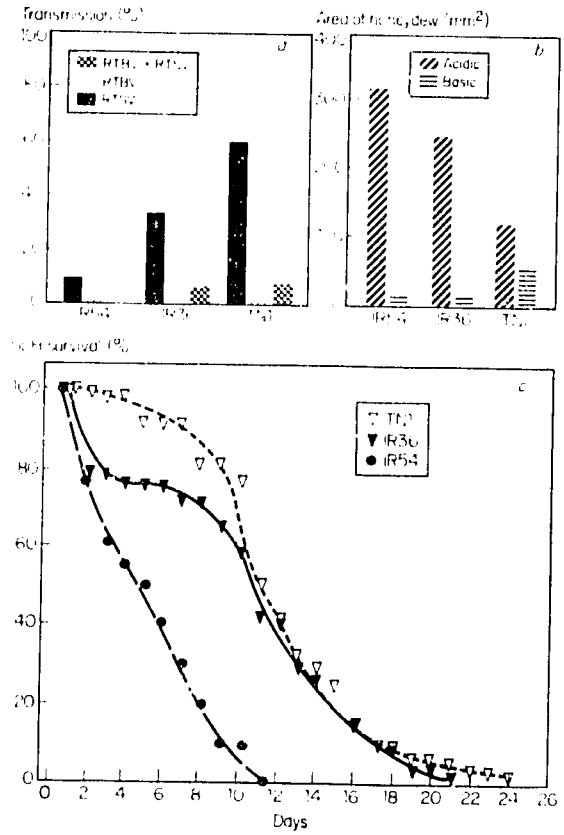
varieties was significantly lower than in intolerant ones (Fig. 11). RTSV concentration in tolerant and intolerant varieties did not significantly differ. In another trial, doubly infected plants of Balimau Putih, Tjempo Kijik, and TN1 exhibiting milder and more severe symptoms were selected at 3 WAI. Plants with more severe symptoms contained more RTBV (Fig. 12).

Virus concentrations in leaf blades and sheaths of doubly infected plants of tolerant and intolerant varieties were compared. RTBV concentration in the leaf sheath was especially lower in tolerant varieties Balimau Putih, Tjempo Kijik, and Utri Merah than in intolerant Cere Centra and TN1 (Fig. 13). RTSV amounts in leaf blades and sheaths of tolerant and intolerant varieties did not significantly differ.

Mode of GLH feeding and tungro transmission (*Plant Pathology and Entomology*). *On IR varieties.* Newly emerged adult GLH of a colony collected in 1986 in Koronadal, South Cotabato, Philippines, and reared on TN1 for 5-6 overlapping



13. Relative amounts of RTBV and RTSV in leaf blades and sheaths of doubly infected plants of 6 varieties at 5 wk after inoculation as indicated in absorbance at 405 nm in ELISA. IRRI, 1986.



14. Percent transmission of RTBV + RTSV, IR36, and TN1 by GLH (a) area of acidic and basic honeydew spots excreted during inoculation access period (b); and survival of GLH on the respective cultivars (c). IRRI, 1986.

xylem feeding. Inoculated plants were indexed by latex serology. After the inoculation feeding, leafhopper life span was tested on 3-wk-old plants.

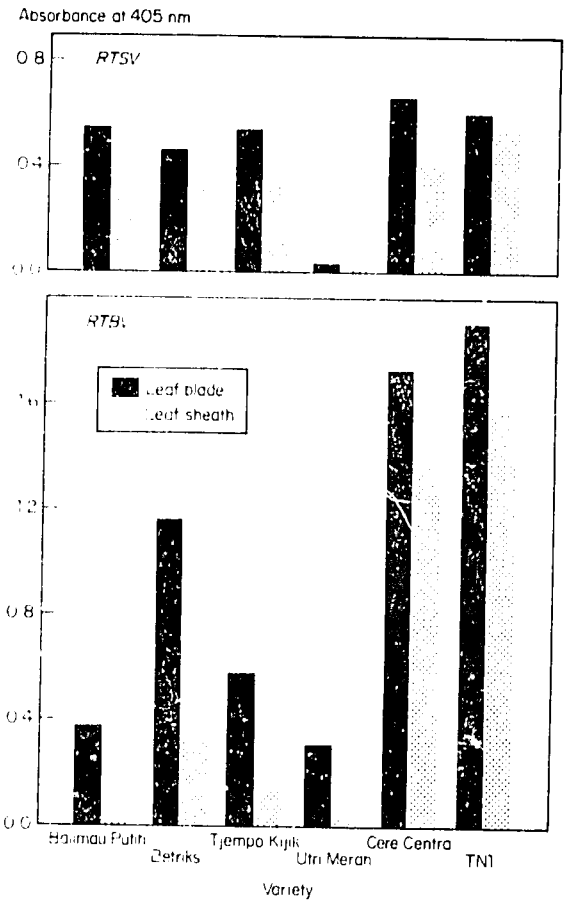
On moderately resistant IR36 and resistant IR54, GLH excreted less basic honeydew, survived fewer days, and transmitted the viruses at lower rates (Fig. 14). On susceptible TN1, GLH excreted more basic honeydew, survived longer, and transmitted the viruses at a higher rate. The size of basic honeydew spots and GLH life span correlated significantly with virus transmission rates. No correlation was observed between basic spot size and GLH life-span in any cultivars.

On IR54, GLH that excreted more basic honeydew did not always transmit the viruses. On IR36 and TN1, the virus-transmitting GLH excreted more basic honeyd w than did non-transmitter GLH.

Irrespective of cultivar, a high proportion of GLH that fed on both phloem and xylem transmitted the viruses. About one-third of GLH that fed on xylem alone transmitted the viruses.

On non-IR varieties. The mode of GLH feeding during inoculation access was also determined on nine non-IR varieties with different resistances to either the vector or RTV. Viruliferous adult GLH of a colony maintained on TN1 for several years were subjected to the bromocresol-transmission test on 1-wk-old seedlings. Inoculated plants were indexed by ELISA.

Greater xylem feeding occurred in GLH-resistant varieties ASD7, Gam Pai 30-12-15, Palasithari 601, and ARC11554 (Fig. 15). In contrast, greater phloem + xylem feeding occurred in GLH-susceptible varieties Utri Rajapan, Habiganj DW8, IR22, and TN1. Except for ARC11554, the GLH-resistant varieties were



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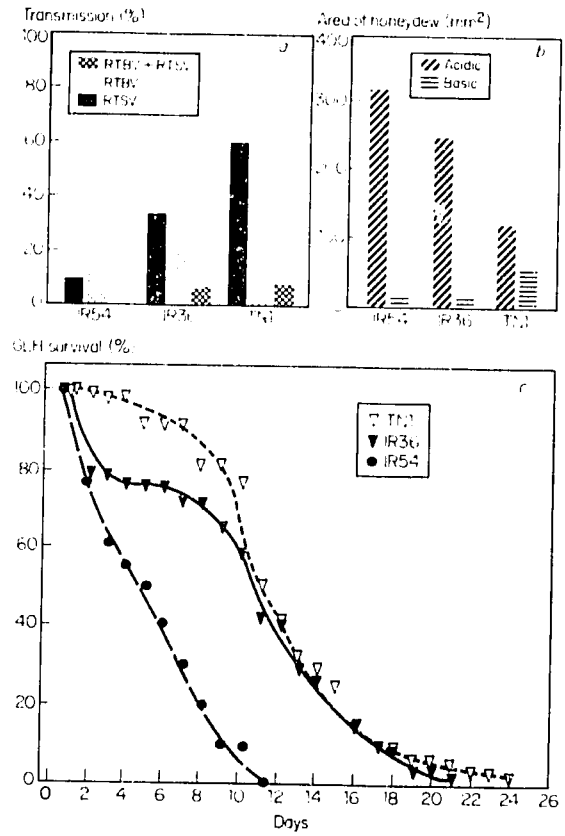

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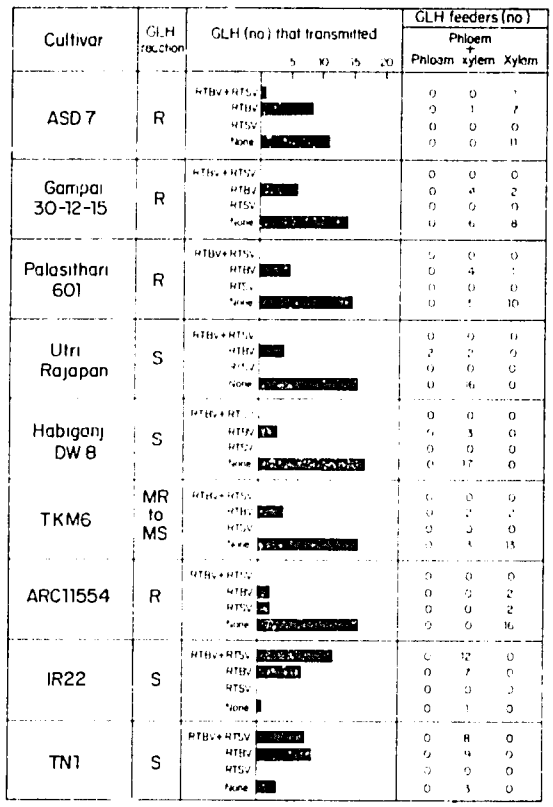

15. Number of RTV-viruliferous GLH that transmitted RTBV + RTSV, or RTBV, or RTSV, and their feeding behavior (phloem or xylem feeding) on 9 selected varieties. IRRI, 1987.

infected predominantly with RTBV alone. On Gam Pai 30-12-15 and Palasithari 601, GLH that transmitted viruses fed as much on phloem + xylem as on xylem. On Utri Rajapan and Habiganj DW8, all GLH fed on either phloem or phloem + xylem, and most GLH failed to transmit either virus.

GLH varied widely in areas of basic and acidic honeydew spots on each variety, though the colony used had been maintained on TN1 for many years. Scatter diagrams did not show selective virus transmission by phloem feeders. Except on a few varieties, there were no significant differences between the amount of basic and acidic honeydew spots excreted by virus transmitter and non-transmitter GLH.

NEMATODE DISEASES

Plant Pathology Department

We reported earlier (Annual report for 1985) that the population of *Pratylenchus zeae* was very high, more than 1,000 nematodes/g of roots, on an upland farm where rice was continuously cultivated. Rice plants were severely stunted. In this collaborative research project with the Commonwealth Agricultural Bureaux International, we examined the growth and yield of a relatively resistant cultivar, Kinandang Patong, and of a relatively susceptible cultivar, UPLRi-5, with different levels of nematode control. Carbofuran was incorporated into the soil to manipulate nematode density. Although root damage was similar in Kinandang Patong and UPLRi-5, only the latter showed increased yield because of nematode control. In UPLRi-5 plots receiving carbofuran at 4 and 8 kg ai/ha, yield increased 29 and 22%, respectively, over the untreated control.

Of 13 upland sites examined in the Philippines, 11 were infested with *P. zeae* and *P. brachyarus*. The population densities of *Pratylenchus* spp. at sites sampled on 26-30 Aug were generally low, with no obvious relationship between crop rating and nematode density. Nevertheless, densities were similar to those in the control plots of the yield loss trial at IRRI: 10-849 nematodes/3 g roots. At upland sites, populations increased rapidly after flowering.

Management of rice pests

Insects

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ECOLOGY AND BIOLOGY

Entomology Department

Life history of the rice skipper. *Pelopidas mathias*, most prevalent in rainfed rice, produces damage similar to that caused by other large defoliators such as armyworms and grasshoppers. Adults require a nectar source for oviposition and favor santan *Ixora chinensis* on the IRRI farm. Lack of nectar may limit the rice skipper in most irrigated environments.

P. mathias was cultured in an insectary in petri dishes on excised rice leaves. The period from egg to adult, ranging from 29 to 40 d, averaged 37 d (Table 1). The butterflies were transferred to mylar film cages for oviposition. Santan flowers and 10% honey solution in cotton provided sugar. Adults lived longer when flowers were introduced. Rice plants were put inside cages for egg deposition. The preovipositional period was 3 d. No eggs hatched because the moths did not mate inside the cages.

Life history of rice root aphids. *Rhopalosiphum rufiabdominalis* and *Tetraneura nigriabdominalis* infest upland rice. Adults and nymphs use their sucking mouthparts to remove fluids from roots, causing leaves to yellow and stunting the plants.

The aphids were reared on the exposed roots of UPLRi-5 rice seedlings inside test tubes with moist cotton. Such seedlings live more than 1 wk. *R. rufiabdominalis* was more active than *T. nigriabdominalis* and easier to rear. Developmental periods were similar, but *R. rufiabdominalis* produced more offspring (Table 2).

Table 1. Development of the rice skipper *Pelopidas mathias*[a] on TN1 rice. IRRI insectary, 1987.

Character	Days	
	Av	Range
Egg incubation period	5.6	4-7
Larval period		
First stadium	3.8	3-5
Second stadium	3.1	2-5
Third stadium	2.7	2-4
Fourth stadium	3.9	2-7
Fifth stadium	7.6	3-10
Pupal period	10.0	5-14
Adult longevity	6.1	3-13
Period from egg to adult	36.8	29-40

[a]n = 50.

Host range and development of green horned caterpillar. *Melanitis leda ismene* may be a minor pest because the larvae prefer wild grasses to rice. Common ricefield weeds were offered to newly hatched larvae and compared with rice as hosts. Larval survival rates were 88% on *Oryza sativa*, 72% on *Echinochloa colona*, and 24% on *E. glabrescens*. Only 28% of 1st-instar larvae survived on *E. crus-galli* and 48% on *Cyperus difformis*. Development was further compared on preferred hosts *O. sativa* and *E. colona* using cut leaves in petri dishes. Larvae passed through 5 stadia in 21 d on *O. sativa* and in 29 d on *E. colona* (Table 3). Rice appeared to be a more nutritious host, allowing a longer oviposition period than did weeds. Factors other than nutrition evidently account for its low level on rice.

Golden apple snail. Formerly called *Pila leopordnillensis*, the golden apple snail *Pomacea canaliculata* (Lamark) has become a widespread rice pest in the Philippines, Japan, and Taiwan, China. It disperses quickly throughout irrigation systems and floodwaters. Snails live 2-5 yr and can deposit 2,400-8,700 eggs/yr. Highly adaptive to temperature extremes (0-35 °C), they can overwinter in temperate climates. Known natural enemies are *Solenopsis* ants, which attack the eggs, and fish, which eat young snails.

Table 2. Development of rice root aphids *Rhopalosiphum rufiabdominalis* and *Tetraneura nigriabdominalis* on UPLRi-5 upland rice. IRRI insectary, 1987.

Character	*R. rufiabdominalis*[a]		*T. nigriabdominalis*[b]	
	Av	Range	Av	Range
Nymph developmental period (d)				
First stadium.	1.5	1-2	1.1	1-2
Second stadium	1.2	1-2	1.0	1-2
Third stadium	1.0	1-2	1.1	1-2
Fourth stadium	1.2	1-2	1.0	1-2
Period from nymph to adult (d)	4.9	4-6	4.4	4-5
Adult longevity (d)	9.2	2-22	6.0	3-14
Fertility				
Nymphs (no./female)	34.6	3-81	24.4	6-73
Nymphs (no./d per female)	3.7	0-14	3.9	0-12

[a]n = 44. [b]n = 70.

Table 3. Development of the green horned caterpillar on *Oryza sativa* and *Echinochloa colona*.[a] IRRI greenhouse, 1987.

Stage	*O. sativa*			*E. colona*			F
	n	Days (no.)		n	Days (no.)		
		Range	Av		Range	Av	
Larva							
1st instar	50	3-4	3.5	50	3-6	4.5	3.46**
2d instar	49	2-4	3.0	30	3-5	4.0	1.12**
3d instar	46	2-4	3.0	21	3-5	4.0	1.42**
4th instar	46	3-5	4.0	21	4-8	6.0	4.48**
5th instar	45	6-9	7.5	21	6-15	10.5	16.43**
Pupa	45	7-11	9.0	21	5-10	7.5	1.16**
Adult (male)	15	5-13	9.0	6	3-6	4.5	6.49**
(female)	30	5-13	9.0	14	8-12	10.0	2.43 ns

[a]Survival from larva to adult was 90% on *O. sativa* and 40% on *E. colona*. *T*-test comparison for each stage; ** = highly significant (P = 0.01); ns = not significant (P < 0.05).

Snails eat almost any vegetation growing in water but prefer *Monochoria vaginalis*, *E. glabrescens*, *Fimbristylis littoralis*, and *C. difformis* to *Ipomoea aquatica*, *Sphenoclea zeylanica*, and *Pistia stratiotes*.

Rice is highly preferred. Snails 1.5 cm in diameter or larger can totally consume seedlings up to 4 wk old. Larger snails can consume older plants.

Research shows snails prefer azolla to rice. Three-week-old rice plants with azolla were less damaged (20%) than plants without azolla (40%) 3 h after infestation. Snails appear to prefer certain species of azolla. Large snails (5-7 cm diameter) consumed 46% less *A. pinnata* var. *imbricata* per day than *A. microphylla*.

Whitebacked planthopper food web. The food web of the whitebacked planthopper (WBPH) *Sogatella furcifera* (Horváth) in the Philippines comprises at least 199 species: 33 parasites, 139 predators, and 27 secondary parasites and predators (Fig. 1). Predators outnumber parasites almost 4:1. Dominant predators are spiders (63), comprising hunters (33), orb-web spinners (22), and space-web spinners (8); true bugs (21); beetles (17); and damselflies (11). Ants, predatory flies, meadow grasshoppers, lacewings, toads, and frogs also prey on WBPH. The pteromalid wasp *Pansteron* nr. *collaris* preys on eggs.

The principal parasites of eggs are *Anagrus optabilis*, *A. flaveolus*, *Gonatocerus* spp., *Oligosita aesopi*, *O. naias*, *Paracentrobia andoi*, and *P. yasumatsui*. The predominant parasites of adults or nymphs are *Pseudogonatopus* spp., *Echthrodelphax* spp., *Haplogonatopus* spp., and the twisted-winged insect *Elenchus* spp. No pipunculids—*Tomosvaryella* spp. and *Pipunculus* spp.—parasitize WBPH.

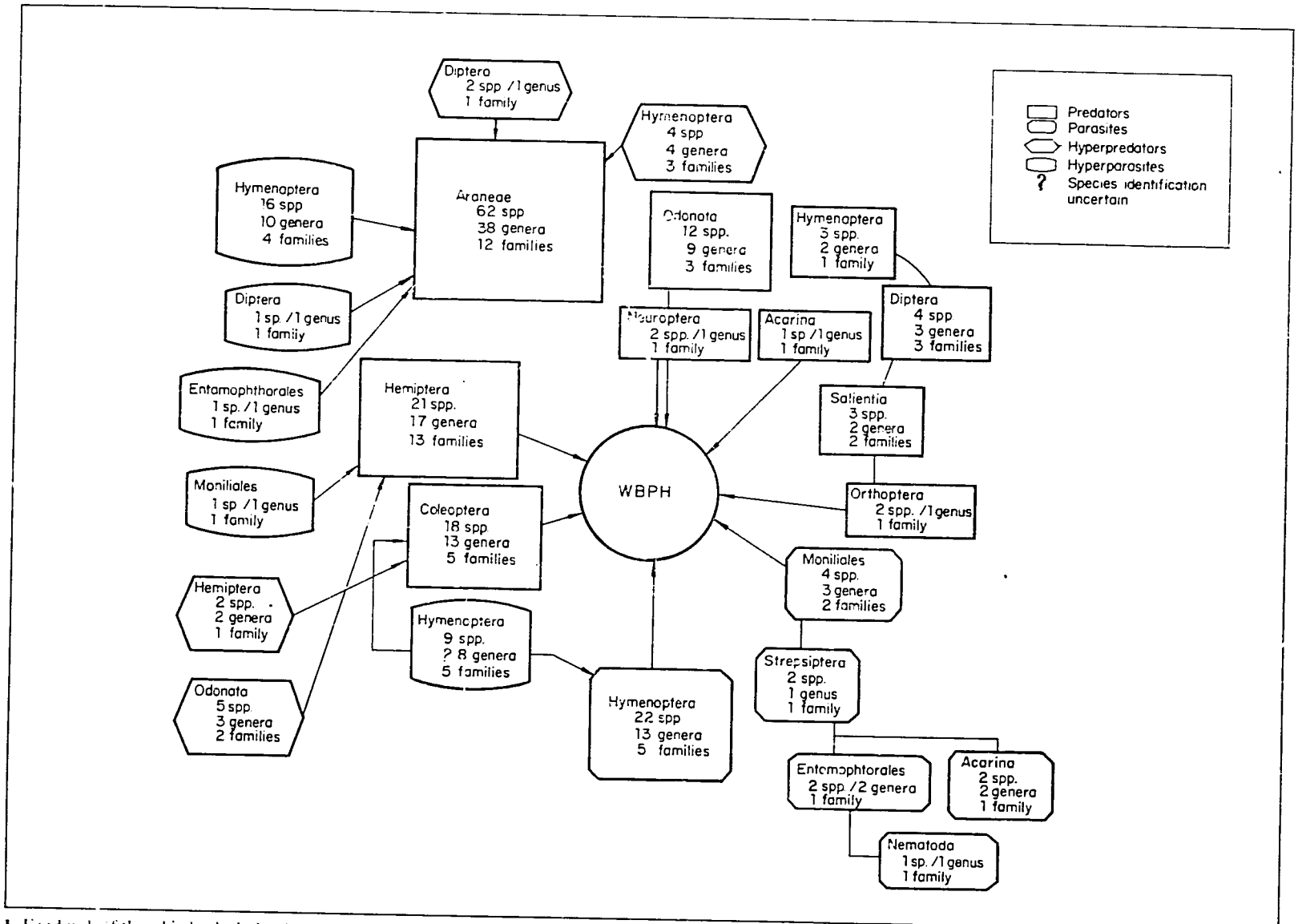
Mermithids parasitize WBPH nymphs and adults. Insect pathogens total 4% of the natural enemy species.

Host range of the whitebacked planthopper. Thirty-one plant species belonging to eight families were evaluated as hosts of WBPH (Table 4). Each host plant was infested with five WBPH pairs. Four biological parameters—fecundity, growth index, survival (percentage), and developmental period—were recorded.

No eggs were laid on *Amaranthus spinosus* (Amaranthaceae), *Eclipta prostrata*, and *Synedrella nodiflora* (L.) Gaertn. (Asteraceae).

Graminaceous weeds *Brachiaria mutica*, *Chloris barbata*, *Echinochloa colona*, *E. glabrescens*, and *Leptochloa chinensis* supported complete development, as did rice and maize. WBPH developed best on *E. glabrescens* with a high survival (66%), high growth index (10.0), and short life cycle (22 d). *L. chinensis*, *E. colona*, and *C. barbata* were less suitable hosts. WBPH developed to the 2d instar on *Digitaria*, *Rottboellia*, and *P. conjugatum* and to the 3d instar on *Leersia hexandra*. The ovipositional preference of WBPH was *E. glabrescens* > rice > maize.

Mating behavior of rice leaffolder. In laboratory experiments, female *Marasmia patnalis* moths mated only once. More than 80% of the females



1. Food web of the whitebacked planthopper in the Philippines.

Table 4. Host range of the whitebacked planthopper.[a] IRRI greenhouse, 1987.

Host plant	Eggs laid (no./5 plants)	Survival[b] (%)	Growth index[c]	Duration of life cycle[d]
Asteraceae				
Ageratum conyzoides L	1 j	0	–	–
Vernonia cinerea (L.) Less.	3 j	0	–	–
Commelinaceae				
Commelina benghalensis L.	59 d-h	0	–	–
C. diffusa Burm. f.	61 d-h	0	–	–
Cyperaceae				
Cyperus brevifolius (Rottb.) Hassk.	36 g-j	0	–	–
C. difformis L.	27 g-j	0	–	–
C. iria L.	38 f-j	0	–	–
C. kyllingia Endl.	28 g-j	0	–	–
C. rotundus L.	24 g-j	0	–	–
Fimbristylis miliacea (L) Vahl	23 hij	0	–	–
Onagraceae				
Ludwigia octovalvis (Jacq.) Raven	5 j	0	–	–
Poaceae				
Brachiaria mutica (Forsk.) Stapf.	22 hij	8.3 e	0.1 d	23 c
Chloris barbata Sw.	50 e-i	42.3 d	0.7 d	23 c
Digitaria sanguinalis (L.) Scop.[e]	12 ij	0	–	–
D. setigera Roth. ex R. & S.	19 ij	0	–	–
Echinochloa colona (L.) Link	75 def	42 d	1.2 d	21 a
E. glabrescens Munro ex Hook f.	389 a	66 b	12.3 a	22 b
Leersia hexandra SW.[f]	79 de	0	–	–
Leptochloa chinensis (L.) Nees	124 c	54.4 c	3.0 c	22 b
Oryza sativa L.	277 b	80 a	10.0 b	22 b
Panicum repens L.	36 g-j	0	–	–
Paspalum conjugatum Berg.[e]	41 f-j	0	–	–
P. distichum L.[g]	46 e-i	0	–	–
P. paspalodes (=*P. distichum* L.)[h]	63 d-g	0	–	–
Rottboellia cochinchinensis (Lovr.) Clayton	23 hij	0	–	–
Zea mays L.	126 c	0.7 e	0.1 d	26 d
Rubiaceae				
Borreria ocymoides (Burm. f.) DC	1 j	0	–	–
Sphenocleaceae				
Sphenoclea zeylanica Gaertn.	95 cd	0	–	–

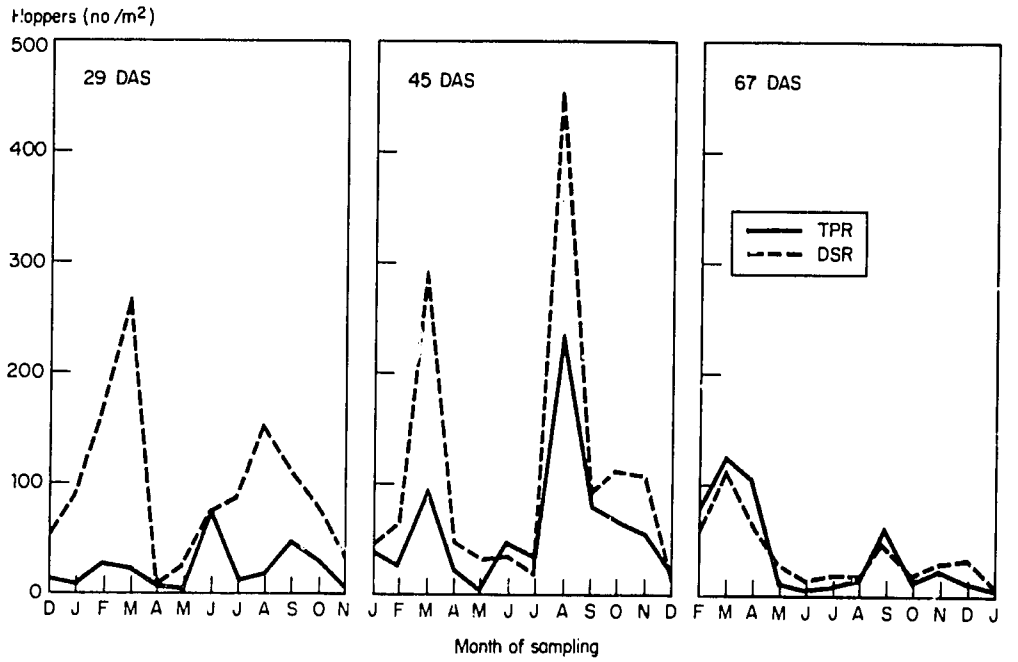
[a]Av of 10 replications. Means followed by a common letter are not significantly different at the 5% level by DMRT. [b]Survival = $\frac{\text{eggs (no.) becoming last instar}}{\text{total number of eggs laid}} \times 100$. [c]Growth index = no. of eggs reaching last instar/mean developmental period (d). [d]n = 10. [e]Reached 2d instar. [f]Reached 3d instar. [g]Collected from rainfed wetland area. [h]Collected from irrigated areas.

mated when 2 d old, although some mated soon after emergence. Attraction appeared greatest at 4 h after darkness. Two-day-old females in ricefield water traps attracted an average of five to six males each. Placing water traps at rice canopy level worked best.

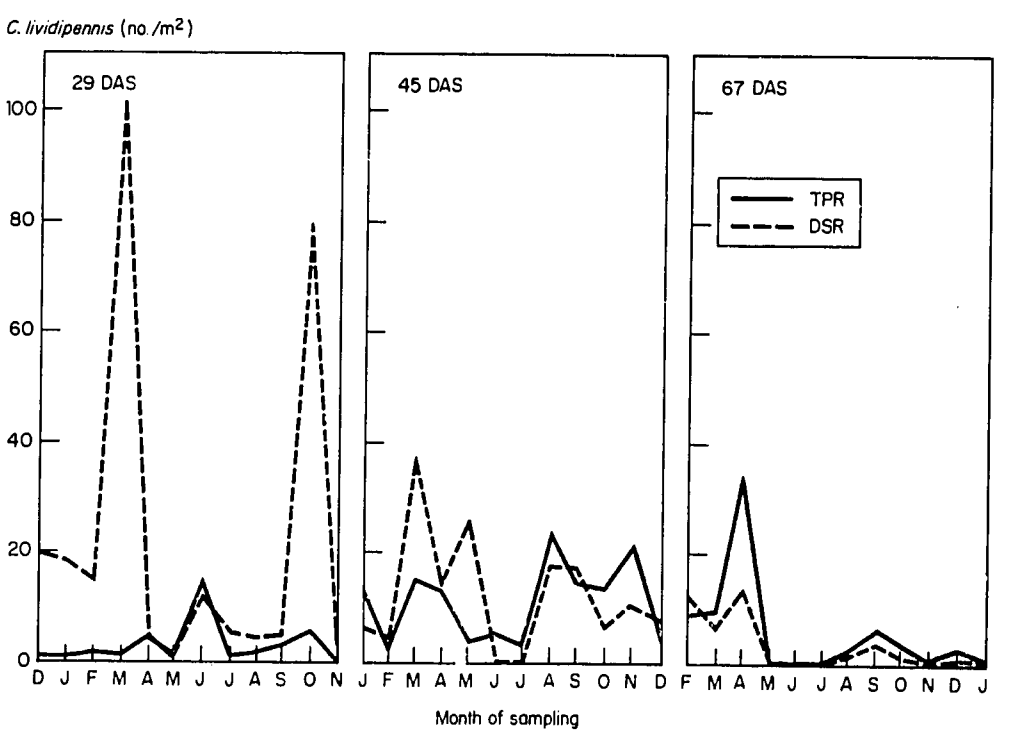
Relative abundance of hoppers, *Cyrtorhinus lividipennis*, and spiders in transplanted and direct seeded rice. Untreated fields at IRRI were established monthly by direct seeding and transplanting to compare populations of hoppers (brown planthopper [BPH], green leafhopper [GLH], and WBPH), spiders, and the predatory mirid bug *Cyrtorhinus lividipennis*.

Populations of hoppers were higher in direct seeded rice (DSR) early in the season (Fig. 2), probably because of the early establishment of the DSR crop. Hopper populations peaked in March and August in both transplanted rice (TPR) and DSR.

Figure 3 shows the seasonal abundance of *C. lividipennis*. Population peaks usually coincided



2. Populations of planthoppers and leafhoppers in transplanted (TPR) and direct seeded (DSR) rice at different crop ages, IRRI, 1987. DAS = days after seeding.



3. Populations of the mirid bug *Cyrtorhinus lividipennis* in TPR and DSR at different crop ages. IRRI, 1987.

with those of hoppers. At 29 d after seeding (DAS), mirid bug populations were higher in DSR than in TPR, as were spider populations (Fig. 4). Spiders generally increased as the crop matured; in contrast, the hoppers and *C. lividipennis* decreased as the crop matured, with no obvious differences in their number in TPR and DSR.

Stem borer populations in traditional and modern varieties. We estimated yellow stem borer (YSB) and striped stem borer (SSB) eggs, larvae, pupae, and damage by field monitoring modern (MVs) and traditional (TVs) varieties.

Egg masses were counted at 63, 70, and 81 d after transplanting (DT). TVs had more SSB egg masses than did MVs (Fig. 5). Larval and pupal populations of SSB also were higher in TVs, as seen in dissected stems from 10 randomly selected hills from each plot (Fig. 6).

SSB preference for TVs may explain the recent overall reduction in SSB damage as more MVs are grown (Fig. 7). With longer maturity, TVs are exposed to borers longer. Their taller, larger stems may be more attractive to stem borers (SBs).

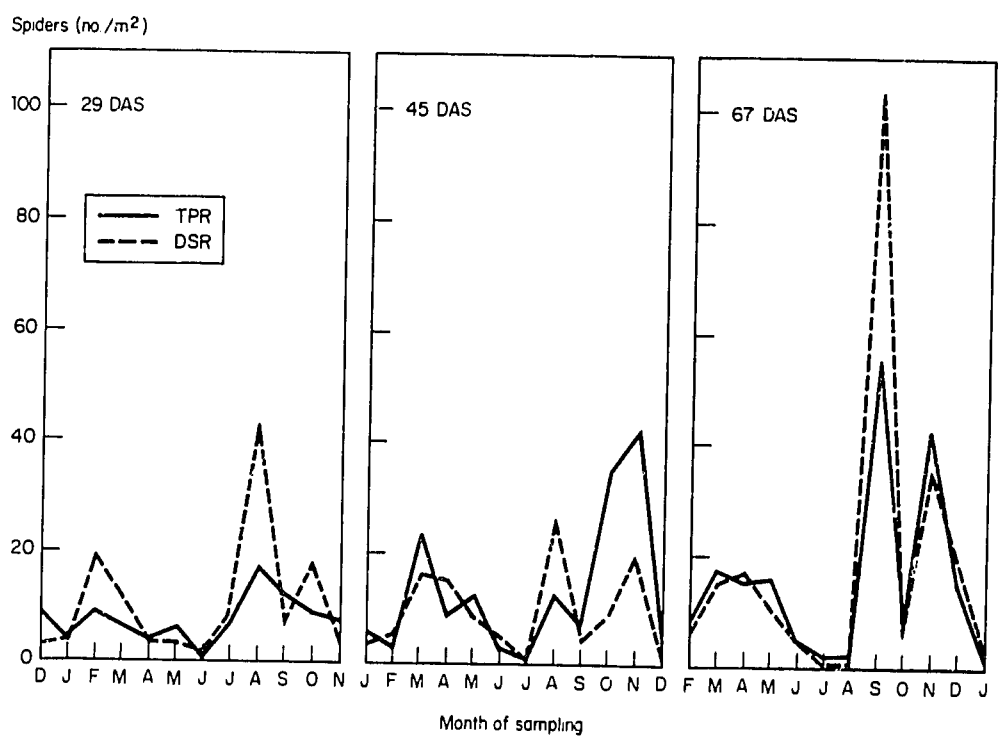
INTEGRATED PEST MANAGEMENT

Entomology, Agronomy, Agricultural Economics, Plant Pathology, and Statistics Departments

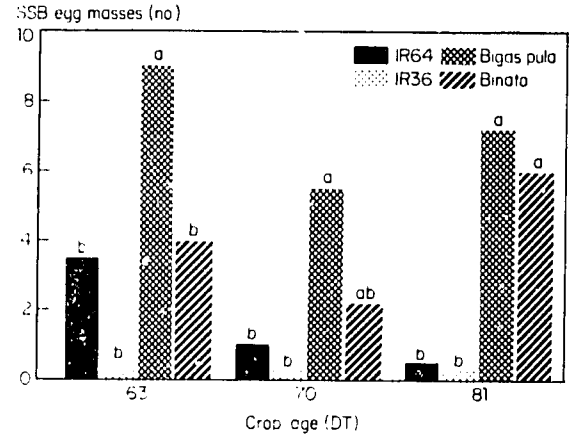
Sequential sampling of planthoppers and predators. A simplified sampling program was designed for planthoppers (BPH and WBPH) and major predators, using a binomial distribution. A relationship was established between the density of planthoppers and the percentage of hills infested with 10 hoppers. Thus, instead of counting individual hoppers, hills with 10 or fewer hoppers were counted as zero and those with more than 10 were counted as 1.

A sequential sampling model (Table 5) was developed for major predators such as spiders, beetles, and crickets. It was field tested in South Cotabato and Laguna Provinces in the Philippines. The sequential sampling plan was compared with a more intensive sampling that used 20 samples per field.

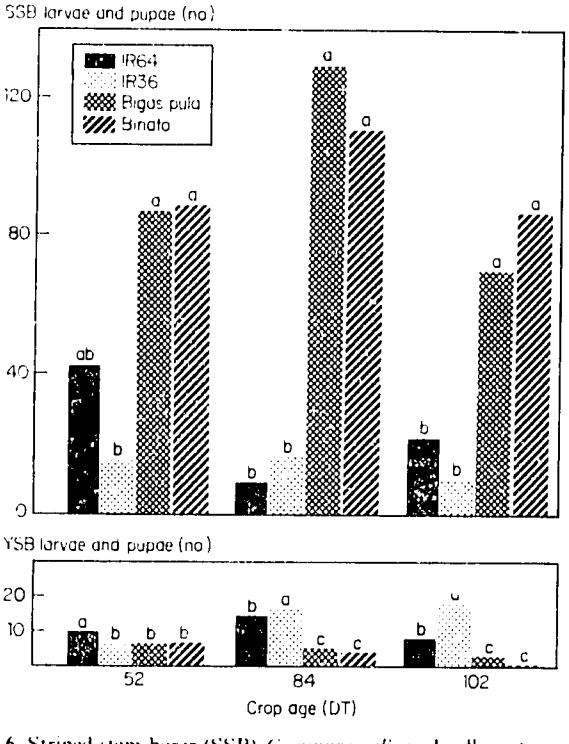
The number of samples required to make an insecticide treatment decision was computed.



4. Spider populations in TPR and DSR at different crop ages. IRRI, 1987.

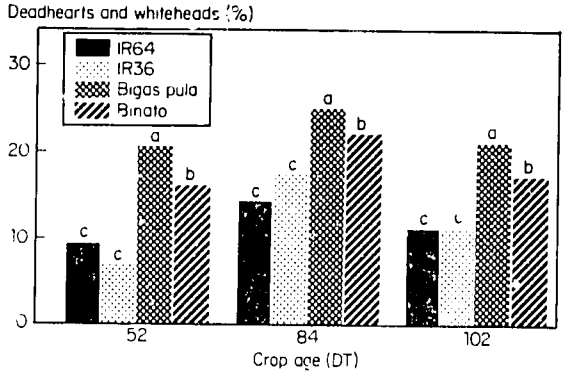


5. Striped stem borer (SSB) *Chilo suppressalis* egg masses per 40 m^2 on 4 varieties, IRRI, 1987. DT = days after transplanting. For each crop age, bars having a common letter are not significantly different at the 5% level.



6. Striped stem borer (SSB) *C. suppressalis* and yellow stem borer (YSB) *Scirpophaga incertulas* larvae and pupae collected on 10 randomly selected hills, IRRI, 1987. DT = days after transplanting.

Sequential sampling reduced the required samples from 20 to 6 in South Cotabato and from 20 to 7 in Laguna. The binomial sequential plan and the fixed-point sampling program agreed almost 100%.



7. Damage due to rice stem borer on 4 rice varieties, IRRI, 1987. DT = days after transplanting.

Because the binomial sequential sampling plan using presence or absence of 10 hoppers is fast and precise, it will be tested on a large scale in an integrated pest management (IPM) program.

Sequential sampling of leaffolder (*Entomology*). A sequential sampling plan was also developed and tested for leaffolder (LF) *Cnaphalocrocis medinalis* and *Marasmia patnalis*. Forty-three data sets were collected from ricefields in Laguna and Batangas Provinces during 1986-87.

LF distribution in the field fitted the negative binomial with a clumping coefficient (K) of 1.1. Decision lines were computed from the following:

M_1 = 1 larva/hill) class limits
M_2 = 2 larvae/hill)
$\alpha = \beta = 0.20$ = the risk level

Samplers zigzagged across the field, examining hills and counting live larvae in folded leaves. A minimum of four samples was taken before applying sequential sampling. Sequential sampling was compared with intensive sampling involving a fixed number of samples (20/field).

Seventy percent fewer samples were required in sequential sampling (Fig. 8). Agreement in decisions reached 90% between the sequential plan and intensive sampling.

Effect of stem borer damage on filled grain percentage (*Entomology*). Hills with different whitehead levels were harvested, and 292 whiteheads were analyzed for filled grains. Not all panicles had empty spikelets. Primary branches contained some filled grains, but more than 80% of grains from panicles with whiteheads were empty. Filled grains ranged from 0.3 to 32.2% per panicle.

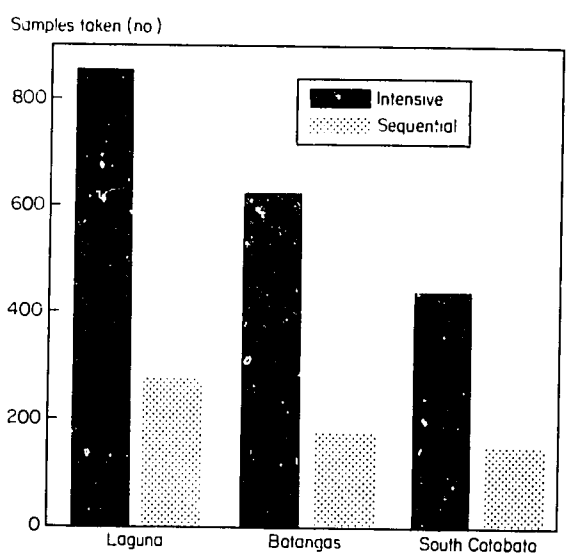
Table 5. Sequential sampling table. IRRI, 1987.

Sequential sampling for planthoppers and predators in rice using binomial distribution

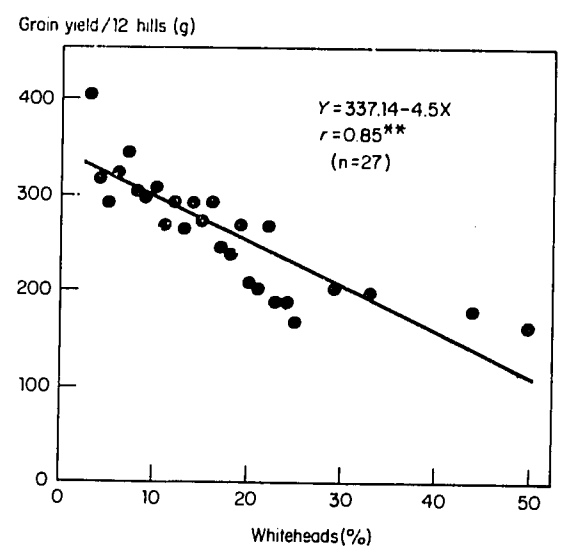
Date _____ Location _____ Field no. _____ DT _____ Variety _____

Sample no.	Predator no.	With predators present: Lower limit	With predators present: Upper limit	Hill infested	Without predators present: Lower limit	Without predators present: Upper limit
1	_____	_		_____	_	_
2	_____	_		_____	_	_
3	_____	_		_____	_	_
4	_____	_		_____	_	_
5	_____	0	4>	_____	_	_
6	Total _____	<1	5>	_____	<0	4>
7		<2	5>	_____	<1	4>
8		<2	6>	_____	<2	5>
9		<3	6>	_____	<2	5>
10		<3	7>	_____	<2	5>
11		<4	7>	_____	<3	6>
12		<4	8>	_____	<3	6>

No treatment required — Continue sampling — Treatment required



8. Samples required with intensive and sequential sampling in deciding whether to apply an insecticide for leaffolder control. Philippines, 1987.



9. Grain yield/12 hills at a given percentage of whiteheads caused by YSB. IRRI, 1987.

SB damage to plants in the reproductive phase caused late tillering in IR64. Forty-five percent of infested hills sampled during the reproductive phase showed 1-10 late tillers bearing flowers or grains at the milk stage, whereas uninfested hills showed all panicles at the hard dough stage. Most late tillers emerged near tillers damaged by stem borers. Carbohydrates from damaged tillers may have been translocated to the new tillers.

Influence of stem borer attack on grain yield of IR62 (*Entomology*). IR62 was transplanted at 20 DAS with 25 × 25 cm between hills in a 1,250-m^2 plot. One week before harvest, stem borer infestation levels (5-50% whiteheads) were sampled, as were undamaged hills for comparison.

With more than 10% whiteheads present, yields were significantly lower (Fig. 9).

Simulated damage by yellow stem borer *Scirpophaga incertulas* (Walker) on lowland rice (*Entomology, Agronomy*). We planted IR64 in a 1,250-m^2

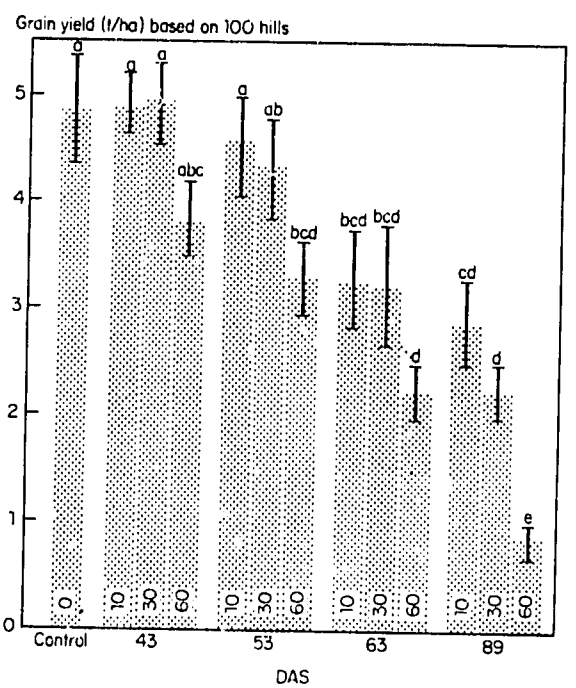
field at IRRI. To simulate insect damage, we injected 0.25 ml of 0.025 ppm paraquat at the growing point of rice plants. Injecting tillers in the vegetative phase simulated deadhearts; injection in the reproductive phase simulated whiteheads. Damage levels were 0% at active tillering (43 DAS), 10% at maximum tillering (53 DAS), 30% at panicle primordia 0.5-1 cm (63 DAS), and 60% at flowering (89 DAS).

The grain yield of uninjected plots (control) was 4.8 t/ha. Damage of 10% at 43 DAS and 30% at 53 DAS did not significantly reduce yield (Fig. 10), but 60% damage at 43 DAS decreased yield 1.0 t/ha.

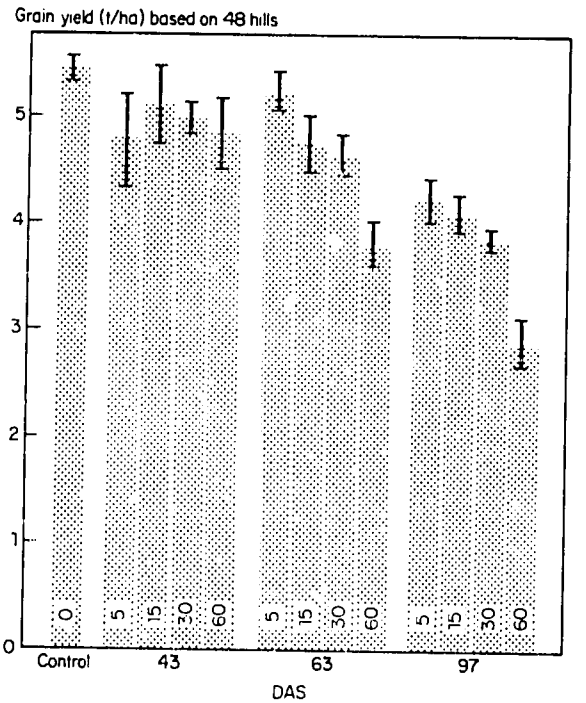
Damage during the reproductive phase and grain filling stage significantly reduced yield. Damage of 10 and 30% reduced yield by 1.6 t/ha at 63 DAS and 2.0 t/ha at 89 DAS.

In a similar experiment, we simulated YSB damage by cutting the base of tillers, using 5, 15, 30, and 60% damage levels. We cut tillers at active tillering (43 DAS), panicle primordia 0.5-1 cm (63 DAS), and grain filling (97 DAS).

Control plots yielded 5.5 t/ha. Damage at all levels at 43 DAS had no yield effect (Fig. 11). Five percent damage at 63 DAS decreased yield by only 0.2 t/ha. Higher damage levels significantly decreased yield—by 0.7 t/ha at 15% damage, 0.8 at 30%, and 1.7 at 60%. Plants could not compensate for higher levels of damage at 63 DAS.



10. Grain yield of IR64 detillered (0, 10, 30, 60% damage) by injecting herbicide at different development stages, IRRI, 1987. Vertical lines indicate standard deviation.



11. Grain yield of IR64 detillered (0, 5, 15, 30, 60% damage) by clipping at different stages. IRRI, 1987.

In summary, injecting and clipping tillers in the vegetative phase of IR64 did not significantly reduce grain yield. Some varieties may compensate for damage by excessive tillering or heavier panicles. However, insect damage during the reproductive phase and grain filling stage did reduce yields and should be prevented.

Relationship between stem borer damage and yield (*Entomology*). In the 1987 wet season (WS), in a field near Zaragosa, Nueva Ecija, Philippines, planted to IR64 heavily infested with YSB, we sampled 15 hills with whiteheads at per hill densities of 0, 1-2, 3-4, 5-6, 7-8, and 9 up.

We computed whitehead percentage, number of borers (larvae + pupae), exit holes, and yield per hill.

At 1-2 whiteheads/hill, yields were maintained (Table 6) because plants compensated for the

Table 6. Relationship between whiteheads, YSB larvae + pupae + exit holes per hill, and IR64 grain yield. Zaragosa, Nueva Ecija, Philippines, 1987.

Whiteheads[a] per hill		YSB larvae + pupae + exit holes (no./hill)	Yield (g/hill)
no.	%		
0	0 a	0.13 a	20.1 a
1-2	7.8 b	2.20 a	21.4 a
3-4	22.37 c	5.07 b	14.4 b
5-6	25.54 cd	8.50 c	14.1 b
7-8	30.27 d	8.80 c	13.0 b
9 up	39.95 e	12.10 d	6.9 c

[a]Av of 15 replications.

damage. More than 2 whiteheads/hill reduced yields significantly. Many farmers unnecessarily treat their crops at fewer than 1 whitehead/hill.

Effect of sweeping pattern in estimating population density of green leafhopper (*Entomology*). Sweep sampling is the usual way to determine GLH population density and the action threshold, using a standard sweepnet (30 cm diam, 1.5 m long). So far, sweeping pattern has not been prescribed.

At the Bohol Agricultural Promotion Center in Carmen, Bohol, Philippines, during the August-November 1987 growing season, we planted IR64 and applied no insecticides to the crop. Sweeping patterns evaluated were 1) parallel—sweeping along the border parallel to plot edge, 2) center—sweeping through the center, and 3) diagonal—sweeping from one corner to the opposite corner. We swept weekly from the seedling stage until 60 DT in six 20- × 50-m plots, taking three 10-sweep samples on each plot for each pattern.

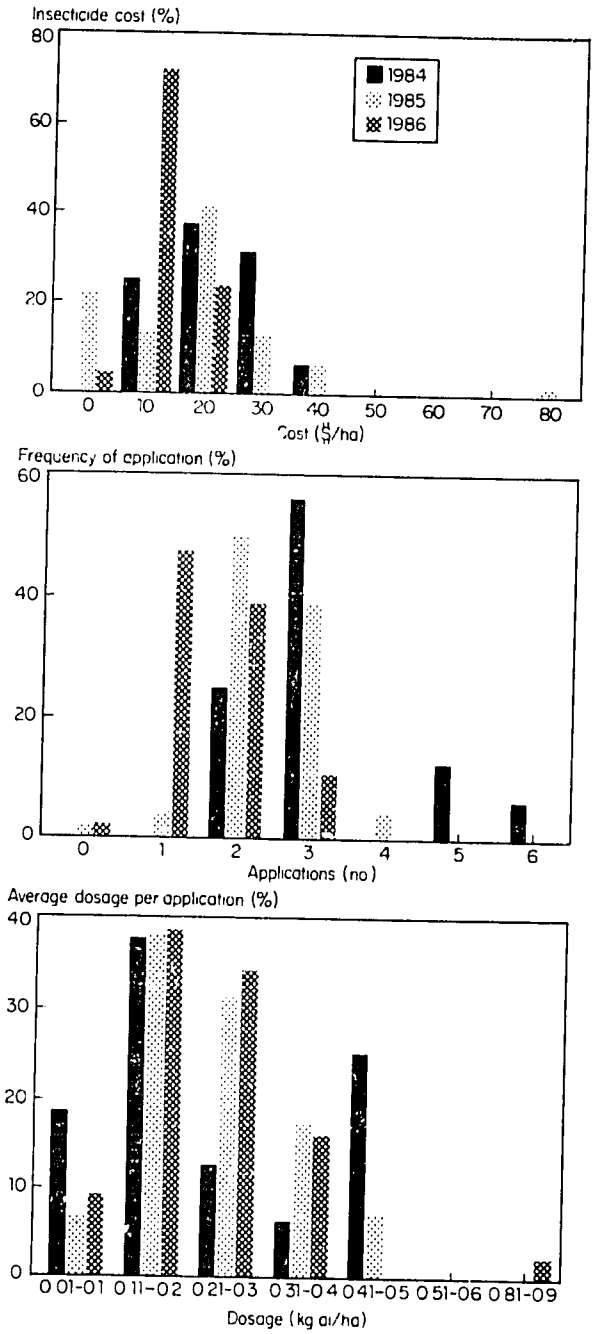
GLH populations were similar irrespective of sweeping pattern.

Simulation of rice leaffolder populations in lowland rice (*Entomology*). In collaboration with personnel of the Centre for Agrobiological Research, a population model of the rice leaffolder (LF), based on the biology of *Cnaphalocrocis medinalis* (Guenée), was coupled to a rice crop growth model and simulated using CSMP on an IBM personal computer. Simulations of both insect population and plant growth were compared with WS field data. The insect submodel satisfactorily predicted the timing of population peaks and the necessity for insecticide applications. The submodel was sensitive to the effects of insecticide sprays, to changes in population density, and to rates of predation and parasitism. Simulated LF population and crop yields were affected more by larval parasitization than by egg parasitization and predation. The earlier in the season LF populations were established, the lower were the simulated yields.

Changing patterns of pesticide use in Laguna, Philippines (*Agricultural Economics and Entomology*). We randomly sampled farmers in Laguna in WS and dry season (DS) from 1984 to 1986. Farmers significantly reduced insecticide use per season from $16.00/ha to $10.92/ha on the average. The reduction was more in WS than in DS. Farmers reduced applications from an average of three in 1984 to two in 1986, and dosage per application as well. In 1984, 50% of farmers applied between 0.2 and 0.3 kg ai/ha; in 1986, 73% did. These results suggest farmers in Laguna are using insecticides more judiciously and are adopting IPM (Fig. 12).

Integrated pest management in farmers' fields (*Entomology, Agricultural Economics, Plant Pathology, Agronomy, and Statistics*) IPM in farmers' fields in Guimba, Nueva Ecija, Philippines, continued for the third cropping season. The results from 1987 DS involve multidisciplinary work by a team from IRRI departments and cooperating agencies such as the University of the Philippines at Los Baños, the Philippine Department of Agriculture, and the Food and Agriculture Organization with six farmer-cooperators. Farmers divided land, half for IPM and half for their standard practices. The IPM fields were monitored weekly and sequentially sampled for insects at a cost averaging $0.50/ha.

Insecticides were applied to farmer-managed fields but not to IPM fields. Insecticide cost ranged from $1.91 to $12.00/ha, averaging $5.68/ha. Herbicide use was similar in farmers' fields and IPM fields. However, farmers applied more fertilizer than recommended for IPM fields. Although yields were slightly higher, but significantly so, in fields managed by farmers (4.9 t/ha vs 4.4 t/ha for IPM fields), the benefit-cost ratio slightly favored fields in the IPM program. Results indicate farmers are overusing insecticides. By field scouting, they could reduce insecticide costs significantly.



12. Costs, frequency of application, and average dosage of insecticides used in the wet season in Laguna Province, Philippines, 1984-86.

BIOLOGICAL CONTROL

Entomology Department

Insect pathogens. *Production of the entomopathogenic Beauveria bassiana in submerged culture.* Several simple liquid media were tested for the production of conidia and hyphal bodies of *B. bassiana.*

Yields of conidia were maximum (170×10^6 conidia/ml) in a medium consisting of sucrose (2%), yeast extract (0.5%), and basal salts; yields of hyphal bodies were maximum (740×10^6 hyphal bodies/ml) in a sucrose (2.5%) and yeast extract (2.5%) medium. This procedure inexpensively produces the fungus for use in pilot trials against several species of insect pests.

Bioassay of Beauveria bassiana and Nomuraea rileyi against the rice leaffolder. The virulence of *B. bassiana* (white muscardine fungus) and of *N. rileyi* (cosmopolitan pathogen of lepidoptera) was tested on LF. Fungal suspensions had 0, 10^4, 10^5, 10^6, 10^7, or 10^8 conidia/ml. Third-instar larvae were dipped in each suspension and incubated in petri dishes with rice leaves. The *B. bassiana* isolate was more infectious to the host.

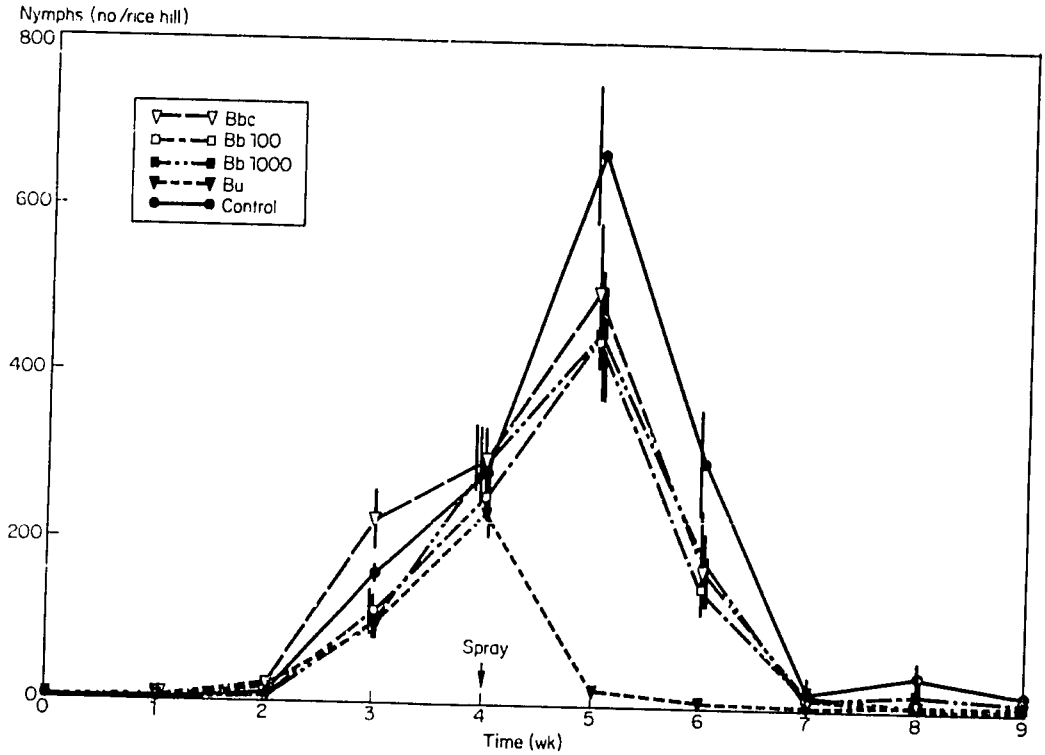
Suppression of brown planthopper by Beauveria bassiana and insectistatic buprofezin. Dry mycelium of the fungus *B. bassiana* at 100 g/ha (Bb 100) and 1,000 g/ha (Bb 1000), conidia at 2×10^{12} conidia/ha (BbC), and buprofezin (Bu) were tested for selective control of BPH *Nilaparvata lugens* (Stål) in the Philippines.

The fungal treatments suppressed the nymphal (Fig. 13) and adult (Fig. 14) BPH in field cages, but no significant control was achieved 2 wk later. Buprofezin effectively suppressed populations of nymphs and thus the subsequent buildup of adults.

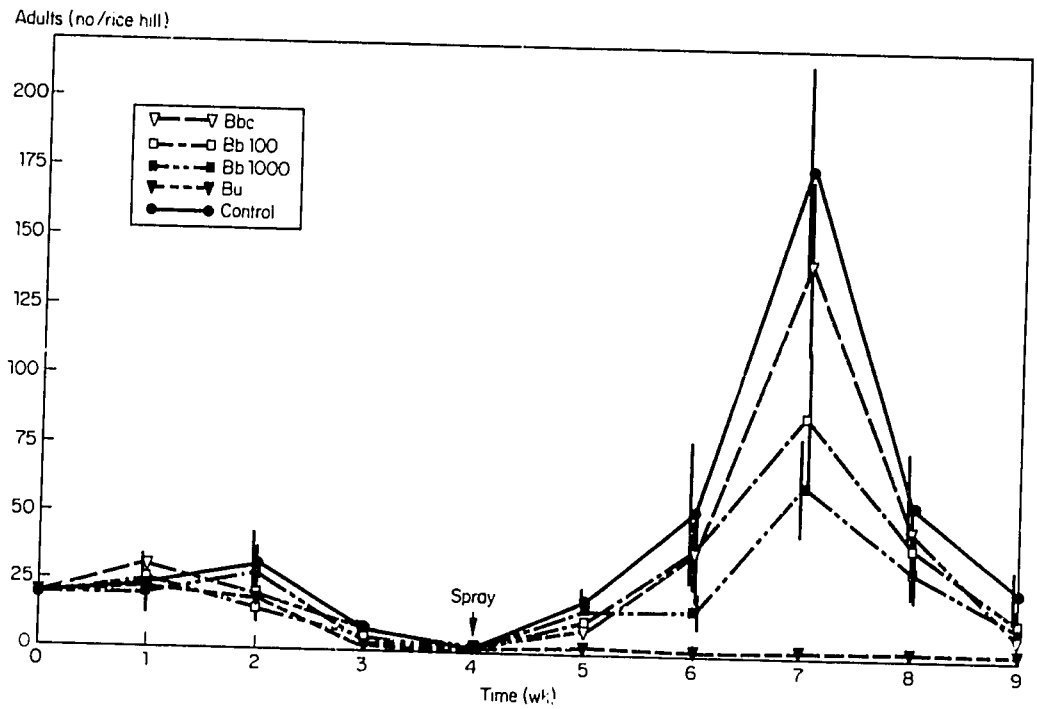
Treatments with Bb, Bb 1000, and Bu significantly reduced numbers of hopperburned hills. There were no hopperburned hills in cages treated with Bu (Fig. 15).

Low fungus infections and the absence of epizootics may have been due to rainfall and low relative humidity during the experiment.

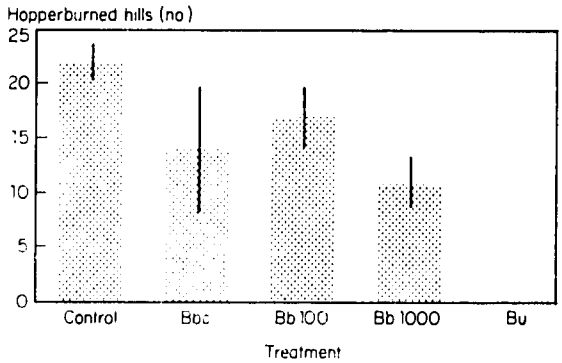
Virus diseases of some lepidopterous pests of rice. Dead and infected larvae of the following rice insect pests were collected: armyworm *Mythimna separata* (Walker), grass webworm *Herpetogramma licarsisalis* (Walker), common cutworm *Spodoptera litura* (Fab), LF *C. medinalis* (Guenée), brown semilooper *Mocis frugalis*, and corn semilooper *Chrysodeixis chalcites* (Esper). Six virus diseases—four nuclear polyhedrosis (NPV) and two granulosis (GV) viruses—were found in the Philippines. Virions were embedded in NPV, while GV had a single virion in each capsule.



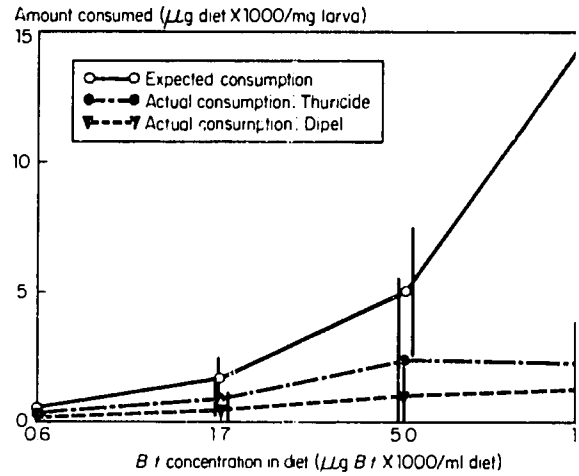
13. Response of BPH nymphs to the fungus *Beauveria bassiana* (Bb) and to buprofezin (Bu), IRRI, 1987. Bbc = *B. bassiana* conidia.



14. Response of BPH adults to the fungus *B. bassiana* (Bb) and to buprofezin (Bu), IRRI, 1987. Bbc = *B. bassiana* conidia.



15. Number of hopperburned hills in plots treated with the fungus *B. bassiana* (Bb) and buprofezin (Bu), IRRI, 1987. Bbc = *B. bassiana* conidia.



16. Expected consumption versus actual consumption of artificial diet by SSB after adding *Bacillus thuringiensis* (*B.t.*), IRRI, 1987. The expected consumption dose would be ingested if no arrested feeding occurred.

A pathogenicity test showed that NPV was highly virulent on 3d-instar larvae of *S. litura*. Dosages above 3.2×10^4 inclusion bodies/ml killed more than 90% of the larvae. The LD_{50} was 2.3×10^4 polyhedral inclusion bodies/ml while LT_{50} was 7 d at the lowest dosage and 6 d at the highest. GV also showed high virulence on third instars of *M. frugalis*.

Low doses of Bacillus thuringiensis arrest feeding of striped stem borer. In the laboratory, the microbial insecticide *Bacillus thuringiensis* Berliner (*B.t.*) formulations of Dipel (R) and Thuricide (R) arrested feeding of SSB *Chilo suppressalis* (Walker). Larvae were fed *B.t.* in an artificial diet for 48 h, then placed on a *B.t.*-free diet. To determine *B.t.* ingestion, larvae and diet were weighed. The initial dose inhibited feeding, but some larvae recovered after 36, 60, and 84 h on the *B.t.*-free diet. Low doses of *B.t.* applied to plants in the field might arrest feeding, slow development, and make larvae more susceptible to predators and parasites (Fig. 16).

Parasites and predators. *Effect of flooding on parasitization of black bug eggs.* In a greenhouse study, we determined the effect of raising the water level on parasitization of black bug *Scotinophara coarctata* F. eggs by *Telenomus triptus*. After oviposition, the female bug positions herself over the egg mass and uses her legs and antennae to prevent parasites from parasitizing the eggs.

Our earlier study showed black bug egg masses deposited about 6 cm above water level. Our objective was to force the female bug off the egg mass by flooding, then to lower the water level to expose the egg masses to parasites.

The experiment used twenty 80-d-old plants in pots covered by a cage made of nylon mesh screen. Twenty female black bugs were introduced into each cage and allowed to oviposit for 24 h. Ten plants were flooded for 24 h at 10.5 cm depth. The remaining plants had water up to 4.0 cm (unflooded). After flooding, the water level was lowered to expose the egg masses, and 5 female *Telenomus triptus* egg parasites were placed in each cage to search and oviposit for 3 d.

Flooded plants had 147 black bug egg masses and unflooded plants 110 egg masses. Recovered egg masses were held in individual tubes until nymphs hatched or parasites emerged.

Egg parasitization increased from 17% in unflooded pots to 54% in flooded ones. Thus, manipulating water levels could aid black bug parasitization.

Influence of two species of parasites on leaf-folder leaf consumption. Goniozus triangulifer and *Copidosomopsis nacoleiae* are important parasites of LF larvae. In a laboratory study, we compared the leaf consumption of parasitized and unparasitized *M. patnalis* larvae. After *G. triangulifer* parasitized 3d-, 4th-, and 5th-instar LF, we measured leaf consumption. Parasitization of all larval stages, especially with 3d-instar LF, reduced

leaf consumption (Fig. 17). In contrast, 4th- and 5th-instar LF larvae parasitized by *C. nacoleiae*, a polyembryonic parasite, fed more than the unparasitized ones.

Biology of the parasite Tetrastichus ayyari. The pupal parasite *T. ayyari* was studied in the laboratory to determine its bionomics. The parasite attacked pupae of several insect pests of rice: two LF species *C. medinalis* and *M. patnalis*, green hairy caterpillar *Rivula atimeta*, SSB *C. suppressalis*, YSB *T. incertulas*, green semilooper *Naranga aenescens*, and green horned caterpillar *Melanitis leda ismene*. Female parasites lived an average of 39 d and males 30 d. The female-to-male ratio was higher (1:12) when the parasite developed in SSB than when it developed in LF (1:8). The total development period for *T. ayyari* was 15 d. More parasites emerged from SSB pupae (84) than from LF pupae (54).

These biological parameters help in understanding this parasite's interactions with its hosts and in rearing *T. ayyari* for possible field release.

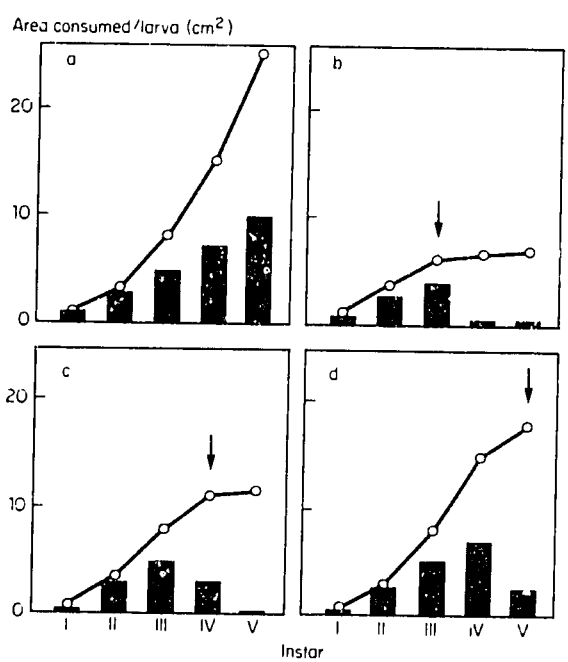
Rice bug egg predation and parasitization. We monitored the mortality of rice bug eggs in fields established by direct seeding and transplanting. Plants bearing rice bug eggs were placed in fields during booting. In 11 mo, 40% of the eggs were attacked by predators and 18% were parasitized. Mortality was generally higher in TPR than in DSR (Fig. 18).

Green horned caterpillar egg predation and parasitization. Ten pots, each with 15-20 marked *Melanitis* eggs, were randomly exposed on 5- m^2 TPR and DSR plots at 29, 45, 67, and 75 DAS. The potted plants were returned to the insectary 4 d after exposure. Missing eggs were presumed to have been preyed upon; the remainder were reared for parasite emergence.

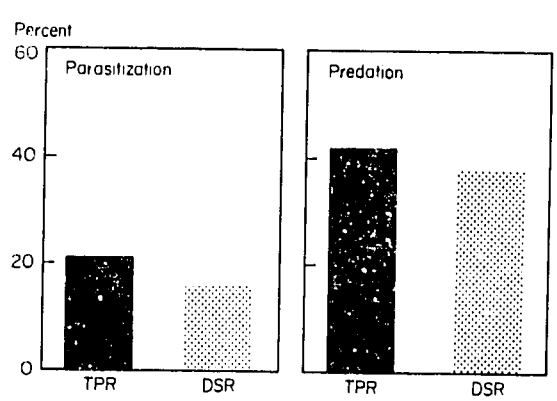
Egg predation — 62% in TPR and 66% in DSR — was 3 times that of parasitization. The most common egg predators were *Anaxipha longipennis, Conocephalus longipennis, Metioche vittaticollis*, and *Micraspis* nr. *crocea*.

Egg parasitization was 20% in TPR and 18% in DSR. Only two species of parasites emerged from recovered eggs. *Trichogramma* nr. *hesperidis* parasitized 60% of the eggs recovered in TPR and 53% in DSR. *Telenomus* sp. parasitized 40% of the eggs recovered in TPR and 47% in DSR.

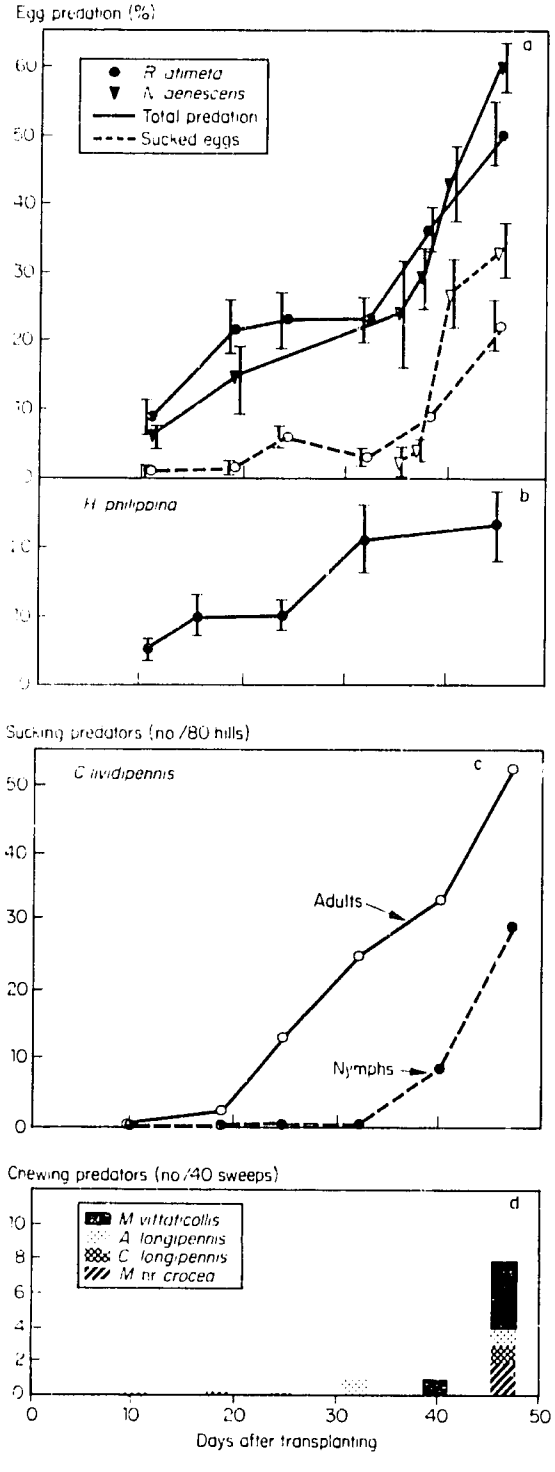
Impact of indigenous predator and parasite communities on eggs of Rivula atimeta, Naranga aenescens, and Hydrellia philippina. Eggs of three early season insect pests—*R. atimeta* (Swinhoe), *N. aenescens* (Moore), and *H. philippina* (Ferino)—were exposed weekly on plants in Philippine farmers' fields to determine predation and parasitization during crop growth.



17. Cumulative leaf consumption by instars of LF larvae. a) Unparasitized, b) parasitized by *C. triangulifer* during the 3d instar, c) parasitized during the 4th instar, and d) parasitized during the 5th instar. IRRI, 1987.



18. Parasitization and predation of rice bug eggs in TPR and DSR. IRRI, 1987.



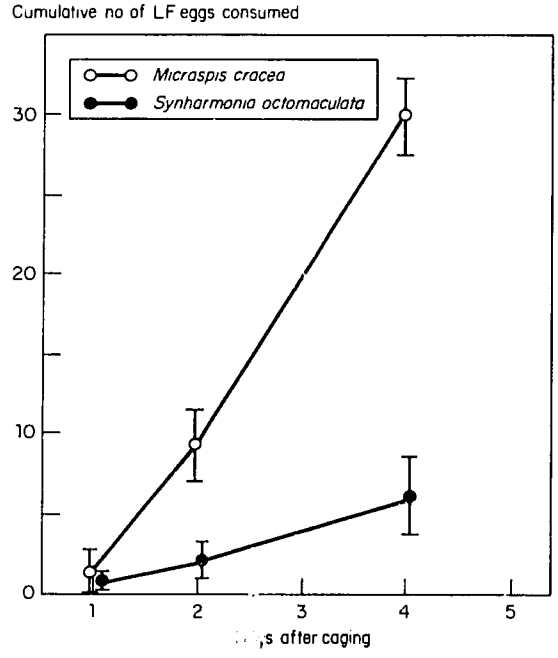
19. a) Predation on eggs of *Rivula atimeta* and *Naranga aenescens*, b) predation on eggs of *Hydrellia philippina*, c) number of adults and nymphs of *C. lividipennis*, d) number of predators with chewing mouthparts. Laguna, Philippines, 1987.

Predation, low the first 3 wk after transplanting, increased to 60% over the next 4 wk for *N. aenescens* (Fig. 19a). Predation on *H. philippina* eggs increased up to 23% (Fig. 19b). Predator numbers sampled from these fields coincided with predation levels. At one site, the mirid *Cyrtorhinus lividipennis* was the major predator of *R. atimeta* and *N. aenescens* eggs (Fig. 19c).

Parasitization of *N. aenescens* eggs, mainly by *Trichogramma japonicum* Ashmead, peaked at 52%, whereas parasitization of *R. atimeta* eggs was not higher than 4%. No parasites were recorded in *H. philippina* eggs.

Predation by coccinellids on leaffolder eggs. The predatory capacities of lady beetles *M. crocea* and *Synharmonia octomaculata* were compared in caged plants containing 50 LF eggs in the IRRI insectary. Consumption of LF eggs by *M. crocea* was twice that of *S. octomaculata* on the second day (Fig. 20). By the fourth day, *M. crocea* had consumed 60% LF eggs. *M. crocea* is likely a more efficient predator of LF eggs in the field than *S. octomaculata*.

Seasonal abundance of and insecticide effects on Conocephalus longipennis and on spiders. Popula-



20. Cumulative number of LF eggs consumed by 2 species of coccinellids. IRRI, 1987.

tions of the predatory grasshopper *C. longipennis* in unsprayed plots increased during the reproductive phase of rice plants, peaking at 63 DT. This population increase may be due to feeding on flowers and tender grains of rice. Laboratory studies reveal that this insect is both predator and pest.

Application of monocrotophos at 0.4 liter/ha at 14 DT and 0.4 liter chlorpyrifos/ha plus BPMC at 56 DT decreased *C. longipennis* and delayed population buildup by 1 wk.

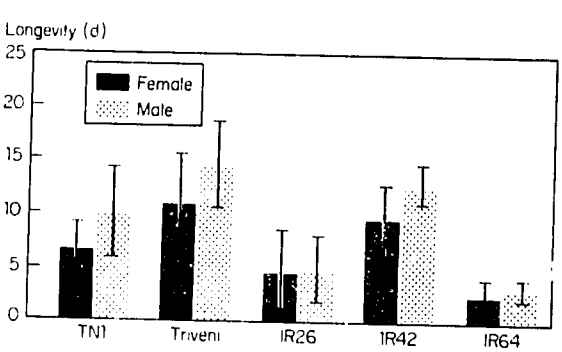
In general, spiders were not harmed by these insecticide applications.

Biology of Cyrtorhinus lividipennis. We studied the effects of varietal resistance (without prey) on the longevity of *C. lividipennis* in greenhouse cages. Female longevity did not differ significantly among varieties, but males lived slightly longer on moderately resistant (Triveni) than on highly resistant (IR64) varieties (Fig. 21). The fecundity of *C. lividipennis* on varieties tested was very low (0-5 eggs/female) and did not significantly differ among varieties.

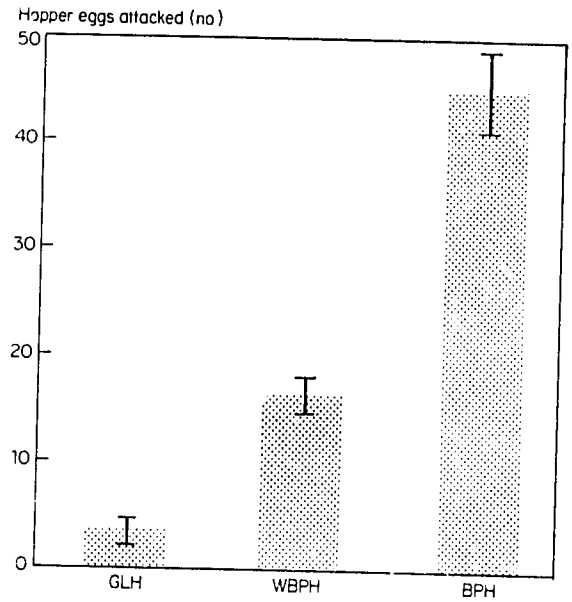
Cyrtorhinus lividipennis predation. Predation by one pair of *C. lividipennis* in mylar cages during 48 h indicated higher attack on BPH eggs than on GLH or WBPH eggs (Fig. 22).

Predation on BPH eggs and nymphs by *C. lividipennis* was studied in test tubes (20 × 2.5 cm). Females and males fed more on eggs than on 1st nymphal instars; females fed more than males did (Fig. 23). The attack rate on BPH eggs in test tubes increased up to a BPH egg density of 25 (Fig. 24).

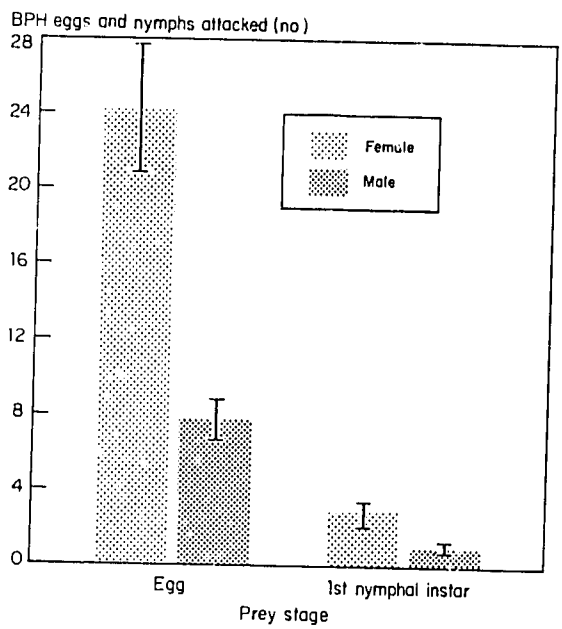
C. lividipennis attacked eggs of several lepidopterous pests. Predation by one pair of *C. lividipennis* on eggs of YSB, SSB, green hairy caterpillar, and LF was studied in cages. *C. lividipennis* attacked LF eggs most and ignored YSB eggs.



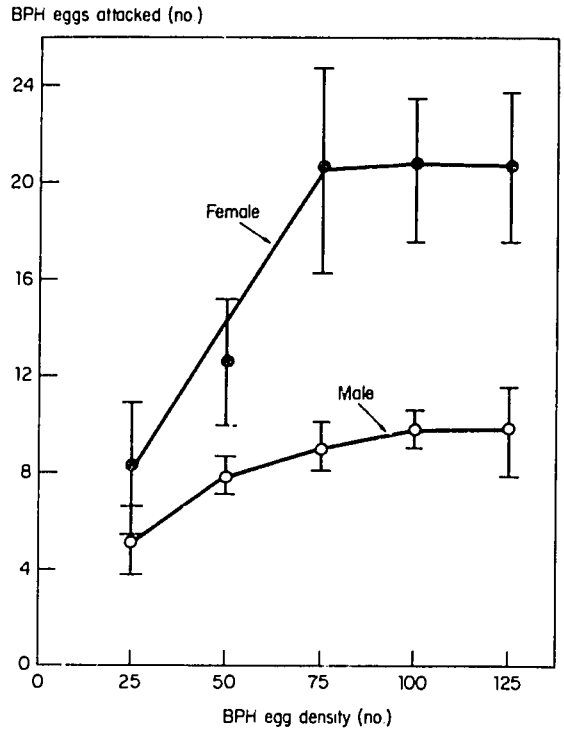
21. Longevity of *C. lividipennis* on resistant and susceptible plants. IRRI, 1987.



22. Predation by one pair of *C. lividipennis* on eggs of GLH, WBPH, and BPH during 48 h, IRRI, 1987. Vertical lines represent standard deviation.



23. Predation by individual *C. lividipennis* on eggs and first instars of BPH. IRRI, 1987.



24. Predation by female and male *C. lividipennis* on eggs of BPH at different densities. IRRI, 1987.

Predatory efficacy of Cyrtorhinus lividipennis. One pair (male and female) each of *C. lividipennis* was introduced into cages with plants containing eggs of GLH, WBPH, and BPH. BPH was the preferred host, with about 45 eggs attacked in 24 h. WBPH was preyed upon significantly less at 17 eggs in 24 h, and GLH eggs were least preferred at less than 4 in 24 h.

In this laboratory test, *C. lividipennis* male and female predation increased with increasing numbers of BPH eggs. Predation by females reached an asymptote of about 20 eggs in 24 h when the host density reached 75 eggs. Predation by males was about 1/2 this amount at an egg density of 75-100 BPH eggs.

Predation on green horned caterpillar. One adult each of common ricefield predators—the katydid *Conocephalus longipennis*, sword-tailed cricket *Metioche vittaticollis*, lady beetle *Micraspis* nr. *crocea*, and wolf spider *Lycosa pseudoannulata*—was held in a test tube with five instars of *Melanitis* larvae. Predation ranged from 40 to 95% on 1st-instar, 15 to 60% on 2d-instar, and 5 to 55% on 3d-instar larvae (Table 7). Only *L. pseudoannulata* attacked 4th and 5th instars, but at low rates (6 to 5%). *L. pseudoannulata* was the most voracious predator and *M. vittaticollis* the least.

Predation by Ochthera sauteri. The ephydrid fly *O. sauteri* preys on a wide range of hosts. Prey, caught in midair and held by the raptorial forelegs, are impaled by large leg spines. *Ochthera* laps up emerging body fluids, feeding only a short while on each of many victims. It prefers highly mobile and relatively small prey. Common preferences in ricefields are *Hydrellia* > *Brachydeutera* = *Psilopa* = *Paralimna* > *Notiphila*. *Ochthera* also preys on common rice leafhoppers and planthoppers.

Fifty adults each of rice whorl maggot (RWM), WBPH, GLH, and BPH were maintained in a large aquarium for 5 d. Each day, one *O. sauteri* fly was introduced into the aquarium with prey. RWM was preferred to leafhoppers and planthoppers (Fig. 25).

Predation by the spider Lycosa pseudoannulata on green leafhopper on susceptible and resistant varieties. Combining plant resistance with predation can improve insect control. We placed GLH adults on IR62 (resistant), ASD7 (resistant), and TN1 (susceptible) plants and then placed wolf spiders *L. pseudoannulata* into the cages. The spiders consumed more GLH on resistant varieties, probably because GLH move more on those varieties, increasing their exposure (Fig. 26).

CHEMICAL CONTROL

Entomology Department

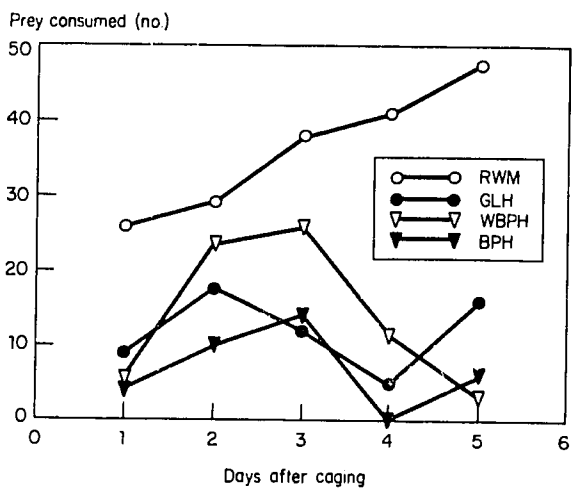
Persistence and distribution of carbosulfan seedling root soak. Three-week-old seedlings of IR1917-3-17 were uprooted, washed, and soaked overnight in a plastic basin with carbosulfan STW. Most insecticide stayed in the roots and leaf sheaths (Fig. 27), very little in the leaf blades, and none in the stems. Carbosulfan rapidly left the leaf sheaths and blades. The low uptake in the leaf blades explains carbosulfan's poor performance against early season defoliators *R. atimeta* and *N. aenescens*. Its rapid decline from the leaf sheaths explains its limited performance as a seedling root soak against rice whorl maggot.

Low insecticide dosage for rice bug control. Three insecticides at four dosages were evaluated against rice bugs in the field. One application

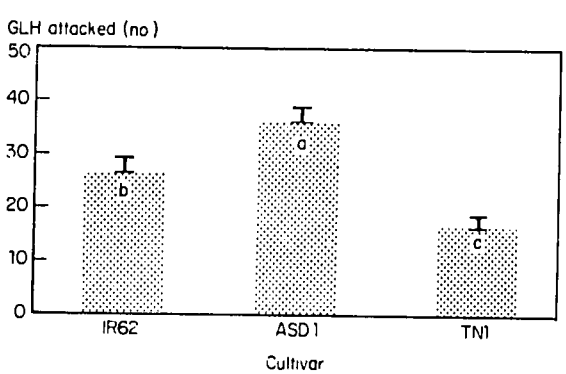
Table 7. Predation on green horned caterpillar.[a] IRRI greenhouse, 1987.

Predator	Larval mortality (%)				
	1st instar	2d instar	3d instar	4th instar	5th instar
Conocephalus longipennis	45	20	15	0	0
Metioche vittaticollis	40	15	5	0	0
Micraspis nr. *crocea*	55	50	25	0	0
Lycosa pseudoannulata	95	60	55	6	5

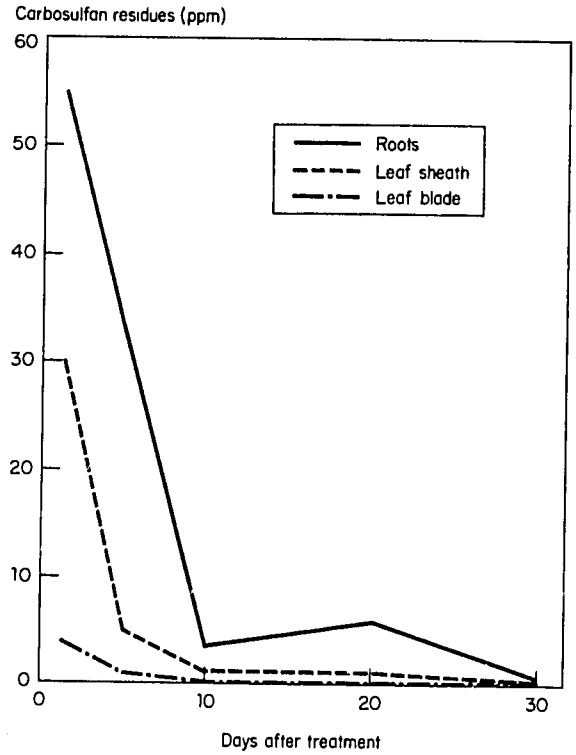
[a]Av of 4 replications; 1 predator/5 larvae per replication. Mortality recorded after 24 h.



25. Predation by *Ochthera sauteri* on rice whorl maggot (RWM), GLH, WBPH, and BPH confined together. IRRI greenhouse, 1987.



26. Predation by *Lycosa pseudoannulata* on GLH on susceptible and resistant plants. IRRI, 1987.



27. Carbosulfan residues on the different parts of IR 1917-3-17 seedlings. IRRI insectary, Jun-Sep 1987.

during the milk stage (75 DT) protected the IR64 crop up to 11 d after treatment (DAT) (Table 8). Effective minimal dosages were deltamethrin 6-12.5 g ai/ha, monocrotophos 100-250 g ai/ha, and phosphamidon 250-500 g ai/ha.

Chemical control of rice whorl maggot. Previous research showed that a minimum of 2 foliar sprays totaling 0.8 kg ai/ha reduced whorl maggot damage in the vegetative phase. Current strategy uses the ovicide azinphos-ethyl, followed by the larvicide monocrotophos. Minimal dosages reduce cost and harm to natural enemies. Total dosage can be reduced to 0.6 kg ai/ha with frequent application (Table 9). Control was best with 0.15 kg ai/ha applied 3-4 times at 5-d intervals.

Golden apple snail control. Methods to control *Pomacea canaliculata* include hand collection, draining the field, and placing screens in irrigation inlets. However, heavy infestation requires molluscicides. All molluscicides work best if the field water depth is maintained at 2 cm for 1 wk. Triphenyltin acetate controls snails best but is highly toxic to fish (Fig. 28). Niclosamide is

Table 8. Field evaluation of 3 insecticides for rice bug control.[a] IRRI farm, 1987.

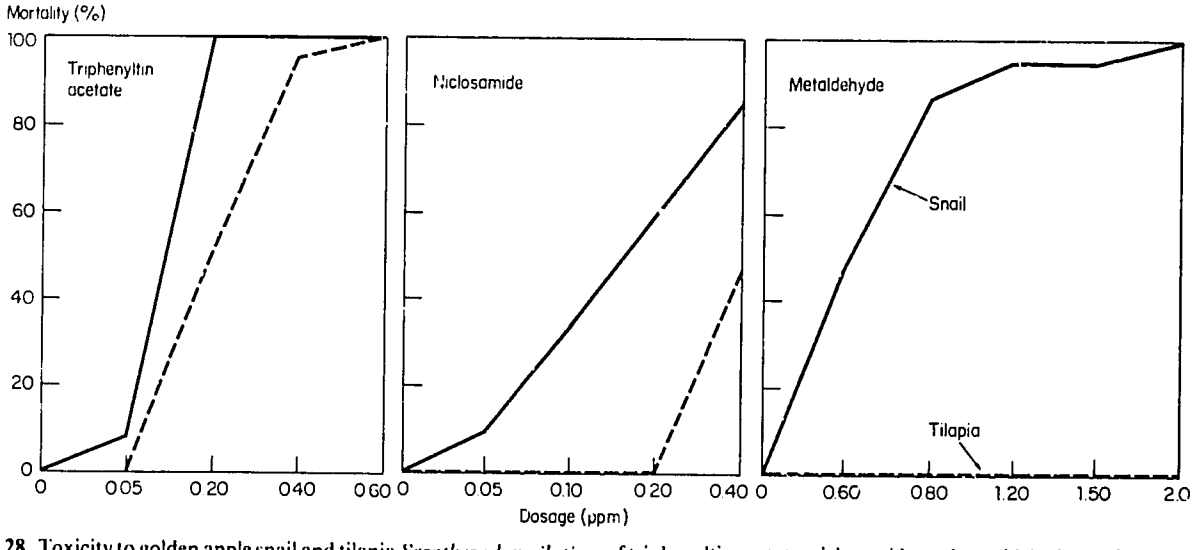
Insecticide[b]	Rate (g ai/ha)	Rice bugs (no./5 m²) at indicated days after treatment[c]			
		1 DBT	1 DAT	7 DAT	11 DAT
Deltamethrin 2.5 EC	25	67 abc	5 abc	8 a	16 a
	12.5	79 c	9 a	10 a	18 a
	6	67 abc	7 bc	7 a	29 ab
	3	58 abc	14 c	12 a	23 ab
Monocrotophos 31 EC	500	58 abc	9 a	9 a	14 a
	250	56 ab	13 ab	5 a	41 bc
	100	56 ab	17 abc	7 a	16 a
	50	74 bc	33 c	27 b	37 abc
Phosphamidon 75 EC	500	47 a	17 abc	10 a	26 a
	250	59 abc	11 a	8 a	18 a
	100	72 bc	28 bc	21 b	32 abc
	50	79 c	32 c	23 b	50 c
Untreated control	–	75 bc	59 d	51 c	45 bc

[a]Av of 4 replications. DBT = days before treatment, DAT = days after treatment. [b]Applied once at 75 d after transplanting at spray volume of 500 liters/ha. [c]10 net sweeps/plot.

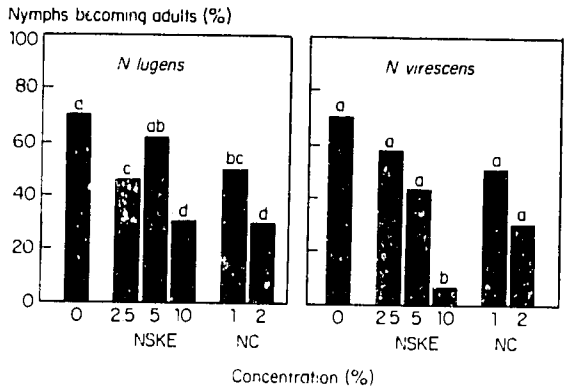
Table 9. Timing and frequency of insecticide spray for effective rice whorl maggot control.[a] IRRI, 1987.

Spray schedule[b] (DT)	Dosage per application (g ai/ha)	Damaged leaves (%)			
		9 DT	15 DT	26 DT	33 DT
3, 8	300 + 300	3 a	17 ab	20 c	16 bc
6, 12	300 + 300	5 a	13 a	16 b	18 c
9, 16	300 + 300	7 ab	22 b	11 a	10 a
5, 10, 15	300 + 150 + 150	4 a	12 a	11 a	12 ab
5, 10, 15, 20	150 + 150 + 150 + 150	4 a	18 ab	8 a	8 a
Control	–	10 b	29 c	26 d	17 c

[a]Av of 4 replications. Twenty randomly selected hills constituted a replication. [b]The first application used azinphos-ethyl; the second to fourth used monocrotophos. DT = days after transplanting.



28. Toxicity to golden apple snail and tilapia *Sarotherodon niloticus* of triphenyltin acetate, niclosamide, and metaldehyde applied to floodwater. IRRI, 1986.



29. Effects of neem seed kernel extract (NSKE) or neem cake (NC) as presowing seed treatments on development of first-instar *N. lugens* and *N. virescens* nymphs, IRRI, 1987. Av of 3 replications, 10 first-instar nymphs replication.

intermediate in controlling both snails and fish at low dosages. Metaldehyde controls snails and is safe to fish but requires a high dosage.

In a greenhouse trial, soaking seedlings in 0.1% ai cartap/ha reduced snail damage from 100% to 35% seedlings consumed. Protection lasts up to 1 wk. Cartap is a repellent, not a molluscicide.

Botanical pesticides *Effects of neem in presowing seed treatments on seedling vigor and on brown planthopper and green leafhopper.* TN1 rice seeds were soaked in 2.5, 5, and 10% neem seed kernel extract (NSKE) for 24 h and incubated for 48 h. In another set, seeds soaked in water for 24 h were dressed with neem cake (NC) powder. Significantly fewer BPH nymphs developed on seeds soaked in 10% NSKE or dressed with 2% NC. However, only 10% NSKE prevented GLH nymphs from developing into adults (Fig. 29). Presowing treatments did not affect seed germination, seedling root and shoot length, or the chlorophyll content of IR36 and IR42 seedlings. Root and shoot growth index and seedling dry weight increased significantly in seedlings receiving NSKE or NC treatments compared with the control (Table 10).

Effects of neem on green leafhopper oviposition and nymph emergence. The efficacy of NSKE and neem seed bitters (NSB) against GLH oviposition and hatchability was tested by root immersion of TN1 seedlings for 12 or 24 h. Root immersion for 12 h in NSKE or NSB did not reduce oviposition or prevent nymph emergence, but 24-h immersion effectively lowered nymph emergence and hatchability. Significantly fewer eggs were laid only in the 5% NSKE relative to the control (Table 11).

Effects of neem on green leafhopper feeding. We electronically monitored the feeding of newly emerged GLH females on 21-d-old TN1 plants

Table 10. Effect on seed germination and vigor of presowing treatment with crude neem seed kernel extract (NSKE) and neem cake (NC).[a] IRRI, 1987.

Neem treatment (%)	Germination (%)	Growth index		Length (mm)		Dry wt (mg)/ 10 seedlings	Chlorophyll[b] (µg/g)
		Root	Shoot	Root	Shoot		
			IR36				
NSKE							
2.5	96 a	77.5 a	66.0 a	250.3 a	105.0 a	91 a	51 a
5.0	95 a	79.8 a	71.3 a	249.3 a	104.0 a	92 a	50 a
10.0	94 a	81.5 a	70.5 a	250.8 a	106.0 a	90 a	52 a
NC							
1.0	94 a	60.8 b	60.5 b	249.3 a	106.0 a	90 a	50 a
2.0	96 a	55.0 c	63.5 b	250.0 a	105.8 a	89 ab	51 a
0 (control)	94 a	34.8 d	44.3 c	249.8 a	105.3 a	85 b	49 a
			IR42				
NSKE							
2.5	96 a	43.8 ab	46.8 b	218.0 a	80.0 a	83 ab	106 a
5.0	96 a	39.5 b	47.8 b	220.5 a	80.8 a	85 a	106 a
10.0	95 a	48.8 a	52.5 a	219.5 a	80.0 a	84 ab	105 a
NC							
1.0	95 a	24.8 c	22.5 c	220.0 a	80.0 a	80 bc	104 a
2.0	95 a	24.8 c	26.3 c	220.8 a	81.0 a	82 abc	106 a
0 (control)	94 a	16.0 d	17.3 d	219.0 a	81.0 a	78 c	104 a

[a]Av of 5 replications. In a column, means for each variety followed by a common letter are not significantly different at the 5% level by DMRT. [b]Fresh weight basis.

Table 11. Ovipositional response and egg hatch of *N. virescens* on TN1 seedling roots dipped for 12 or 24 h in NSKE or neem seed bitters (NSB) solution.[a] IRRI, 1987.

Treatment	Eggs laid (no.)	Hatchability (%)	Nymphs that emerged (no.)
		12 h	
2500 ppm NSB	43 a	75 abc	40 ab
5000 ppm NSB	27 a	71 abc	19 abc
2.5% NSKE	21 a	89 ab	20 abc
5.0% NSKE	21 a	76 ab	16 abc
		24 h	
2500 ppm NSB	15 ab	55 bcd	11 bcd
5000 ppm NSB	19 a	67 bc	12 bc
2.5% NSKE	14 ab	36 cd	7 cd
5.0% NSKE	8 b	28 d	5 d
0 (control)	50 a	100 a	50 a

[a]Av of 5 replications.

systemically treated by overnight root immersion or by dipping foliage for 25 s in a 2500 ppm NSB solution. During 3-h observation, waveform patterns showed significantly less phloem feeding in neem-treated plants than in the control (Table 12), with a corresponding increase in probing, salivation period, and xylem feeding in neem-treated plants.

Effects of neem and carbofuran mixtures on green leafhopper and rice tungro virus transmission. We evaluated the efficacy of carbofuran combined with NC or neem seed kernel (NSK) powder at 1 kg ai/ha (33.3 kg NSK or NC + 33.3 kg carbofuran 3G) and compared it with carbofuran alone at 1 or 2 kg ai/ha. The treatments were applied to soil of potted TN1 rice seedlings at 10 DT. Untreated plants served as controls. GLH survival in plants treated with carbofuran alone or with neem-mixed carbofuran was negligible compared with 100% insect survival in the control. Rice tungro virus (RTV) infection was significantly lower in plants treated with NSK-carbofuran mixture than in plants treated with carbofuran alone. No nymphs emerged in plants treated with carbofuran at 2 kg ai/ha or with neem-mixed carbofuran (Table 13).

Effects of neem on green leafhopper and its predator Cyrtorhinus lividipennis. NSB and neem oil (NO) were applied directly to GLH females and *C. lividipennis* females at 0, 5, 10, or 20 μg/individual. Oil was significantly toxic to GLH at 10 and 20 μg and to the mirid at 5, 10, and 20 μg (Table 14). However, NSB were significantly more toxic to GLH at all doses than to the predator.

Predation by *C. lividipennis* adults on plants laden with GLH eggs was not affected by NO or NSB. Mortality of GLH nymphs on plants sprayed with NO increased with increasing oil concentration, and increased significantly more on plants sprayed with 9% NO in the presence of the predator. GLH nymphs mortality on plants systemically treated or sprayed with NSB increased with concentration. Also, mortality increased on plants sprayed with or root-dipped in NSB solution with the predator present.

GLH population on TN1 plants increased significantly less with the predator than in the control and compared with that on plants treated with NSB or NO (Fig. 30). Population increase on

Table 12. Means of various events in 3-h feeding by *N. virescens* females on TN1 plants systemically treated with or dipped in 2500 ppm NSB solution.[a] IRRI, 1987.

Treatment	Probes (no.)	Salivation (min)	Phloem ingestion (min)	Xylem ingestion (min)	Total ingestion (min)
Systemic	25 a	21 a	29 b	23 a	52 a
Foliar	24 a	15 ab	41 b	29 a	70 a
Control	13 b	10 b	76 a	1 b	77 a

[a]Av of 10 replications.

Table 13. Comparison of *Nephotettix virescens* adult mortality, nymph emergence, and rice tungro virus (RTV) infection in TN1 rice plants treated with carbofuran mixed with neem seed kernel (NSK) or neem cake (NC) powder, or carbofuran alone.[a] IRRI, 1987.

Treatment	Adult mortality (%) in infestations		Nymphs that emerged (no.)	RTV infection (%)
	1st	2d		
Carbofuran (1 kg ai/ha) + NSK (1:1)	100 a	100 a	0 a	2 a
Carbofuran (1 kg ai/ha) + NC (1:1)	98 a	96 a	0 a	8 b
Carbofuran (2 kg ai/ha)	100 a	100 a	0 a	10 b
Carbofuran (1 kg ai/ha)	100 a	98 a	4 b	28 c
Untreated (control)	0 b	0 b	285 c	100 d

[a]Av of 5 replications.

Table 14. Mortality of *C. lividipennis* and *N. virescens* females 24 h after topical application with neem oil or neem seed bitters.[a] IRRI, 1987.

Treatment (μg/individual)	Mortality (%)		
	C. lividipennis	*N. virescens*	Difference[b]
	Neem oil		
5	22.8 ab	4.0 b	18.8*
10	19.7 abc	30.0 a	10.3 ns
20	26.8 a	36.0 a	9.2 ns
0 (control)	9.3 c	1.0 b	8.3 ns
	Neem seed bitters		
5	14.8 a	35.6 b	20.8**
10	10.9 a	55.0 a	44.1**
20	8.3 a	59.0 a	50.7**
0 (control)	11.3 a	0.0 c	11.3*

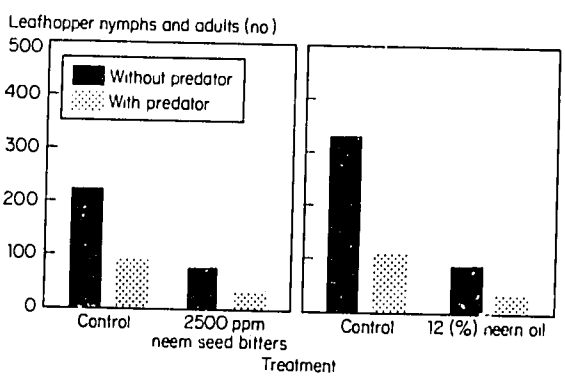
[a]For each neem form, means in a column followed by a common letter are not significantly different at 5% level by DMRT. Av of 10 replications, 10 individuals/replication.

neem-treated plants together with the predator was significantly less than on plants without the predator or with neem treatments alone.

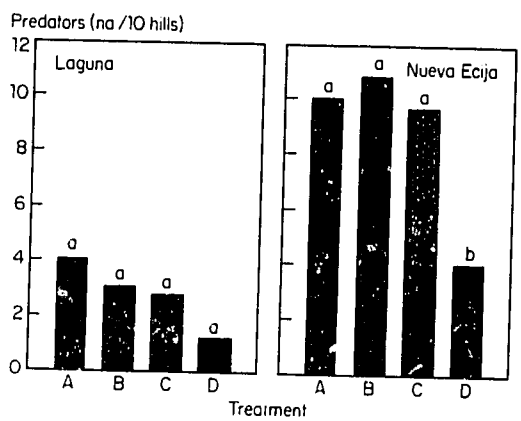
Effects of neem forms and custard-apple oil on green leafhoppers and predatory mirids and spiders. Four field trials, two each in Laguna and Nueva Ecija, Philippines, were conducted in November 1986-May 1987 using a 50% NO: custard-apple oil (CAO) mixture (4:1 vol/vol) sprayed with an ultralow-volume applicator, either alone or in combination with 150 kg NC as basal application. Spray applications, weekly in Laguna and fortnightly in Nueva Ecija, commenced from 5 DT. Weekly application of NO:CAO mixture at 6 liters/ha significantly reduced GLH population. Neem treatments did not reduce field populations of the predatory mirid bug and spiders; however, insecticide applications did (Fig. 31).

Cost effectiveness of neem oil and BPMC insecticide for rice tungro virus management. The control potential and the cost effectiveness of a 50% NO:CAO mixture (4:1 vol/vol) at 8 liters/ha were compared with those of BPMC (0.75 kg ai/ha) insecticide treatment in 3 consecutive croppings in 1984-85 for RTV management. January-April 1984 RTV incidence was negligible and yields were high in all treatments. In June-October 1985, plots treated with the oil mixture had significantly less RTV infection than the untreated control, but yields were not significantly different. In November 1984-March 1985, RTV incidence was significantly less in plots treated with the oil mixture than in insecticide-treated and untreated control plots. Yield was significantly higher in plots treated with the oil mixture. Net economic gain was consistently higher in plots treated with the oil mixture than in the untreated control or BPMC treatment, mainly because of reduced RTV, increased yield, and less expensive oil treatment (Table 15).

Effect of nonedible seed oils on survival of green leafhopper and on rice tungro virus transmission. Oils extracted from seeds of the trees karanj *Pongamia pinnata*, mahua *Madhuca longifolia*,



30. Increase in *N. virescens* population on neem-treated TN1 plants with or without *C. lividipennis* adults at 30 d after infestation, IRRI, 1987. Av of 5 replications, each with 1 pair of leafhoppers and 1 pair of predators. NSB = neem seed bitters, NO = neem oil.



31. Populations of predators *C. lividipennis* and *L. pseudoannulata* in plots planted to IR42, Laguna and Nueva Ecija, Philippines, 1987 WS. A = untreated control, B = neem cake basally applied, and spray with neem oil (NO)-custard-apple oil mixture, C = NO-custard-apple oil mixture, and D = monocrotophos. Av of 5 replications and 6 observations at each site.

Table 15. RTV control, yield, and net gain in ricefields sprayed with NO:CAO and an insecticide.[a] IRRI, 1987.

Treatment	RTV (%)	Yield (t/ha)	Value of yield ($)	Cost of treatment ($)	Net gain[b] (value of yield less cost of treatment)
			January-April 1984		
NO:CAO	5 a	6.1 a	1068	44	1024
BPMC	4 a	6.1 a	1068	125	943
Control	7 a	5.6 a	980	12	968
			June-October 1984		
NO:CAO	4 a	5.1 a	892	44	848
BPMC	6 ab	4.7 a	822	125	697
Control	9 b	4.6 a	805	12	793
			November 1984-March 1985		
NO:CAO	29 a	3.1 a	542	44	498
BPMC	56 b	2.5 b	438	125	313
Control	52 b	2.3 b	402	12	390

[a]Av of 4 replications/cropping season. Cost of palay = $0.175/kg (NFA price). NO:CAO mixture and BPMC were applied 8 times during each cropping season. For each cropping season, means in a column followed by a common letter are not significantly different at the 5% level by DMRT. [b]Cost of treatment includes labor and materials. Control treatment cost included labor ($10) and 8 pc DC batteries ($2) for applying 1.66% Teepol-water solution (emulsifier) using an ultralow-volume spray applicator.

and pinnai *Calophyllum inophyllum* were more effective than NO in reducing the survival of GLH and its transmission of RTV, and as effective as CAO. Insect mortality was 100% after 4 d on rice plants sprayed with oils at 5% concentration in contrast to 69% insect survival on control plants (Table 16). RTV infection was 17 to 35% on oil treated plants and 51% in the control.

Cytogenetic effects of neem seed bitters on spermatocytes of green leafhopper and brown planthopper. Exposure to neem seed derivatives can reduce the reproductive potential of several insect pests. We investigated the effect on reproductive fitness of first-generation male progeny of GLH and BPH parents caged on rice plants sprayed with an aqueous solution of 100, 500, or 2500 ppm NSB.

The meiotic process, but not interphase, was significantly affected by NSB treatment. Few spermatogonia carried on the meiotic divisions that produced primary and secondary spermatocytes. This significantly reduced the meiotic index in the progeny derived from treated parents (Table 17).

Leaffolder feeding on rice plants sprayed with neem oil or neem seed bitters. Thirty-day-old TN1 rice plants were sprayed with 2500, 5000, or 10,000 ppm solution of NSB or 1.25, 2.5, 5, or 10% emulsified NO. Plants sprayed with Citowett or 1.6% Teepol solution served as controls. One hour after treatment, a starved 4th-instar *Cnaphalocrocis medinalis* larva was allowed to feed for 1 h on treated or control plants. The 9 to 10 replications for each treatment used fresh plants and fresh larvae. Electronic monitoring showed that feeding duration decreased significantly on plants sprayed with ≥ 2.5% neem or with ≥ 2500 ppm NSB solution (Fig. 32).

Effect of neem seed bitters on leaffolder and its parasitization and predation. Fourth-instar LF *Marasmia patnalis* larvae failed to grow when fed leaves from IR36 rice plants dipped in 100, 200,

Table 16. Survival of *Nephotettix virescens* adults after exposure on TN1 rice seedlings sprayed with emulsified 5% nonedible oils, and RTV infection.[a] IRRI, 1987.

Treatment	Survival (%) after indicated time				RTV infection (%)
	1 d	2 d	3 d	4 d	
Karanj oil	44 c	30 b	14 b	0 a	17 a
Manua oil	35 ab	22 ab	7 ab	0 a	23 ab
Pinnai oil	32 a	16 a	1 a	0 a	19 ab
Neem oil	71 d	55 c	29 c	0 a	35 c
Custard-apple oil	13 bc	25 ab	10 b	0 a	25 b
Teepol 1% (control)	86 e	84 d	78 d	69 b	51 d

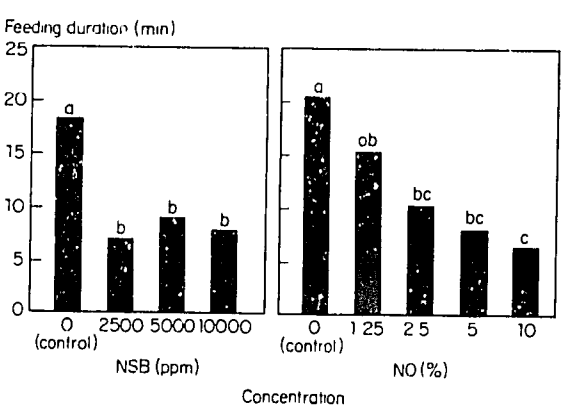
[a]Av of 10 replications, 10 seedlings and 10 adults/replication.

Table 17. Mean frequencies of meiocytes and nonmeiocytes, and meiotic indices in progeny derived from *N. virescens* and *N. lugens* parents on TN1 rice plants treated with NSB.[a] IRRI, 1987.

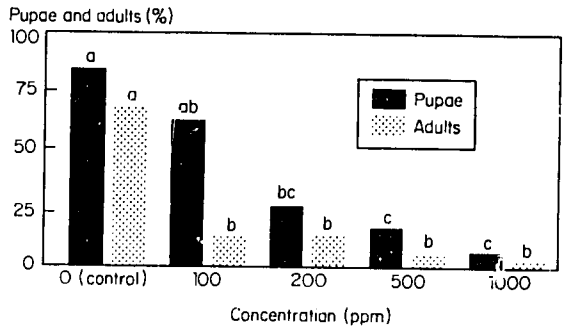
Neem treatment (ppm)	Frequency (no.)		Meiotic index
	Meiocytes	Nonmeiocytes	
	N. virescens		
100	450 a	197 a	0.69 b
500	86 b	91 b	0.48 c
2500	77 b	89 b	0.45 c
0 (control)	484 a	96 b	0.83 a
	N. lugens		
100	82 b	221 a	0.28 b
500	81 b	273 a	0.22 b
0 (control)	233 a	375 a	0.38 a

[a]In a column, means followed by a common letter are not significantly different at the 5% level by DMRT for *N. virescens* (av of 15 replications, 1 male/replication) and at the 10% level by *t*-test for *N. lugens* (av of 10 replications, 1 male/replication).

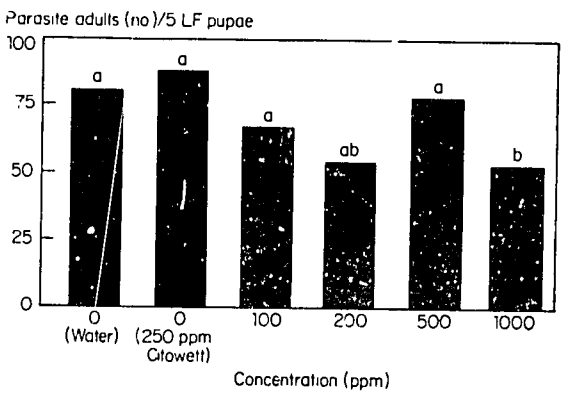
500, or 1000 ppm NSB solution (Fig. 33). A prolonged larval period led to developmental abnormalities. Hatchability of eggs was significantly reduced on rice leaves dipped in a 500 or 1000 ppm NSB solution. Growth disruption persisted even after larvae emerged. Adult emergence decreased when LF pupae were dipped in a 500 ppm solution. However, the emergence of the parasite *Tetrastichus ayyari* from treated, preparasitized pupae was not affected, except at the highest dose (Fig. 34). Topical application of NSB at 5, 10, 20, or 50 μg in the presence of *Goniozus*



32. Duration of feeding by 4th-instar *C. medinalis* larvae recorded electronically on IR36 rice plants sprayed with NSB solution (av of 9 replications) or neem oil (NO) (av of 10 replications). IRRI, 1987.



33. *Marasmia patnalis* pupae and adults developed from 4th-instar larvae fed with rice leaves treated with NSB, IRRI, 1987. Av of 4 replications, 10 larvae/replication.



34. Emergence of *Tetrastichus ayyari* adults from preparasitized pupae of *M. patnalis* treated with NSB, IRRI, 1987. Av of 8 replications, 5 pupae/replication.

triangulifer, a LF parasite, did not affect the parasite's longevity. In field tests, predation of LF eggs on plants sprayed with an electrodyn formulation of NO was as high as in untreated control.

Botanicals against stored grain pests. Insecticides or fumigants commonly used to protect stored grains can be hazardous to farmers. Therefore, plant materials used traditionally as grain protectants need reevaluation.

In a food preference chamber, fewer adults of the red flour beetle *Tribolium castaneum* settled on rice grain treated with 100, 500, or 1000 ppm of the oil of turmeric *Curcuma longa*, sweet flag *Acorus calamus*, or neem, or of a Margosan-O(R)-azadirachtin-based formulation (Table 18). Repellency increased with increasing concentrations of the oils and Margosan. *T. castaneum* adults fed wheat flour treated with the test materials at 200 ppm or higher produced fewer and

underweight larvae, pupae, and adults compared with those in the control.

Table 18. *Tribolium castaneum* **adults that settled on rice treated with plant products and in control rice grain at 24 h after exposure in a food preference chamber.[a] IRRI, 1987.**

Plant product	Concentration (ppm)	Adults (no.) in rice grain	
		Treated	Control
Neem oil	100	34 c	50
	500	18 ab	69
	1000	11 a	68
Turmeric oil	100	31 bc	57
	500	15 ab	61
	1000	15 ab	52
Margosan-0	500	13 a	61
	1000	6 a	59
Sweet flag oil	1000	17 ab	55

[a]Av of 3 replications, 120 individuals/replication.

Test materials also repelled the lesser grain borer *Rhyzopertha dominica*. Turmeric oil and sweet flag oil were slightly more repellent the first 2 wk than NO and Margosan, but thereafter less so. *R. dominica* adults made fewer and smaller feeding punctures in filter paper disks (7 cm diam) treated with the test materials at 100, 500, or 1,000 $\mu g/cm^2$ than in the control. NO alone or in combination with fumigation applied to rice storage jute sacks at 1,000 or 4,000 $\mu g/cm^2$ or to the grains at 500 or 1,000 ppm significantly reduced populations of *R. dominica*, *T. castaneum*, the rice weevil *Sitophilus oryzae*, the saw-toothed grain beetle *Oryzaephilus surinamensis*, the mealworm moth *Corcyra cephalonica*, and the Angoumois grain moth *Sitotroga cerealella*, and decreased weevilled grain and grain weight loss (Table 19). Seed germination and seedling shoot and root growth were significantly better in NO treatment than in the control.

Table 19. Live adults of important storage insect pests in rice stored either after direct treatment or stored in treated jute sacks for 8 mo in a warehouse at Calauan, Philippines.[a] IRRI, 1987-88.

Treatment no.	Treatment	Insect pest adults (no.)				Weevilled[c] grains
		R. dominica	*S. oryzae*[b]	*T. castaneum*	*O. surinamensis*	
1	Bag treatment with 1% NO	4.3 ab	3.7 a	1.3 abc	0.3 ab	4.3 ab
2	Beg with 4% NO	3.5 ab	3.7 a	1.0 abc	0.3 ab	3.3 a
3	Grain with 5% NO	3.9 ab	3.0 a	0.7 ab	0.7 ab	3.3 a
4	Grain with 1% NO	4.8 ab	3.7 a	0.3 a	0.0 a	3.3 a
5	Fumigation + T1	4.8 ab	3.3 a	1.0 abc	0.0 a	3.6 ab
6	Fumigation + T2	4.8 ab	3.7 a	1.0 abc	1.0 b	3.1 a
7	Fumigation + T3	3.1 a	3.7 a	1.3 abc	0.7 ab	3.4 a
8	Fumigation + T4	3.1 a	3.7 a	1.0 abc	1.0 b	3.3 a
9	Bag treated with pirimiphos-methyl	3.9 ab	3.0 a	1.7 abc	1.3 b	3.1 a
10	Grain treated with pirimiphos-methyl	3.9 ab	3.7 a	2.0 bc	0.7 ab	3.7 ab
11	Fumigation	6.3 bc	5.3 ab	2.3 bc	0.7 ab	5.9 b
12	Control	8.5 c	6.7 b	2.7 c	1.0 b	13.3 c

[a]Av of 3 replications, 1 bag of 44 kg of paddy/replication per treatment. Regular 250-g samples were drawn from each bag for 8 consecutive mo with a spear sampler. [b]At 5 mo. [c]At 8 mo.

Management of rice pests

Weeds

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HERBICIDE SCREENING

Research to identify herbicides for weed control in rice continued at IRRI; at the Maligaya, Bicol, and Visayas research stations of the Philippine Bureau of Plant Industry (BPI); and in farmers' fields in Batangas and Nueva Ecija.

Echinochloa crus-galli ssp. *hispidula*, *E. glabrescens*, *Monochoria vaginalis*, and *Cyperus difformis* were common in transplanted rice (TPR) and broadcast seeded rice (BSR). *Echinochloa colona*, *Eleusine indica*, *Rottboellia cochinchinensis*, *Amaranthus spinosus*, *Trianthema portulacastrum*, *Commelina benghalensis*, *Cyperus iria*, and *Ageratum conyzoides* were dominant in the upland fields, while *Echinochloa colona* was dominant in dry seeded rice.

Irrigated transplanted rice. *Preliminary screening.* There were no significant differences due to low weed pressure between most treatments and the untreated check (Table 1). However, Mon 7200 gave grain yields of about 1 t more than those of the standard herbicide butachlor. Early application of SC 0735 damaged the rice, severely reducing yield.

Advanced trials at IRRI and BPI. In the dry season (DS) at IRRI, bensulfuron, naproanilide -thiobencarb, pretilachlor + fenclorim, butachlor, and the hand-weeded check gave comparable yields, all significantly higher than that of the untreated check (Table 2). At the Maligaya station, all treatments gave similar yields. All herbicide treatments at the Bicol station and most at the Visayas station yielded significantly higher than the untreated check.

In the wet season (WS), yields with herbicide treatments at IRRI and at the Maligaya station were not significantly different from that of the untreated control (Table 3). At the Bicol station, all herbicide treatments except for quinclorac gave significantly higher yields than the untreated check. At the Visayas station, the untreated check was markedly outyielded only by bensulfuron.

Irrigated broadcast seeded rice. *Preliminary screening.* Most treatments adequately controlled *M. vaginalis* However, only Mon 7200 at 0.12 kg ai/ha applied at 6 d after seeding (DAS) and NC 311 at 0.021 kg ai/ha applied at 10 DAS, gave higher grain yields than did the untreated check (Table 4). Both herbicides were nontoxic to rice; WL 95481 and SC 0735 were apparently toxic.

Advanced trials at IRRI and BPI. In DS, bensulfuron, thiobencarb - 2,4-D, naproanilide - thiobencarb, and butachlor followed by hand weeding at IRRI and piperophos - 2,4-D, quinclorac, and thiobencarb - 2,4-D at the Maligaya station gave significantly higher yields than the untreated control (Table 5). At the Bicol station, yields were comparable.

Table 1. Effect of herbicides on weed control, crop tolerance, and yield of irrigated transplanted IR64.[a] IRRI, 1987 WS.

Treatment	Application		Weed weight (g/m²)			Visual toxicity rating[c]	Yield (t/ha)
	Rate (kg ai/ha)	Time (DT)[b]	Broadleaf weeds	Grasses	Sedges		
Mon 7200	0.09	8	14 a	10 abc	42 c	0	4.2 a
Mon 7200	0.09	3	2 a	12 abc	38 c	0	4.1 a
Dowco 356	0.3	3	0 a	4 abc	28 c	0	4.1 a
SC 0735	0.035	8	2 a	10 abc	8 ab	2	4.0 a
Hand-weeded check	Twice	15 + 30	2 a	0 a	2 a	0	4.0 a
NC 311	0.014	8	2 a	38 c	4 ab	0	3.9 a
Untreated check	–	–	8 a	14 abc	34 c	0	3.6 a
WL 95481	0.2	3	10 a	2 ab	32 c	0	3.4 a
WL 95481	0.2	8	4 a	10 abc	28 c	0	3.4 a
NC 311	0.014	3	18 a	8 abc	10 bc	0	3.3 a
Dowco 356	0.3	8	10 a	12 abc	54 c	0	3.2 a
Butachlor	1.0	8	4 a	8 abc	66 c	0	3.2 a
SC 0735	0.035	3	18 a	16 abc	184 c	4	1.3 b

[a]Av of 3 replications. [b]DT = days after transplanting. [c]Rated 2 wk after herbicide application on a scale of 0-10: 0 = no toxicity, 10 = complete kill.

Table 2. Effect of granular herbicides applied before weed emergence (3-5 DT) on IR64 yield at 4 Philippine sites, 1987 DS.

Treatment[a]	Rate (kg ai/ha)	Yield[b] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Hand-weeded check[c]	–	5.3 a	3.7 a	5.5 a	5.4 a
Bensulfuron[d]	0.04	4.5 ab	3.9 a	4.9 ab	5.4 a
Pretilachlor + fenclorim[e]	0.45	4.1 ab	4.1 a	4.2 bc	4.5 b
Butachlor	1.0	4.5 ab	3.9 a	4.0 bc	4.3 b
Piperophos – 2,4-D	0.3-0.2	3.3 bc	3.9 a	5.0 ab	4.5 b
Naproanilide – thiobencarb	1.0-0.7	4.1 ab	3.8 a	3.6 c	4.0 b
Pendimethalin	0.75	3.7 bc	4.0 a	3.2 c	4.3 b
Quinclorac	0.2	3.2 bc	4.0 a	4.3 abc	3.7 bc
2,4-D	0.8	3.9 bc	3.8 a	3.0 c	3.1 cd
Untreated check	–	2.6 c	3.7 a	0.6 d	2.7 d
CV (%)		21	12	21	14

[a]A plus (+) sign means herbicides were tank-mixed; a spaced dash (–) means the herbicides were applied as a proprietary mixture. [b]Av of 4 replications/site. [c]At 15 and 35 d after transplanting (DT). [d]Wettable powder. [e]Emulsifiable concentrate.

Table 3. Effect of granular herbicides applied before weed emergence (3-5 DT) on IR64 yield at 4 Philippine sites, 1987 WS.

Treatment	Rate (kg ai/ha)	Yield[a] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Hand-weeded check[b]	–	4.1 a	3.7 a	4.6 a	6.0 ab
Bensulfuron[c]	0.04	3.5 b	3.9 a	4.4 a	6.4 a
Piperophos – 2,4-D	0.3-0.2	3.6 b	4.0 a	4.3 a	5.4 abc
2,4-D	0.8	3.5 b	4.0 a	4.2 a	5.2 abc
Pretilachlor + fenclorim[d]	0.45	3.0 c	3.9 a	4.4 a	5.1 abc
Butachlor	1.0	3.6 b	3.4 a	4.3 a	5.0 abc
Pendimethalin	0.75	3.3 bc	3.7 a	4.1 a	4.8 bc
Naproanilide – thiobencarb	1.0-0.7	3.5 b	3.8 a	4.4 a	4.2 c
Quinclorac	0.2	3.3 bc	3.7 a	2.9 b	4.8 bc
Untreated check	–	3.2 bc	3.4 a	3.0 b	4.2 c
CV (%)		8	11	8	18

[a]Av of 4 replications/site. [b]At 15 and 35 d after transplanting (DT). [c]Wettable powder. [d]Emulsifiable concentrate.

Table 4. Effect of herbicides on weed control, crop tolerance, and yield of irrigated broadcast seeded IR64.[a] IRRI, 1987 WS.

Treatment	Application		Weed weight (g/m²)			Visual toxicity rating[c]	Yield (t/ha)
	Rate (kg ai/ha)	Time (DAS)[b]	Broadleaf weeds	Grasses	Sedges		
Mon 7200	0.12	6	0 a	24 a	20 a	2	2.9 a
NC 311	0.021	10	0 e	30 ab	0 a	0	2.8 a
SC 0735	0.070	10	6 ab	54 ab	1 a	2	2.4 ab
Mon 7200	0.012	10	4 ab	26 a	18 a	3	2.3 ab
WL 95481	0.1	6	18 ab	102 b	20 a	4	2.2 ab
NC 311	0.021	6	26 abc	48 ab	22 a	1	2.2 ab
SC 0735	0.070	6	34 bc	78 ab	16 a	4	2.0 ab
Butachlor	1.0	10	3 ab	44 ab	10 a	1	1.9 ab
Untreated check	–	–	72 c	84 ab	14 a	0	1.2 b

[a]Av of 3 replications. [b]DAS = days after seeding. [c]Rated 2 wk after herbicide application, on a scale of 0-10: 0 = no toxicity, 10 = complete kill.

In WS, yields with butachlor and naproanilide - thiobencarb at IRRI and pendimethalin, naproanilide - thiobencarb, and quinclorac at the Visayas station were not significantly different from that of the untreated check (Table 6). At the Bicol station, all herbicide treatments gave significantly higher yields than the untreated control. At Maligaya, all treatments gave similar and very low yields because of tungro infection.

Herbicide combination. In DS, all quinclorac and bensulfuron combinations, regardless of application time, controlled weeds adequately and gave yields higher than did the untreated check (Table 7). Quinclorac combined with 2,4-D produced lower yields, possibly because of initial 2,4-D toxicity. Dowco 356-Dowco 433 as a proprietary mixture gave low yields because, at all application times, sedges, predominantly *Scirpus maritimus*, were uncontrolled.

In WS, new herbicides were used. Grain yields were low because of lodging at the spikelet filling stage (Table 8). However, all herbicide combinations gave yields higher than did the untreated check and three other treatments. Single applications at 6 DAS of bensulfuron at 0.05 kg ai/ha and of NC 311 at 0.02 kg ai/ha gave yields higher than the untreated check and comparable to those of the combination treatments.

Table 5. Effect of early postemergence (6-8 DAS) application of granular herbicides on yield of irrigated broadcast seeded IR64 at 3 Philippine sites, 1987 DS.

Treatment	Rate (kg ai/ha)	Yield[a] (t/ha)		
		IRRI	Maligaya	Bicol
Butachlor fb hand weeding[b]	0.5	3.8 ab	3.6 bcd	4.1 a
Bensulfuron[c]	0.04	4.4 a	2.9 d	4.0 a
Piperophos – 2,4-D	0.3-0.2	2.2 cde	4.5 a	3.9 a
Quinclorac	0.2	2.3 cde	4.2 ab	4.0 a
Thiobencarb – 2,4-D	1.0-0.5	2.4 cd	4.3 ab	3.6 a
Naproanilide – thiobencarb	1.0-0.7	3.0 bc	3.9 abc	2.8 a
Pretilachlor + fenclorim[d]	0.45	2.1 cde	3.9 abc	3.7 a
Pendimethalin	0.75	1.4 de	3.8 abc	3.6 a
Butachlor	1.0	2.0 cde	3.3 cd	2.8 a
Untreated check	–	1.3 e	3.2 cd	2.0 a
CV (%)		26	12	29

[a]Av of 4 replications/site. [b]At 35 DAS. fb = followed by. [c]Wettable powder. [d]Emulsifiable concentrate.

Table 6. Effect of early postemergence (6-8 DAS) application of granular herbicides on yield of irrigated broadcast seeded IR64 at 4 Philippine sites, 1987 WS.

Treatment	Rate (kg ai/ha)	Yield[a] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Butachlor fb hand weeding[b]	0.5	4.6 a	1.9 a	4.5 a	4.3 a
Pretilachlor + fenclorim[c]	0.75	3.8 bc	1.7 a	4.7 a	4.0 a
Bensulfuron[d]	0.04	3.9 abc	1.3 a	4.4 a	4.4 a
Piperophos – 2,4-D	0.3-0.2	4.2 ab	1.6 a	3.9 bc	3.6 ab
Thiobencarb – 2,4-D	1.0-0.5	3.9 abc	1.4 a	3.8 c	3.6 ab
Pendimethalin	0.75	3.9 abc	1.1 a	4.3 ab	2.9 bc
Butachlor	1.0	3.4 cd	0.9 a	3.8 c	3.7 ab
Naproanilide – thiobencarb	1.0-0.7	3.3 cd	1.5 a	4.5 a	2.5 c
Quinclorac	0.2	3.8 bc	1.4 a	3.7 c	2.5 c
Untreated check	–	2.8 d	0.7 a	2.5 d	1.9 c
CV (%)		12	40	8	20

[a]Av of 4 replications/site. [b]At 35 DAS. [c]Emulsifiable concentrate. [d]Wettable powder.

Table 7. Effect of herbicide combination and application time on weed control and yield of irrigated broadcast seeded IR64.[a] IRRI, 1987 DS.

Treatment	Application		Weed weight (g/m²)		Visual toxicity rating[c]	Yield (t/ha)
	Rate (kg ai/ha)	Time (DAS)[b]	Grasses	Sedges		
Quinclorac + bensulfuron	0.1 + 0.04	6	4 abc	36 ab	1	5.6 a
Quinclorac + bensulfuron	0.1 + 0.04	8	0 a	4 a	0	5.4 ab
Quinclorac + bensulfuron	0.1 + 0.04	10	0 a	4 a	0	5.4 ab
Quinclorac + bensulfuron	0.1 + 0.02	10	2 ab	4 a	0	5.4 ab
Quinclorac + 2,4-D	0.1 + 0.4	6	0 a	40 ab	4	3.6 c
Quinclorac + 2,4-D	0.1 + 0.4	8	8 bc	32 ab	3	3.2 c
Quinclorac + 2,4-D	0.1 + 0.4	10	0 a	28 ab	3	4.2 bc
Dowco 356-Dowco 433	0.45	6	10 c	84 c	2	1.5 d
Dowco 356-Dowco 433	0.45	8	4 abc	88 c	2	1.1 d
Dowco 356-Dowco 433	0.45	10	2 ab	84 c	1	1.5 d
Butachlor	0.75	3 DBS	2 ab	68 bc	1	3.2 c
Untreated check	–	–	26 d	46 ab	0	2.9 c

[a]Av of 3 replications. [b]DAS = days after seeding, DBS = days before seeding. [c]Rated 2 wk after herbicide application on a scale of 0-10: 0 = no toxicity, 10 = complete kill.

Table 8. Effect of herbicide combination on weed control and yield of irrigated broadcast seeded IR64.[a] IRRI, 1987 WS.

Treatment	Application		Weed weight (g/m²)			Yield (t/ha)
	Rate (kg ai/ha)	Time (DAS)	Broadleaf weeds	Grasses	Sedges	
WL 95481	0.1	6	21 abc	8 a	218 c	0.3 c
Bensulfuron	0.05	6	0 a	23 ab	26 ab	4.0 a
NC 311	0.02	6	0 a	11 ab	11 a	3.5 a
Mon 7200	0.12	6	37 c	9 ab	139 bc	1.4 bc
Butachlor	1.0	6	39 c	27 b	149 c	1.2 bc
WL 95481 + bensulfuron	0.075 + 0.02	6	3 ab	15 ab	71 bc	2.8 a
WL 95481 + bensulfuron	0.075 + 0.02	8	0 a	9 ab	11 a	3.9 a
WL 95481 + NC 311	0.075 + 0.02	6	0 a	20 ab	54 bc	3.0 a
WL 95481 + NC 311	0.075 + 0.02	8	2 a	11 ab	16 a	3.8 a
Mon 7200 + bensulfuron	0.09 + 0.02	6	0 a	32 b	19 ab	3.3 a
Mon 7200 + bensulfuron	0.09 + 0.02	8	0 a	12 ab	13 a	3.2 a
Untreated check	–	–	24 bc	12 ab	96 bc	1.8 b

[a]Av of 4 replications.

Rainfed transplanted rice. Most treatments satisfactorily controlled *Echinochloa* spp. but not sedges (Table 9). At both application times, only NC 311 gave yields higher than that of the untreated check. At 8 d after transplanting (DT), it gave yields comparable to that of the hand-weeded check. SC 0735 was the only herbicide toxic to TPR.

Rainfed broadcast seeded rice. Grain yields were low because of water stress during early crop growth (Table 10). Nevertheless, NC 311 gave excellent control of *M. vaginalis*, substantially reduced the grass population, and gave higher yields than the untreated check at both application times.

Upland rice. *Advanced trials at IRRI and in a farmer's field.* At IRRI, no herbicide controlled weeds as well as did two hand weedings (Table 11). Among the herbicides, oxadiazon gave the best control and butachlor performed poorest. Thiobencarb, dinitramine, and oxyfluorfen performed as well as oxadiazon and better than the unweeded check. All other herbicides gave control similar to the unweeded check. Only propanil injured rice.

Table 9. Effect of herbicides on weed control, crop tolerance, and yield of rainfed transplanted IR64.[a] IRRI, 1987 WS.

Treatment	Application		Weed weight (g/m²)			Visual toxicity rating[c]	Yield (t/ha)
	Rate (kg ai/ha)	Time (DT)[b]	Broadleaf weeds	Grasses	Sedges		
Hand-weeded check	Twice	15 + 30	1 a	14 b	48 a	0	3.2 a
NC 311	0.021	8	0 a	16 bc	56 ab	0	3.0 ab
NC 311	0.021	3	0 a	28 bc	80 bc	0	2.1 bc
Mon 7200	0.015	8	0 a	42 bcd	88 bc	0	2.0 cd
Mon 7200	0.015	3	0 a	20 bc	158 bc	0	1.6 cd
SC 0735	0.035	8	1 a	52 bcd	104 bc	2	1.4 cd
WL 95481	0.2	3	1 a	20 bc	166 bc	0	1.3 cd
WL 95481	0.2	8	0 a	8 a	122 bc	0	1.1 d
SC 0735	0.035	3	1 a	78 cd	66 bc	2	1.1 d
Untreated check	–	–	1 a	116 d	92 bc	0	1.1 d
Butachlor	1.0	3	0 a	4 a	178 c	0	1.0 d

[a]Av of 3 replications. [b]DT = days after transplanting. [c]Rated 2 wk after herbicide application on a scale of 0-10: 0 = no toxicity, 10 = complete kill.

Table 10. Effect of herbicides on weed control, crop tolerance, and yield of rainfed broadcast seeded IR64.[a] IRRI, 1987 WS.

Treatment	Application		Weed weight (g/m²)			Visual toxicity rating[b]	Yield (t/ha)
	Rate (kg ai/ha)	Time (DT)	Broadleaf weeds	Grasses	Sedges		
NC 311	0.014	10	1 ab	36 a	34 a	0	1.9 a
Butachlor	1.0	10	6 abc	70 c	154 bc	1	1.4 b
NC 311	0.014	6	1 ab	98 c	82 ab	0	1.3 b
SC 0735	0.035	10	18 bc	100 c	50 a	3	1.1 bc
Mon 7200	0.15	6	3 abc	34 a	216 bc	2	0.9 bcd
Untreated check	–	–	2 ab	196 c	130 bc	0	0.6 cde
WL 95481	0.1	10	12 bc	28 a	228 c	3	0.6 cde
WL 95481	0.1	6	6 abc	58 bc	212 bc	3	0.4 de
Mon 7200	0.15	10	0 a	56 b	259 c	1	0.4 de
SC 0735	0.035	6	30 c	218 c	73 ab	4	0.2 e

[a]Av of 3 replications. [b]Rated 2 wk after herbicide application on a scale of 0-10: 0 = no toxicity, 10 = complete kill.

Table 11. Effect of herbicides on weed weight and crop injury in upland rice IR36.[a] IRRI, 1987 WS.

Treatment	Application[b]		Crop injury rating[c]	Weed weight[d] (g/m²)
	Rate (kg ai/ha)	Time		
Hand-weeded twice	–	15 and 35 DE	0	8 a
Oxadiazon	1.0	3 DAS	0	333 b
Oxyfluorfen	0.36	3 DAS	0	356 b
Dinitramine	1.5	3 DAS	0	388 bc
Thiobencarb	3.0	3 DAS	0	398 bc
Pendimethalin	2.0	3 DAS	0	515 bcd
Propanil	2.0	10 DE	3	532 bcd
Butralin	2.0	3 DAS	0	619 bcd
Butachlor	2.0	3 DAS	0	673 cd
Unweeded check	–	–	0	723 d

[a]Av of 4 replications. [b]DAS = days after seeding, DE = days after emergence of rice and weeds. [c]0-10 rating scale, where 0 = no injury, 10 = complete kill. Recorded about 7 d after herbicide application. [d]Weeds were sampled at 58 DE. Major weeds were *Rottboellia cochinchinensis, Amaranthus spinosus, Echinochloa colona, Eleusine indica,* and *Ipomoea triloba.*

Hand-weeded plots yielded 1.8 t/ha. All herbicide-treated plots gave zero yields, attributed to profuse growth of uncontrolled weeds.

In Batangas, all herbicides significantly reduced grasses and, except for pendimethalin, broadleaf weeds (Table 12). Butachlor, oxadiazon, and oxyfluorfen gave outstanding control of sedges. The herbicides, except for dinitramine, pendimethalin, and propanil, gave significantly higher yields than the untreated control. Propanil-treated plots gave zero yield because of heavy weed resurgence.

Herbicide combination. A trial at IRRI examined the performance of herbicides and their combinations in controlling weeds in upland rice. Pendimethalin and fluazifop-butyl were applied alone or combined with bentazon, 2,4-D, and one hand weeding. Hand-weeded and untreated checks were included.

Pendimethalin, singly or in combination, effectively controlled the grasses *R. cochinchinensis*, *E. colona*, and *E. indica* and the broadleaf weeds *T. portulacastrum* and *A. spinosus*. It gave yields comparable to those of the hand-weeded check (Table 13). Fluazifop-butyl controlled the grasses but not the broadleaf weeds. A follow-up application of either bentazon or 2,4-D on fluazifop-butyl-treated plots decreased the broadleaf weed stand but increased the grass weed stand. Consequently, all fluazifop-butyl treatments, except one hand

Table 12. Effect of herbicides applied before weed emergence (1 DAS) on weed control and yield of upland IR36 in a farmer's field.[a] Batangas, Philippines, 1987 WS.

Treatment	Rate (kg ai/ha)	Weed weight[b] (g/m²)			Yield (t/ha)
		Broadleaf weeds[c]	Grasses[d]	Sedges[e]	
Oxyfluorfen	0.37	60 ab	44 a	2 a	2.7 a
Thiobencarb	3.0	60 ab	92 a	11 a	2.6 a
Hand-weeded check[f]	–	22 a	10 a	20 a	2.5 a
Butralin	2.0	272 cd	48 a	15 a	2.4 a
Butachlor	2.0	49 ab	174 ab	0 a	2.3 a
Oxadiazon	1.0	77 ab	95 a	0 a	2.2 a
Dinitramine	1.5	273 cd	66 a	38 a	1.3 b
Pendimethalin	2.0	364 de	19 a	37 a	1.2 b
Propanil[g]	2.0	156 bc	260 b	37 a	0 c
Untreated check	–	468 e	533 c	55 a	0 c

[a]Av of 3 replications. [b]Sampled at 55 DE. [c]*Commelina benghalensis, Ageratum conyzoides,* and *Commelina diffusa.* [d]*E. colona, Eleusine indica, R. cochinchinensis,* and *Dactyloctenium aegyptium.* [e]*Cyperus iria* and *C. compressus.* [f]At 15 and 41 DE. [g]Applied at 10 DE.

Table 13. Effect of herbicide combinations on weed control and grain yield of UPLRi-5.[a] IRRI, 1987 WS.

Treatment	Application[b]		Weed weight[c] (g/m²)		Grain yield (t/ha)
	Rate (kg ai/ha)	Time	Broadleaf weeds[d]	Grasses[e]	
Pendimethalin	2.0	PE	69 ab	55 a	1.7 ab
Pendimethalin fb bentazon	2.0 fb 2.0	PE fb 20 DE	14 a	41 a	1.4 b
Pendimethalin fb 2,4-D	2.0 fb 0.8	PE fb 20 DE	6 a	41 a	1.8 ab
Pendimethalin fb hand weeding	2.0	PE fb 30 DE	1 a	2 a	2.3 a
Fluazifop-butyl	0.08	12 DE	602 d	144 ab	0 c
Fluazifop-butyl fb bentazon	0.08 fb 2.0	12 DE fb 20 DE	183 bc	337 cd	0.1 c
Fluazifop-butyl fb 2,4-D	0.08 fb 0.8	12 DE fb 20 DE	4 a	377 d	0.3 c
Fluazifop-butyl fb hand weeding	0.08	12 DE fb 30 DE	4 a	26 a	1.8 ab
Hand-weeded check	–	15 and 30 DE	1 a	50 a	2.0 a
Untreated check	–	–	325 c	558 d	0 c

[a]Av of 4 replications. [b]PE = preemergence, DE = days after emergence, fb = followed by. [c]Sampled at 56 DE. [d]*A. spinosus* and *Trianthema portulacastrum.* [e]*R. cochinchinensis, Echinochloa colona,* and *Eleusine indica.*

weeded, gave yields as low as did the untreated control.

Application rate and timing of fluazifop-butyl. In collaboration with the Agronomy Department of the University of the Philippines at Los Baños, we determined rice and weed response to different herbicide doses. Fluazifop-butyl was applied at 0.01, 0.05, 0.10, and 0.25 kg/ha to IR58 and at 0.01, 0.05, 0.10, 0.25, and 0.50 kg/ha to 3 grass weeds—*E. colona*, *R. cochinchinensis*, and *E. indica*—at pretillering and early tillering. Another experiment determined the effect of application rate and timing of fluazifop-butyl at 0.01 and 0.05 kg/ha on rice and at the same 5 rates on weeds at 4 growth stages.

At 7 d after fluazifop-butyl application, rice plants treated at pretillering at the 3 highest herbicide rates had 60% or more injury; those treated at the 2 highest rates did not recover (Table 14). When fluazifop-butyl was sprayed at early tillering, rice had 46% or more injury at the 3 highest rates. Injury increased to more than 60% at 2 wk after treatment.

Shoot fresh weights showed that plants treated with fluazifop-butyl at 0.01 kg/ha at pretillering and those at 0.01 and 0.05 kg/ha at early tillering recovered fully (Table 14). Except in plants treated at pretillering, root fresh weights were not reduced with later applications. Inhibited apical shoot growth may have stimulated tillering with 0.05 and 0.10 kg/ha at both application times.

Time of application produced injury ratings and shoot and root fresh weights that showed trends similar to those of the dose-response study (Table 14). Application at 21 to 28 d after emergence (DE) showed negligible differences in shoot and root fresh weights. Probably because of damaged apical meristems, increased tillering was observed at 0.05 kg/ha applied at or later than 14 DE.

Application at 0.25 and 0.50 kg/ha completely

Table 14. Injury, fresh weight, and tiller production of IR58 seedlings treated with fluazifop-butyl.[a] IRRI, 1987 DS.

Growth stage	Rate (kg ai/ha)	Injury rating[b]		Fresh weight[c] (g/plant)		Tillers (no./20 plants)
		7 DAT	14 DAT	Shoot	Root	
		Dose response				
Pretillering (7 DE)	0	0	0	6.5	3.5	23
	0.01	39	10	8.1	4.6	23
	0.05	60	35	2.3	1.5	41
	0.10	62	60	2.0	1.6	37
	0.25	84	90	0.4	0.5	25
Early tillering (14 DE)	0	0	0	7.6	3.5	21
	0.01	25	13	5.2	2.3	27
	0.05	46	33	5.4	3.6	41
	0.10	21	65	2.0	2.7	27
	0.25	77	73	1.1	1.1	23
LSD (0.05)				2.6	2.6	5
		Time of application				
Pretillering (7 DE)	0	0	0	26	30	36
	0.01	45	3	23	20	39
	0.05	95	55	16	11	36
Early tillering (14 DE)	0	0	0	35	21	24
	0.01	38	5	32	20	25
	0.05	76	23	24	16	37
Tillering (21 DE)	0	0	0	41	21	32
	0.01	19	0	45	21	34
	0.05	39	15	38	19	50
Late tillering (28 DE)	0	0	0	40	20	28
	0.01	10	0	38	19	22
	0.05	23	3	35	19	37
LSD (0.05)				6	4	8

[a]Av of 3 replications. [b]Rating scale: 0 = as untreated, 100 = dead plant. DAT = days after treatment. [c]Taken at 30 DAT.

controlled *R. cochinchinensis* regardless of application time (Table 15). Lower application rates did not adequately control *R. cochinchinensis* even at the earlier growth stages.

At pretillering, all rates except the lowest one completely controlled *E. colona*. Only the higher rates applied at 14-21 DE provided adequate control. At 28 DE, *E. colona* was tolerant of all rates except one. *Eleusine indica* was more susceptible to fluazifop-butyl than were the two other weeds. At 0.10 kg/ha or higher, all plants were completely controlled at all growth stages. Even herbicide applied at 0.01 kg/ha at pretillering and early tillering gave excellent control (90-100%). Application at later than 14 DE required higher rates (0.05-0.10 kg/ha).

E. indica was consistently more susceptible to fluazifop-butyl at all application times than were *E. colona* and *R. cochinchinensis*. *E. colona* was more susceptible than *R. cochinchinensis* to early applications of fluazifop-butyl but was more tolerant of later applications.

Dry seeded rice. In 1986 WS in Guimba, Philippines, all herbicide treatments except thiobencarb, butachlor, and the sequential butachlor application reduced weed growth at 30 DE (Table 16). An additional hand weeding was done at 40 DE because of the high weed infestation and the short-lived herbicide effect. At 60 DE, weed weights in all treatments were significantly different from those in the unweeded plots.

Grain yields were significantly higher in the herbicide-treated plots than in the untreated check. The yield from the plot with propanil 2 kg ai/ha at 10 and 29 DE was significantly higher than that from the hand-weeded check. Other treatment yields were comparable to that of the hand-weeded check.

Table 15. Injury and shoot fresh weights of 3 grass weeds at 30 d after treatment with 5 rates of fluazifop-butyl at 4 growth stages.[a] IRRI, 1987 WS.

Time	Rate (kg ai/ha)	*Rottboellia cochinchinensis* Injury rating[b]	*Rottboellia cochinchinensis* Shoot fresh weight (g/plant)	*Echinochloa colona* Injury rating[b]	*Echinochloa colona* Shoot fresh weight (g/plant)	*Eleusine indica* Injury rating[b]	*Eleusine indica* Shoot fresh weight (g/plant)
Pretillering (7 DE)	0	0	5.23	0	4.25	0	5.92
	0.01	0	5.37	0	5.35	93	2.94
	0.05	55	0.34	100	–	100	–
	0.10	63	0.13	100	–	100	–
	0.25	93	0.06	100	–	100	–
	0.50	100	–	100	–	100	–
Early tillering (14 DE)	0	0	3.80	0	5.80	0	2.73
	0.01	7	2.95	0	0.99	93	0.73
	0.05	17	1.27	77	0.54	92	0.72
	0.10	47	0.17	100	–	100	–
	0.25	88	0.14	93	0.83	100	–
	0.50	97	0.14	100	–	100	–
Tillering (21 DE)	0	0	10.08	0	5.68	0	8.82
	0.01	13	4.39	0	7.95	0	4.77
	0.05	45	1.75	0	4.69	100	–
	0.10	62	0.74	63	2.06	100	–
	0.25	87	0.79	100	–	100	–
	0.50	100	–	100	–	100	–
Late tillering (28 DE)	0	0	9.42	0	13.68	0	6.57
	0.01	28	4.07	0	10.02	0	6.83
	0.05	43	2.23	0	10.00	28	5.03
	0.10	88	1.32	10	12.20	100	–
	0.25	90	0.66	15	7.96	100	–
	0.50	98	0.94	68	5.44	100	–
LSD (0.05)			2.29		2.43		1.55

[a]Av of 3 replications. [b]Rating scale: 0 = as untreated, 100 = dead plant. Taken at 30 d after treatment.

Table 16. Effect of herbicides on weed weight and yield of dry seeded rice.[a] Guimba, Nueva Ecija, Philippines, 1986 WS.

Treatment	Application		Weed weight (g/m²)		Grain yield (t/ha)
	Rate (kg ai/ha)	Time	30 DE	60 DE	
Propanil fb propanil	2 fb 2	10 fb 29 DE	24.7 ab	55.6 a	4.8 a
Propanil + thiobencarb	2 + 1	10 DE	11.3 a	45.7 a	4.7 ab
Pendimethalin fb propanil	2 fb 3	PE fb 17 DE	6.8 a	47.1 a	4.6 abc
Thiobencarb fb hand weeding	3	PE fb 40 DE	174.0 cd	67.6 a	4.5 abcd
Butachlor fb butachlor + propanil	1 fb 1 + 2	PE fb 10 DE	36.9 ab	70.4 a	4.5 abcd
Propanil	3	10 DE	24.4 ab	76.6 a	4.2 abcd
Oxadiazon + thiobencarb fb hand weeding	0.25 + 1.5	PE fb 40 DE	76.0 ab	36.0 a	4.2 abcd
Butachlor fb butachlor fb hand weeding	1 fb 1	PE fb 6 DE	225.4 d	31.2 a	4.2 abcd
Butachlor fb hand weeding	2	PE fb 40 DE	181.1 cd	27.7 a	4.2 abcd
Hand weeding three-times	–	15, 30, 40 DE	46.9 ab	70.5 a	4.1 bcd
Pendimethalin fb hand weeding	2	PE fb 40 DE	106.9 bc	78.3 a	4.0 cd
Butachlor fb propanil	1.5 fb 2.0	PE fb 10 DE	31.9 ab	96.4 a	3.9 d
No weeding	–		248.7 d	353.0 b	1.7 e

[a]DE = days after emergence, PE = preemergence.

Propanil applied sequentially again performed well in 1987 when weed growth was greater than in 1986 (Table 17). Other treatments that controlled weeds and yielded as well as the hand-weeded check were butachlor followed by (fb) hand weeding, pendimethalin fb propanil, and quinclorac + propanil 2 kg ai/ha. Weed control with other treatments was not satisfactory. SC 0735 was toxic to rice.

SEEDLING NURSERIES

In an experiment at IRRI and in Guimba, Nueva Ecija, doubling the seed rate in the seedling

Table 17. Effect of herbicide treatments on weed weight and yield of dry seeded rice.[a] Guimba, Nueva Ecija, Philippines, 1987 WS.

Treatment	Application		Weed weight (g/m²) at 40 DE	Grain yield (t/ha)
	Rate (kg ai/ha)	Time		
Weeded check[a]	–	–	136.5 a	4.0 a
Butachlor fb hand weeding	2	PE fb 23 DE	119.6 a	3.7 a
Pendimethalin fb propanil	1.5 fb 2.0	PE fb 23 DE	194.1 ab	3.6 a
Propanil fb propanil	2.0 fb 2.0	8 fb 23 DE	218.6 ab	3.2 ab
Quinclorac + propanil	0.5 + 2.0	8 DE	231.5 abc	2.4 abc
Butachlor fb butachlor + propanil	1 fb 1 + 2	PE fb 23 DE	255.7 a-d	1.9 bcd
Quinclorac + thiobencarb	0.5 + 1.5	8 DE	302.2 a-d	1.8 b-f
Quinclorac + propanil	0.5 + 1.5	8 DE	297.4 a-d	1.5 c-f
Quinclorac + pendimethalin	0.5 + 1.5	8 DE	337.1 bcd	1.4 c-f
Quinclorac	0.5	8 DE	282.7 a-d	1.3 c-f
Quinclorac + butachlor	0.5 + 1.5	8 DE	278.3 a-d	1.3 c-f
Propanil + thiobencarb	2.0 + 1.0	8 DE	287.9 a-d	1.2 c-f
Propanil	3	8 DE	351.2 bcd	0.9 c-f
Oxadiazon + thiobencarb	0.25 + 1.5	PE	361.9 bcd	0.4 d-f
SC 0735	0.035	8 DE	343.9 bcd	0.4 d-f
Quinclorac	0.375	8 DE	367.9 bcd	0.4 d-f
SC 0735	0.07	8 DE	416.0 cd	0.2 d-f
No weeding	–	–	425.6 cd	0.1 f
SC 0735	0.140	8 DE	438.6 d	0.02 f

[a]Hoe weeding at 8 DE fb hand weeding at 20 and 30 DE.

Table 18. Effect of weed control treatments on weed seedling numbers in rice seedling nursery. IRRI and Guimba, Nueva Ecija, Philippines, 1987 DS.

Treatment	Application		Weeds (no.)/bundle of rice seedlings from 0.25-m² nursery			
	Rate (kg ai/ha)	Time[a]	IRRI		Guimba	
			Field 1	Field 2	Field 1 (turod)	Field 2 (lungog)
Weedy check	–	–	64 c	78 e	77 e	95 f
Quick separation (removing tallest seedlings from rice seedling bundles)	–	–	30 b	52 d	53 d	70 e
Slow separation (examining every plant carefully)	–	–	3 a	7 ab	5 a	4 a
Double seed rate	–	–	23 b	35 cd	73 e	50 d
Propanil	2.5	10 DAS	4 a	12 ab	25 c	24 bc
Thiobencarb	0.75	6 DAS	3 a	3 a	16 bc	21 abc
Butachlor	0.45	3 DBS	5 a	24 abc	11 ab	22 abc
Pretilachlor + fenclorim	0.3	3 DAS	11 a	28 bc	11 ab	21 abc
Quinclorac	0.3	3 DAS	3 a	9 ab	6 a	16 ab
Bensulfuron	0.03	3 DAS	4 a	22 abc	21 c	36 cd
Quinclorac + bensulfuron	0.2 + 0.02	3 DAS	2 a	7 ab	5 a	15 ab

[a]DAS = days after seeding, DBS = days before seeding.

nursery—a practice some farmers use—reduced weed density by 60% at IRRI and by 26% in Guimba (Table 18). Removing the tallest seedlings from the rice seedling bundles before transplanting (quick separation) removed only 36% of the weed seedlings at both sites and required the equivalent of 25 h/ha. Slow separation, examining every plant carefully, removed 94% of the weed seedlings and took 719 h/ha. This is impractical because it is laborious, time-consuming, and expensive.

At IRRI, good weed control was obtained with thiobencarb, quinclorac, quinclorac + bensulfuron, propanil, and butachlor. In Guimba, quinclorac + bensulfuron, quinclorac, butachlor, and pretilachlor + fenclorim were most effective.

The cost of treating a 440-m² seedling nursery—the area required to plant 1 ha—was US$0.70 or less. Using the double seed rate or removing the large seedlings from the seedling bundles gave less than 50% control of the weeds, yet cost 5-10 times as much as the most expensive herbicide treatment. Herbicides appear practical for controlling weeds in rice seedling nurseries.

Table 19. Effect of *Echinochloa glabrescens* infestation on weed weight at 90 DT and on rice grain yield. IRRI, 1986 WS.

Echinochloa glabrescens infestation (%)	Weed weight (g/m²)	Grain yield (t/ha)	Yield loss (%)
0	0 a	5.4 a	–
5	60 b	5.0 ab	7
10	134 c	4.7 b	13
15	177 d	4.1 c	24
20	216 e	3.3 d	39
25	264 f	3.0 d	44
30	318 g	2.4 e	56
40	378 h	1.6 f	70
50	435 i	0.7 g	87

COMPETITIVE EFFECT AND CONTROL OF TRANSPLANTED *ECHINOCHLOA GLABRESCENS* IN TRANSPLANTED RICE

Seedlings of *Echinochloa* spp. are often transplanted into the field with rice seedlings because they are morphologically similar. When *E. glabrescens* was transplanted with rice, yield losses ranged from 7% when 5% of the rice hills were infested with the weed, to 87% when 50% were infested (Table 19). At 90 DT, there was a highly significant negative correlation between rice grain yield and weed weight ($Y = 5.769 - 1.098X$, $r = -0.97^{**}$).

All herbicides tested reduced transplanted *E. glabrescens* dry weight significantly compared with

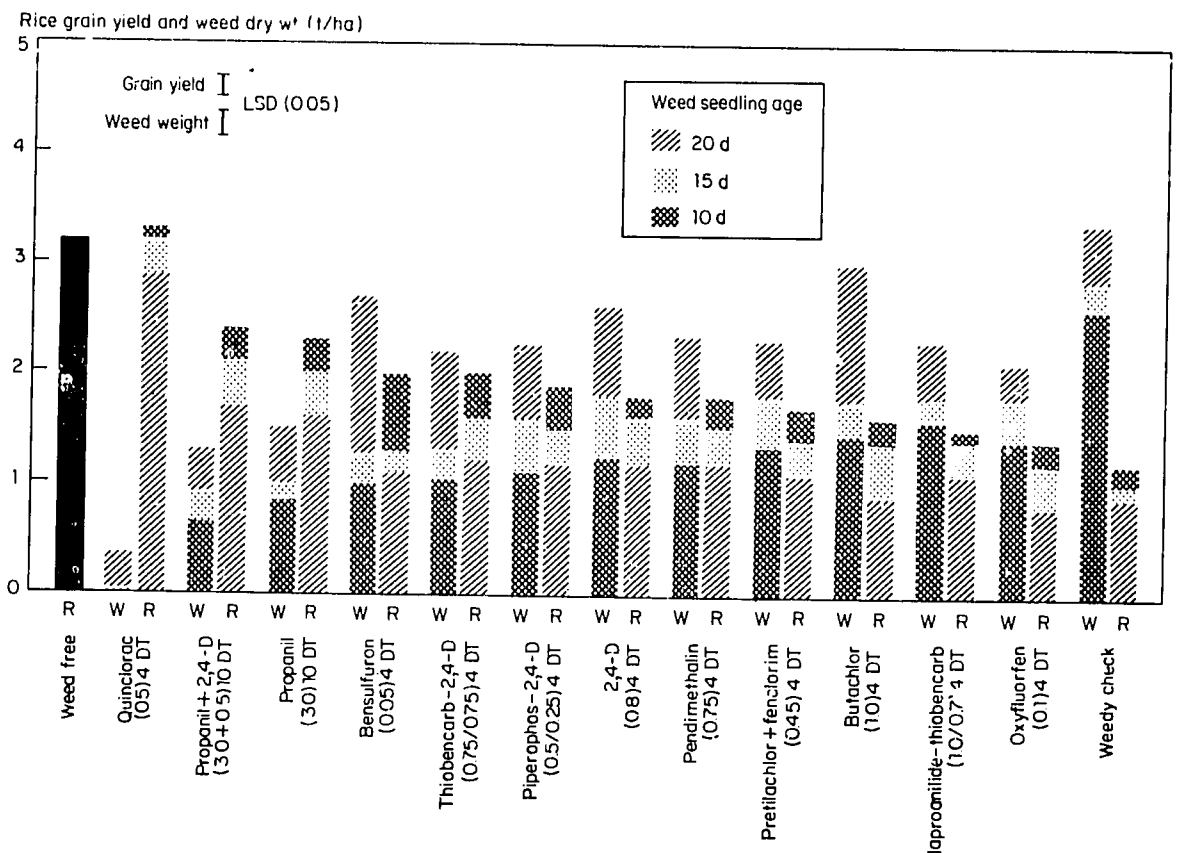
the weedy check (Fig. 1). Quinclorac was the most effective herbicide, killing all 10-d-old seedlings of *E. glabrescens* and reducing the dry weight of 15-d-old seedlings by 99% and that of 20-d-old seedlings by 90%. Yields with quinclorac treatment were as good as those from the weed-free check, but yields from all other treatments were significantly lower. There was a highly significant negative correlation between grain yield and weed weight ($Y = 2.801 - 0.717X$, $r = -0.88^{**}$).

CULTURAL CONTROL METHODS

Effect of tillage, cultivar, and planting method. Research on the long-term effects of tillage level (conventional, minimum, and zero), rice cultivar (IR42, IR64, and IR29723-143-3-2-1), and planting method (transplanting and direct seeding) on weed shift continued in 1987 DS (27th crop) and WS (28th crop). Conventional tillage was one plowing and two harrowings, minimum tillage was one plowing and one harrowing, and zero tillage was cutting and removing weed debris.

In the 27th crop, tillage level affected only the *Scirpus maritimus* stand (Fig. 2). Minimum tillage gave significantly less *S. maritimus* biomass than the two other tillage treatments and higher grain yield than the zero tillage treatment. IR29723-143-3-2-1, which best suppressed growth of all weed types, yielded significantly higher than did IR42 and IR64. IR42 controlled *Paspalum distichum* and annual weeds better and gave yields higher than did IR64. Compared with transplanting, direct seeding reduced *P. distichum* and annual weeds and gave higher grain yield.

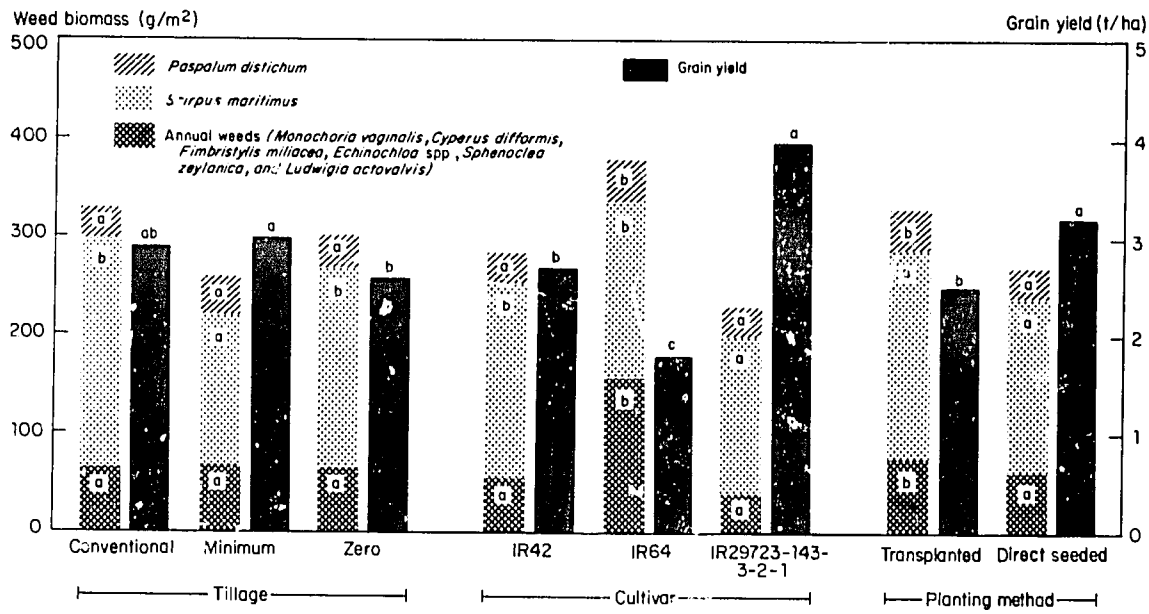
In the 28th crop, tillage level did not change weed stands (Fig. 3). However, conventional and minimum tillage gave markedly higher yields than did zero tillage. IR64 suppressed *S. maritimus* better but yielded lower than did IR42 and



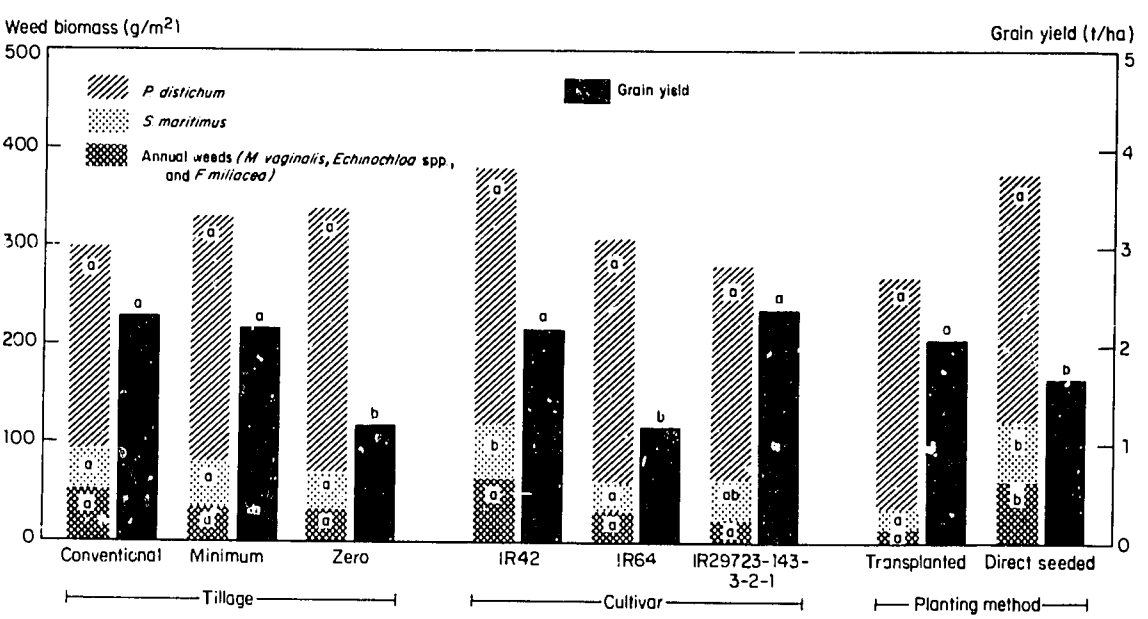
1. Effect of age of transplanted *Echinochloa glabrescens* and weed control treatments on weed dry weight at 60 d after transplanting (DT) and on rice grain yield, IRRI, 1986 WS. R = rice, W = weed, + = tank-mixed herbicides, - = proprietary mixture. Figures in parentheses indicate application rate in kg ai/ha.

IR29723-143-3-2-1. Direct seeded rice yielded lower than TPR because poor stand establishment led to heavy *P. distichum* and annual weed infestation.

Effect of flooding time. The effect of flooding time (0, 2, 4, 6, and 8 DAS) on weed control and yield of broadcast seeded IR64 was studied in DS.



2. Weed biomass and grain yield in the 27th crop as affected by tillage, cultivar, and planting method, IRRI, 1987 DS. Within a parameter, e.g., tillage, and within a weed type or within grain yield, items with a common letter are not significantly different at the 5% level by DMRT.



3. Weed biomass and grain yield in the 28th crop as affected by tillage, cultivar, and planting method, IRRI, 1987 WS. Within a parameter, e.g., tillage, and within a weed type or within grain yield, items with a common letter are not significantly different at the 5% level by DMRT.

Flooding at seeding time (0 DAS) reduced both weeds and the crop (Table 20). The best time to irrigate for effective weed control, ideal crop establishment, and high grain yield was 4 DAS.

Effect of mulching. Experiments at IRRI and in Batangas evaluated the effect of mulching and hand weeding time (15, 20, and 25 DE) on weed control and upland rice yield using cultivar UPLRi-5. Weeds removed were used as mulch.

At both sites, all treatments significantly reduced weeds. Grain yield in treated plots was higher than that in the unweeded check, but lower than that in the hand-weeded check (two weedings) (Table 21). Overall, mulching did not improve weed control. At IRRI, delaying weeding from 15 to 25 DE significantly decreased weed weight in mulched plots and increased grain yield. No effect of weeding time was observed in Batangas. The differences in weed control and grain yield between sites are attributed to differing competitiveness of dominant weeds. *A. spinosus* and *R. cochinchinensis* at IRRI appeared more competitive and persistent than *C. benghalensis* and *E. colona* in Batangas.

Table 20. Effect of flooding time on weed control, crop stand, and yield of broadcast seeded IR64.[a] IRRI, 1987 DS.

Flooding time (d)	Weed count[b] (no./m²) at 30 DAS	Rice count[c] (no./m²)	Panicle count (no./m²)	Grain yield (t/ha)
0	221 a	50 b	156 c	1.2 b
2	323 ab	100 b	230 bc	3.0 ab
4	336 ab	153 a	405 a	4.3 a
6	412 b	181 a	363 ab	3.8 a
8	375 ab	165 a	287 abc	4.1 a

[a]Av of 4 replications. [b]Weeds were *Scirpus maritimus*, *Echinochloa* spp., *Cyperus difformis*, and *Monochoria vaginalis*. [c]At 15 DAS.

APPLICATION TECHNIQUES

Effect of sprayer type on herbicide performance. A greenhouse experiment evaluated the effect of sprayer type — the controlled drop applicators Micronherbi and Birky and the conventional knapsack sprayer — on fluazifop-butyl and propanil control of *R. cochinchinensis*. Three rates for each herbicide were used.

Sprayer type did not affect the shoot fresh weight and shoot dry weight of the weed.

Averaged over 3 sprayers, fluazifop-butyl at the highest rate of 0.10 kg/ha gave the best control (Table 22). Propanil at 2.0 kg/ha and fluazifop-butyl at 0.05 kg/ha also produced low shoot fresh weights. In shoot dry weights, fluazifop-butyl at any rate did as well as propanil at the highest rate.

Postemergence herbicide application with controlled drop applicators. In a field infested with the sedge *S. maritimus*, the herbicides 2,4-D, bensulfuron, propanil, and fluazifop-butyl were applied at their recommended rates using Birky, Micronherbi, and conventional knapsack sprayers.

Table 21. Effect of mulching and time of hand weeding on weed control and grain yield of upland rice UPLRi-5 at IRRI and in a farmer's field in Batangas Province, Philippines, 1987 WS.

Treatment	Weeding time (DE)	IRRI[a] Weed weight (g/m²) at 75 DE	IRRI[a] Yield (t/ha)	Batangas[b] Weed weight (g/m²) at 75 DE	Batangas[b] Yield (t/ha)
With mulch	15	419 d	0.6 c	198 b	2.5 b
	20	236 abc	1.0 bc	219 b	2.3 b
	25	207 ab	1.3 b	120 ab	2.8 b
Without mulch	15	298 bc	0.9 bc	195 b	2.8 b
	20	340 cd	1.0 bc	149 ab	3.1 b
	25	293 bc	0.7 c	108 ab	2.1 b
Hand-weeded check	15 fb 30	151 a	2.2 a	47 a	4.2 a
Unweeded check	–	1054 e	0 d	1275 c	0 c

[a]Av of 4 replications. Major weeds were *A. spinosus*, *R. cochinchinensis*, *T. portulacastrum*, and *E. colona*. [b]Av of 3 replications. Major weeds were *Commelina benghalensis*, *E. colona*, *E. indica*, and *A. conyzoides*.

Table 22. Effect of propanil and fluazifop-butyl applied at 3 rates using different sprayer types on shoot fresh and dry weights of *R. cochinchinensis*.[a] IRRI greenhouse, 1987 WS.

Herbicide[b]	Application rate (kg ai/ha)	Shoot fresh weight[c] (g/plant)	Shoot dry weight[c] (g/plant)
Propanil	0.5	0.61 c	0.15 bc
	1.0	0.51 c	0.16 c
	2.0	0.20 ab	0.09 ab
Fluazifop-butyl	0.025	0.28 b	0.10 abc
	0.05	0.21 ab	0.10 abc
	0.10	0.11 a	0.06 a
Mean		0.32	0.11

[a]Av of 3 replications. [b]Propanil was sprayed 12 d after weed emergence and fluazifop-butyl at 13 d. [c]Weed was sampled at about 17 d after spraying.

Table 23. Effect of sprayer type and herbicide on dry weight of *S. maritimus* in irrigated broadcast seeded IR64.[a] IRRI, 1987 DS.

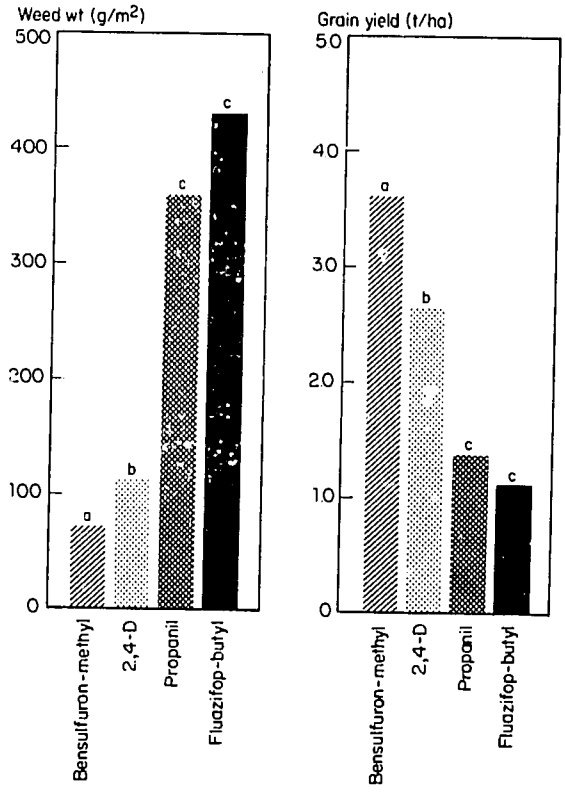
Herbicide	Dry weight of *S. maritimus*[b] (g/m²)		
	Micronherbi	Birky	Conventional
Bensulfuron	54 [1.74]	23 [1.38]	55 [1.75]
2,4-D	65 [1.82]	67 [1.83]	62 [1.80]
Propanil	320 [2.51]	378 [2.58]	345 [2.54]
Fluazifop-butyl	431 [2.64]	559 [2.75]	294 [2.47]
LSD (0.05) = [0.26]			

[a]Av of 3 replications. Values inside the brackets are log (x+1) transformed values of actual means. To compare between 2 means in a column or in a row, use the transformed values against the LSD (0.05) value given in the table. [b]Weed sampled at 50 d after seeding.

2,4-D and bensulfuron controlled *S. maritimus* better than did propanil and fluazifop-butyl, regardless of sprayer used (Table 23). With 2,4-D and propanil, the dry weights of *S. maritimus* did not significantly differ among sprayers. Bensulfuron-methyl performed better applied by the Birky than by the Micronherbi or the conventional knapsack sprayer. Fluazifop-butyl, however, gave lower sedge dry weight with the conventional sprayer than with either the Micronherbi or the Birky.

Sprayer type did not affect grain yield or total weed weight, but herbicide did. Bensulfuron gave the highest grain yield and the lowest total weed weight (Fig. 4).

Effect of butachlor application method on irrigated wet seeded rice. Undiluted butachlor at 1 kg ai/ha, poured directly into standing water in the field or into irrigation water entering the field, had no detrimental effect on rice plant height. All application methods (pouring on 1 side, 2 sides, 4 sides, in 4 corners, or in irrigation water) controlled weeds and resulted in satisfactory yields.



4. Weed weight and grain yield of irrigated broadcast seeded IR64 as affected by herbicide, IRRI, 1987 DS. For each parameter, bars with the same letter are not significantly different at the 5% level by DMRT.

INTEGRATED WEED MANAGEMENT

Effect of seedbed preparation on herbicide performance. We evaluated butachlor, piperophos - 2,4-D, and thiobencarb - 2,4-D control of weeds in broadcast seeded IR64 using two seedbed preparations: leveled and unleveled. Leveling was done with a shovel prior to seeding.

Weed control was similar in leveled and unleveled seedbeds (Table 24). However, crop establishment (rice count) on leveled plots was con-

Table 24. Effect of seedbed preparation and herbicide application at 6 DAS on weed control, crop stand, and yield of irrigated broadcast seeded IR64.[a] IRRI, 1987 DS.

Herbicide	Seedbed preparation	Weeds (no./m²) at 30 DAS	Rice plants (no./m²) at 15 DAS	Grain yield (t/ha)
Butachlor (1.0 kg ai/ha)	Leveled	122 a	144 ab	4.2 a
	Unleveled	151 a	98 b	3.0 ab
Piperophos - 2,4-D (0.3 - 0.2 kg ai/ha)	Leveled	172 a	127 b	4.0 a
	Unleveled	108 a	82 b	1.5 c
Thiobencarb - 2,4-D (1.0 - 0.5 kg ai/ha)	Leveled	57 a	205 a	4.1 a
	Unleveled	83 a	83 b	2.2 bc
Untreated check	–	407 b	95 b	2.0 bc

[a]Av of 4 replications.

sistently better than on unleveled plots, as were yields. Yields from the unleveled plots were not significantly better than that of the untreated control.

Nitrogen management and weed control in rainfed transplanted rice. N as urea at 80 kg N/ha was applied to IR64 at different times and proportions. Weed control treatments were superimposed on N treatments.

N application and weed control did not affect tiller count, plant height, or leaf area index of IR64. N management did not affect total weed weight, probably because weed growth was minimal. Weed weight was lowest in hand-weeded plots and highest in untreated plots.

Both N management and weed control interacted to affect grain yield. In hand-weeded plots, 3-split application of equal N amounts gave the highest grain yield of 3.2 t/ha (Table 25).

When weeds were not controlled, the highest grain yield of 2.2 t/ha was similar to yields obtained with other N treatments, except for the low yield where all the N was topdressed at 7 DBPI.

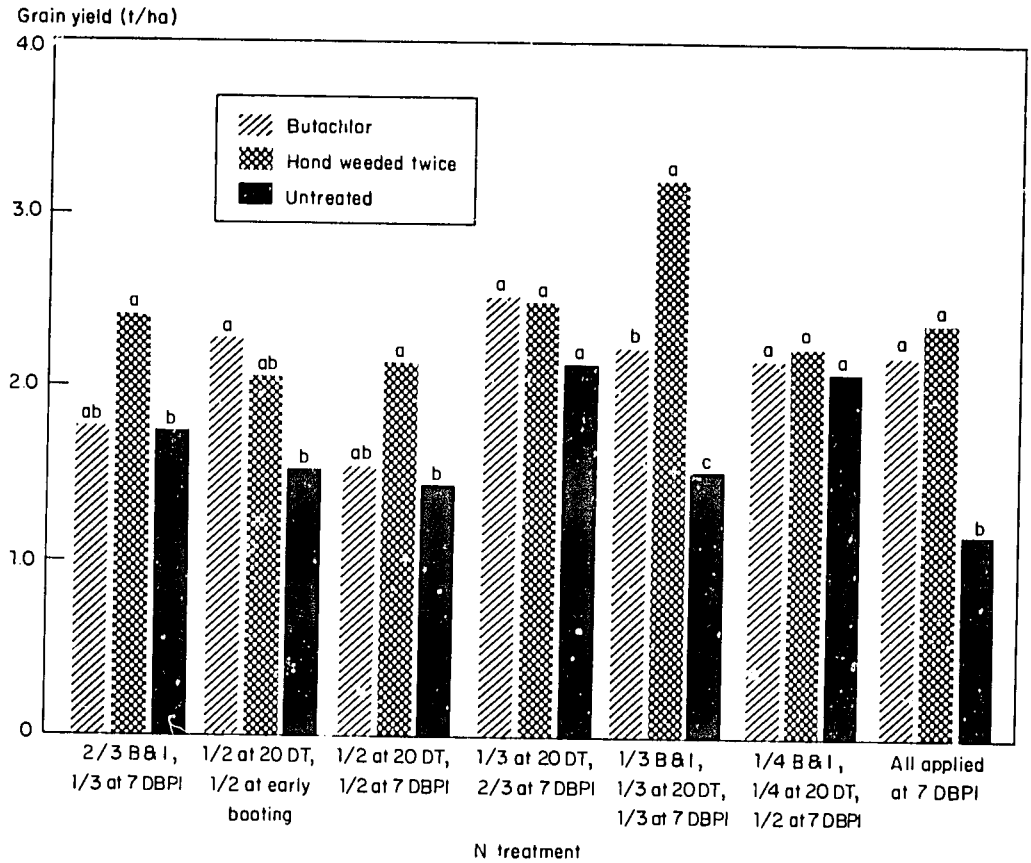
Grain yields were higher in hand-weeded plots than in untreated checks, often significantly so (Fig. 5).

Wet seeded rice. Wet seeded rice (WSR) was sown in rows using a drum-type seeder developed by the Agricultural Engineering Department. This facilitated hand weeding and interrow cultivation using a cono weeder. Nevertheless, yield losses were substantial because the cono weeder failed to control weeds within the rows, and hand weeding

Table 25. Grain yield of rainfed transplanted IR64 as affected by N management and weed control.[a] IRRI, 1987 WS.

N treatment[b]	Grain yield[c] (t/ha)			
	Butachlor	Hand-weeded twice	Untreated	N mean
2/3 N basal incorporated + 1/3 N at 7 DBPI	1.8 b	2.4 ab	1.8 ab	2.0
1/2 N at 20 DT + 1/2 N at early booting	2.3 ab	2.1 b	1.5 ab	2.0
1/2 N at 20 DT + 1/2 N at 7 DBPI	1.5 b	2.2 b	1.5 ab	1.7
1/3 N at 20 DT + 2/3 N at 7 DBPI	2.5 a	2.5 ab	2.2 a	2.4
1/3 N basal incorporated + 1/3 N at 20 DT + 1/3 N at 7 DBPI	2.2 ab	3.2 a	1.5 ab	2.3
1/4 N basal incorporated + 1/4 N topdressed at 20 DT + 1/2 N at 7 DBPI	2.2 ab	2.2 b	2.2 a	2.2
All N at 7 DBPI	2.2 ab	2.4 ab	1.2 b	1.9
Weed control mean	2.1	2.4	1.7	

[a]Av of 3 replications. [b]DBPI = days before panicle initiation, DT = d after transplanting. [c]Butachlor at 1.5 kg/ha was applied preemergence to weeds at 4 DT. Crop was hand-weeded twice – 15 and 30 DT.



5. Grain yield of rainfed transplanted IR64 as affected by N management and weed control, IRRI, 1987 WS. At each N management level, bars having a common letter are not significantly different at the 5% level by DMRT. B&I = broadcast and incorporated, DBPI = days before panicle initiation, DT = days after transplanting.

removed some of the rice (Table 26). In most cases, the highest yields were obtained when herbicides were combined with hand weeding or the cono weeder (interrow cultivation).

Dry seeded rice. All treatments reduced weeds and permitted significant yield increases compared with the unweeded check (Table 27). The highest returns to weed control were obtained when pendimethalin or butachlor applied preemergence was combined with hoe weeding at 30 DE and hand weeding at 45 DE.

All treatments gave acceptable marginal benefit-cost ratios, the highest when pendimethalin applied preemergence was combined with a hoe weeding at 30 DE. However, weed control for all treatments was costly more expensive than would be acceptable to Philippine rice farmers.

RICE-WEED COMPETITION

Upland rice. A trial in a farmer's field in Batangas compared the competitive ability of grass, sedge, and broadleaf weeds interspecifically and with upland rices IR36 and UPLRi-5. A pure stand of each weed type was maintained to represent individual treatments, which were compared with unweeded and weed-free checks.

Table 28 shows the summed dominance ratio and height of major weeds. *E. colona* was the tallest and the most dominant among the grasses and unweeded treatments. Among the broadleaf weeds, *C. benghalensis* was the most competitive, and *Ludwigia octovalvis* the least competitive. But in the unweeded plots, the grasses and the only sedge, *C. iria*, dominated the broadleaves.

Table 26. Effect of weed control practices on weed weight and grain yield of wet seeded rice. Guimba, Nueva Ecija, Philippines, 1987 WS.

Treatment[a]	Weed weight (g/m^2)	Grain yield (t/ha)
Pretilachlor + fenclorim (0.15) and HW, 3 and 21 DAS	4.8 a	4.4 a
Bensulfuron + quinclorac (0.02 + 0.20), 6 DAS	41.7 abc	4.2 ab
Butachlor (0.30) and cono weeder, 3 DBS and 21 DAS	49.2 abc	4.0 abc
Butachlor (0.30) and HW, 3 DBS and 21 DAS	22.2 abc	4.0 abc
Butachlor (0.60), 3 DBS	105.7 bcd	3.8 abc
Bensulfuron (0.01) and cono weeder, 3 and 21 DAS	30.8 abc	3.7 abc
Piperophos-2,4-D (0.25) and HW, 6 and 21 DAS	12.4 ab	3.7 abc
Cono weeder + HW 15 and 30 DAS	14.1 abc	3.6 a-d
Bensulfuron (0.01) and HW, 3 and 21 DAS	10.1 ab	3.5 a-d
Pretilachlor + fenclorim (0.30), 3 DAS	105.9 bcd	3.4 a-e
Quinclorac (0.15) and HW, 3 and 21 DAS	9.0 ab	3.4 a-e
Pretilachlor + fenclorim (0.15), and cono weeder, 3 and 21 DAS	24.0 abc	3.4 a-e
Bensulfuron + quinclorac (0.01 + 0.1) and HW, 6 and 21 DAS	9.7 ab	3.3 a-g
Bensulfuron + quinclorac (0.01 + 0.1) and cono weeder, 6 and 21 DAS	34.9 abc	3.2 b-h
HW, 15 and 30 DAS	16.8 abc	3.2 b-h
Cono weeder, 15 and 30 DAS	44.3 abc	3.1 c-i
Quinclorac (0.15) and cono weeder, 6 and 21 DAS	46.9 abc	2.9 c-i
Thiobencarb (0.3) and cono weeder, 6 and 21 DAS	24.0 abc	2.9 c-i
Piperophos-2,4-D (0.25) and cono weeder, 6 and 21 DAS	70.4 a-d	2.5 d-i
Piperophos-2,4-D (0.5), 6 DAS	211.8 ef	2.4 e-i
Thiobencarb (0.6), 6 DAS	156.1 de	2.3 f-i
Bensulfuron (0.02), 3 DAS	143.9 de	2.3 f-i
No weeding check	283.7 f	2.2 hi
Quinclorac (0.3), 6 DAS	109.7 cd	2.1 i

[a]Figures in parentheses are application rates in kg ai/ha. HW = hand weeding, DAS = days after seeding, DBS = days before seeding.

Regardless of cultivar, weed density was in the order grasses > broadleaves > sedges; grain yield was in the reverse order, sedges > broadleaves > grasses (Table 29). UPLRi-5 plots had lower weed biomass and yielded better than IR36. Yield reductions due to sedges, broadleaf weeds, and grasses were 78, 85, and 100%, respectively, with IR36, and 54, 68, and 83%, respectively, with UPLRi-5. The superior competitiveness of UPLRi-5 over IR36 can be attributed to UPLRi-5's greater height, and its higher grain yield to its higher spikelet number (Table 30).

Lowland rice. *Salvinia molesta. S. molesta*, introduced into the Philippines around 1979, is hindering rice establishment in irrigated areas of Iloilo, Capiz, and Aklan Provinces on Panay Island.

We tested the effect of time and duration of *S. molesta* competition on rice. *S. molesta* infestation at 3, 7, and 14 DAS reduced the stand of WSR at 21 DAS by 54-70%. At harvest, even though *S. molesta* competition had reduced tiller numbers as high as 22%, yield was not affected. Stand reduction usually promoted longer panicles and more filled grains per panicle.

Pistia stratiotes. Similar results were obtained with *P. stratiotes*, common in some irrigated rice areas in the Philippines. When the weed was introduced into the field at 3 DAS, it reduced stands of WSR by 27-69%. Weed cover ranged from 10 to 100%. However, grain yields were maintained because surviving plants produced more tillers.

Lowland weed species. A trial in 1987 DS determined the effect of weed density on TPR. Yield losses ranged from 0 to 24% with competition from 5 weeds/m^2, and from 28 to 73% with 80 weeds/m^2 (Table 31). Average yield in the weed-free check was 4.0 t/ha. Weed competition reduced tillers/hill, grain weight/panicle, and panicle length in addition to grain yield.

ECOPHYSIOLOGY OF WEEDS

Research sought to establish the competitive relationship between rice and weeds and their adaptation mechanisms to changing light environment. In field studies under upland conditions in 1987 WS, IR43 at 100 kg seed/ha was grown in

Table 27. Effect of weed control treatments on grain yield, weed weight, and returns to weed control in dry seeded rice. Cuimba, Nueva Ecija, Philippines, 1987 WS.

Treatment[a]	Weed weight (g/m^2) at 40 DE	Grain yield (t/ha)	Cost[b] ($/ha)			Gross income ($/ha)	Return to weed control ($/ha)	Marginal benefit-cost ratio
			Labor	Herbicide	Total			
Pendimethalin (1.32) fb hoe fb HW, PE fb 30 fb 45 DE	14.8 a	4.6 a	128.50	50.00	178.50	742.40	563.90	4.2
Butachlor (1.5) fb hoe fb HW, PE fb 30 fb 45 DE	18.5 a	4.6 a	151.20	26.25	177.45	740.80	563.35	4.2
Hoe weeding 15, 30, and 45 DE	21.6 a	4.3 a	194.50	–	194.50	688.00	493.50	3.5
HW 15, 30, and 45 DE	20.6 a	4.2 a	290.90	–	290.90	667.20	376.30	2.3
Pendimethalin (1.32) fb hoe, PE fb 30 DE	133.4 a	3.6 b	21.20	50.00	71.20	567.00	495.90	8.0
Hoe 15 and 30 DE	89.6 a	3.0 c	111.30	–	111.30	486.40	375.10	4.4
Hoe + HW + butachlor (1.5), 15 DE	189.2 a	2.6 cd	121.30	26.25	147.55	408.00	260.45	2.8
Hoe + HW + pendimethalin (1.32), 15 DE	234.9 a	2.5 cd	100.20	50.00	150.20	404.00	254.60	2.7
Butachlor (1.5) fb hoe, PE fb 30 DE	200.2 a	2.2 d	30.10	26.25	56.35	344.00	287.65	6.1
Unweeded check	613.9 a	0 e	–	–	–	–	–	–

[a]Figures in parentheses are application rates in kg ai/ha. DE = days after emergence, fb = followed by, hoe = hoe weeding, HW = hand weeding, PE = preemergence. [b]Labor = $1/d, butachlor = $10.50/liter, pendimethalin = $12.50/liter.

Table 28. Summed dominance ratio and height of major weeds.[a] Batangas, Philippines, 1987.

	Summed dominance ratio[b]				Height[c] (cm)
	Sedge	Grass	Broad-leaf weeds	Un-weeded	
Cyperus iria	100	–	–	29	122
Echinochloa colona	–	61	–	31	147
Eleusine indica	–	39	–	21	132
Commelina benghalensis	–	–	49	8	85
Ageratum conyzoides	–	–	21	3	66
Commelina diffusa	–	–	15	7	100
Ludwigia octovalvis	–	–	6	0	76
Others[d]	–	–	9	2	–

[a]Av of 3 replications and 2 rice cultivars. [b]Taken at 45 DE. [c]Taken at flowering stage of the weed. [d]*Borreria ocymoides, Synedrella nodiflora,* and *Portulaca oleracea.*

Table 29. Biomasses of weed types and their effect on upland rice yield.[a] Batangas, Philippines, 1987.

Treatment	Biomass[b] (g/m^2)		Yield (t/ha)	
	IR36	UPLRi-5	IR36	UPLRi-5
Weed free	0 a	0 a	2.7 a	3.5 a
Sedges	154 a	124 a	0.6 b	1.6 b
Broadleaf weeds	414 b	189 a	0.4 bc	1.1 c
Grasses	902 c	525 b	0 c	0.6 d
Unweeded	951 c	760 c	0 c	0 e
Mean	484 a	320 a	0.7 b	1.4 a

[a]Av of 3 replications. [b]Sampled at 45 DE.

Table 30. Plant characters of IR36 and UPLRi-5 under weed competition.[a] Batangas, Philippines, 1987.

Cultivar	Height[b] (cm)	Tiller count[c] ($no./m^2$)	Panicle count ($no./m^2$)	Spikelet count (no./panicle)
IR36	70 b	307 a	110 a	51 b
UPLRi-5	113 a	252 a	109 a	101 a

[a]Av of 3 replications and 5 weed type treatments. [b]At flowering stage. [c]At 45 DE.

replacement series with *R. cochinchinensis* and *Cyperus rotundus, E. colona* and *C. rotundus*, and *R. cochinchinensis* and *E. colona*. Nutrients and moisture were not limiting.

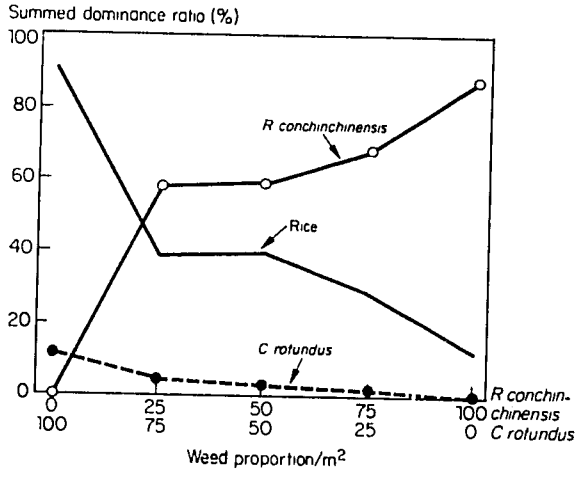
The rice competitive relationship with the weeds depended on the weed mixture and weed density. IR43 was dominant over *E. colona* in the *R. cochinchinensis-E. colona* mixture but subordinate in the *E. colona-C. rotundus* mixture. Dominance

Table 37. Effect of weed densities on yield loss in transplanted rice. IRRI, 1987 DS.

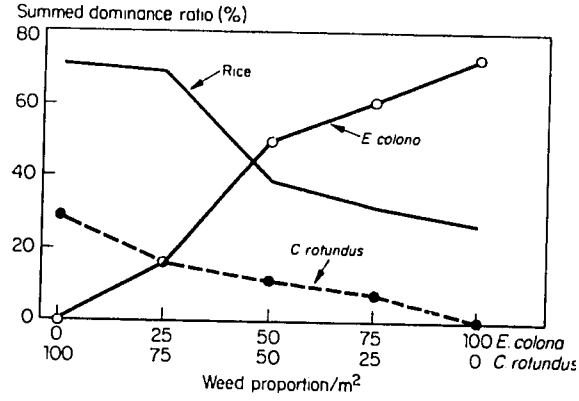
Weed density (no.)	Yield loss (%) from					
	Fimbristylis miliacea	*Ludwigia octovalvis*	*Monochoria vaginalis*	*Echinochloa colona*	*E. crus-galli* ssp. *hispidula*	*E. glabrescens*
5	3	0	0	8	24	13
10	13	5	0	13	32	27
20	9	21	20	30	53	42
40	16	21	22	35	58	54
80	26	35	50	50	71	73

was in the order of *R. cochinchinensis* > *E. colona* > IR43 > *C. rotundus* (Fig. 6, 7, 8). Substituting the dominant weed *R. cochinchinensis* for the less competitive weed *C. rotundus* (Fig. 6) increased pressure on rice. *R. cochinchinensis* reduced IR43 yields by 100%, *E. colona* by 84%, and *C. rotundus* by 27%.

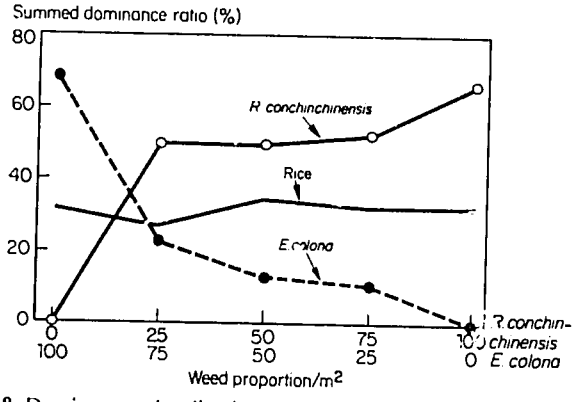
At 53 DAS, the light transmission ratio (LTR) at 50 cm within the canopy was 2.8% for *R. cochinchinensis*, 26% for *E. colona*, and 98.7% for *C. rotundus*. Weed competition reduced rice tiller number, increased shoot N concentration, and nonsignificantly increased leaf area ratio (21%) (Table 32, 33, 34). N content in shoots correlated linearly with LTR (Fig. 9). Rice, therefore, adapted to partial shading by having high leaf N content, which increased its photosynthetic rates at low light intensity.



6. Dominance-subordination relationship of rice with varying proportions of *Cyperus rotundus* and *Rottboellia cochinchinensis*. IRRI, 1987 WS.



7. Dominance-subordination relationship of rice with varying proportions of *Echinochloa colona* and *C. rotundus*. IRRI, 1987 WS.



8. Dominance-subordination relationship of rice with varying proportions of *R. cochinchinensis* and *E. colona*. IRRI, 1987 WS.

POPULATION DYNAMICS OF *ECHINOCHLOA COLONA* AND *ROTTBOELLIA COCHINCHINENSIS*

A population dynamics model of a weed provides information on the rate of weed population increase or decrease in the absence or presence of a

Table 32. Competitive effect of varying proportions of *R. cochinchinensis* and *C. rotundus* on growth and yield of IR43.[a] IRRI, 1987 WS.

Weed proportion (no./m²)		IR43				*R. cochinchinensis* height (cm) at 53 DAS	*C. rotundus* height (cm) at 53 DAS
R. cochinchinensis	*C. rotundus*	Grain yield (t/ha)	Tillers (no./plant) at 53 DAS	Leaf area ratio (dm²/g) at 53 DAS	LTR[b] at 50 cm canopy (%)		
100	0	0.0 c	3.5 bc	2.8 a	2.6 b	153 a	–
75	25	0.0 c	3.0 bc	2.4 a	17.5 b	134 b	38 a
50	50	0.0 c	2.5 c	2.4 a	21.7 b	129 b	41 a
25	75	0.0 c	4.2 bc	3.4 a	22.4 b	123 b	39 a
0	75	2.0 b	6.4 ab	2.9 a	98.7 a	–	33 a
Weed-free		2.7 a	8.1 a	2.2 a	96.0 a	–	–

[a]Av of 4 replications. [b]Light transmission ratio.

Table 33. Competitive effect of varying proportions of *R. cochinchinensis* and *E. colona* on growth and yield of IR43.[a] IRRI, 1987 WS.

Weed proportion (no./m²)		IR43					*R. cochinchinensis* height (cm) at 53 DAS	*E. colona* height (cm) at 53 DAS
R. cochinchinensis	*E. colona*	Grain yield (t/ha)	Tillers (no./plant) at 53 DAS	Height (cm) at 53 DAS	Leaf area ratio (dm²/g)	LTR at 60 DAS (%)		
100	0	0.0 b	5.4 bc	55	4.3 a	2.8 c	150 a	74 a
75	25	0.0 b	3.7 c	53	4.0 a	4.6 c	147 a	68 a
50	50	0.0 b	4.7 bc	59	4.1 a	3.8 c	134 a	83 a
25	75	0.0 b	5.5 bc	59	4.1 a	4.1 c	133 a	83 a
0	100	0.1 b	6.9 b	55	2.7 a	26.0 b	–	69 a
Weed-free		2.7 a	10.3 a	50	1.9 a	92.1 a	–	–

[a]Av of 4 replications.

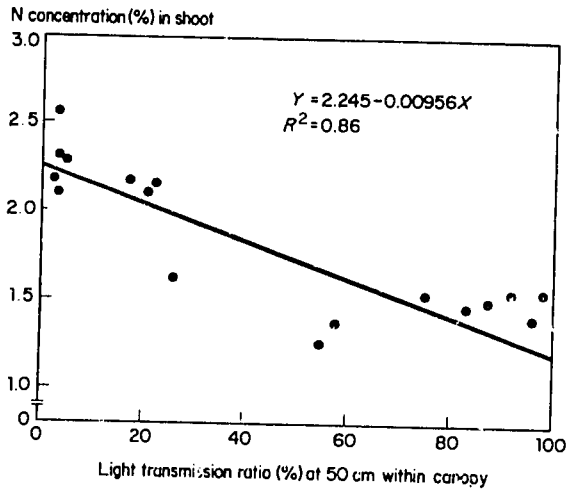
Table 34. Competitive effect of varying proportions of *E. colona* and *C. rotundus* on growth and yield of IR43.[a] IRRI, 1987 WS.

Weed proportion (no./m²)		IR43				*E. colona* height (cm) at 55 DAS	*C. rotundus* height (cm) at 55 DAS
E. colona	*C. rotundus*	Grain yield (t/ha)	Height (cm) at 55 DAS	Leaf area ratio (dm²/g)	LTR at 60 DAS (%)		
100	0	0.8 d	47 a	3.5 a	59 a	69 a	–
75	25	1.0 cd	48 a	3.2 a	57 a	75 a	45 a
50	50	1.0 cd	44 a	3.2 a	75 a	81 ab	42 a
25	75	1.5 bc	43 a	2.9 a	80 a	49 b	42 a
0	100	2.0 b	41 a	3.3 a	84 a	–	40 a
Weed-free		2.7 a	37 a	3.4 a	87 a	–	–

[a]Av of 4 replications.

control measure. This technique can determine the weed control level necessary to contain or eradicate the weed. During 1987 WS, *E. colona* and *R. cochinchinensis* were studied in separate experiments without rice. An upland experiment, also in 1987 WS, examined the effect of the presence of rice cultivars IR43 and UPLRi-5 seeded at 100 and 200 kg seed/ha on the growth of *E. colona*, *R. cochinchinensis*, and *C. rotundus*.

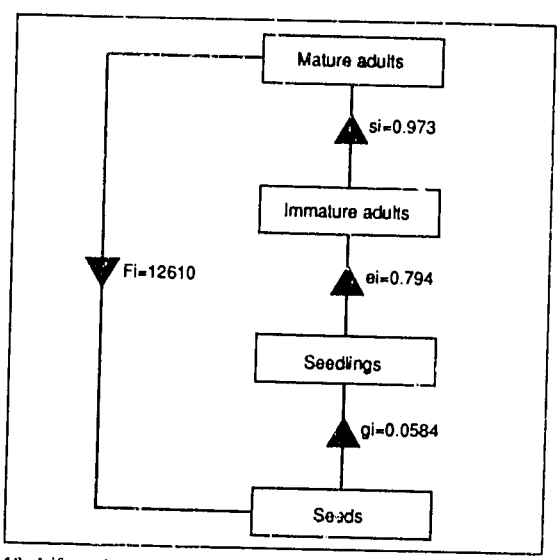
E. colona and *R. cochinchinensis* had low seed



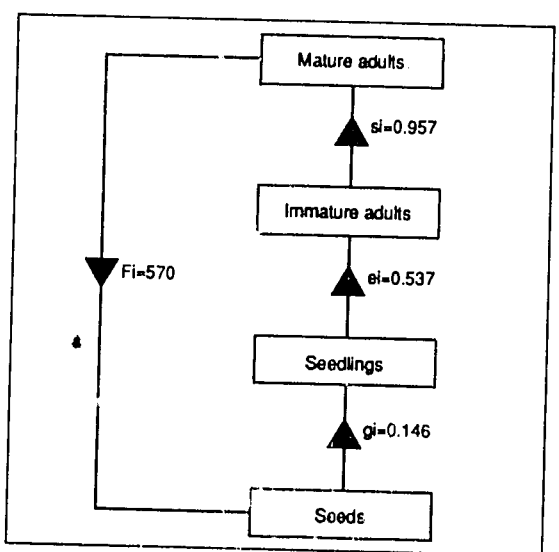
9. Relationship between light transmission ratio and N concentration in rice shoots 75 d after sowing. IRRI, 1987 WS.

germination and high seedling mortality (Fig. 10, 11). Both species were susceptible to intraspecific density stress, as shown by the number of seed produced per plant (fecundity), tiller number per plant, plant height, and weed biomass (Table 35). The presence of rice did not affect weed seedlings emerging with it but did reduce the number of later emerging weed seedlings (Table 36).

The population dynamics models shown in Figures 10 and 11 represent one life cycle without a seed bank. *E. colona* population increased at the rate of 561 mature plants and *R. cochinchinensis* at 43. A complete version of this model, considering the seed bank and number of life cycles per year under weed control practices, is being developed to determine the economic level of control that will eradicate these weeds.



10. Life cycle of *E. colona*. F_i = adult fecundity. Probability of a seed surviving to produce seed = gi · si · ei = 561.



11. Life cycle of *R. cochinchinensis*. F_i = adult fecundity. Probability of a seed surviving to produce seed = gi · si · ei = 43.

Table 35. Growth and seed production of *E. colona* and *R. cochinchinensis* as affected by intraspecific competition.[a] IRRI, 1987 WS.

Density (plants/m²)	*E. colona*				*R. cochinchinensis*		
	Tillers (no./plant) at 30 DE	Height (cm) at 30 DE	Biomass (g/m²)	Seeds (no./plant)	Tillers (no./plant) at 30 DE	Height (cm) at 33 DE	Seeds (no./plant)
1	36.1 a	20 c	119 b	99,971 a	13.0 a	57 a	1,535 a
50	22.5 b	36 b	824 a	12,287 a	9.4 a	60 a	626 b
100	21.5 b	43 a	1,200 a	12,933 a	5.5 a	59 a	515 b

[a]Av of 4 replications.

Table 36. Effect of IR43 and UPLRi-5 at 2 seeding rates on the growth of *R. cochinchinensis*, *E. colona*, and *C. rotundus*.[a] IRRI, 1987 WS.

Cultivar	Density	*R. cochinchinensis*				*E. colona*		*C. rotundus*	
		Seedlings (no./m²) at 7 DAS	Seedlings (no./m²) at 35 DAS	Biomass at harvest (t/ha)	Height (cm) at 60 DAS	Height (cm) at 60 DAS	Biomass (t/ha) at harvest	Stand count (no./cm) at 35 DAS	Height (cm) at 35 DAS
IR43	100	43 a	8 b	14 a	167 a	70 a	8 a	182 ab	45 abc
IR43	200	25 a	3 b	13 a	164 a	67 a	7 a	108 b	45 abc
UPLRi-5	100	28 a	6 b	14 a	163 a	68 a	8 a	156 ab	56 a
UPLRi-5	200	33 a	5 b	12 a	163 a	70 a	7 a	101 b	39 bc
None	None	31 a	29 a	14 a	173 a	66 a	9 a	265 a	34 c

[a]Av of 4 replications.

Table 37. Competitive effectiveness of IR43 and UPLRi-5 with *R. cochinchinensis*, *E. colona*, and *C. rotundus*, and of the weeds with rice, under upland conditions at 60 DAS.[a] IRRI, 1987 WS.

Cultivar	Density (kg/ha)	Reduction (%) in rice due to weed			Reduction (%) in weed due to rice		
		R. cochinchinensis	*E. colona*[b]	*C. rotundus*	*R. cochinchinensis*	*E. colona*[b]	*C. rotundus*
IR43	100	74	50	66	59	11	72
IR43	200	28	46	26	65	17	74
UPLRi-5	100	79	53	42	49	6	73
UPLRi-5	200	47	45	28	68	18	86

[a]Av of 4 replications. [b]At harvest.

Table 38. Effect of *R. cochinchinensis*, *E. colona*, and *C. rotundus* on growth and yield of IR43 and UPLRi-5 at 2 seeding rates.[a] IRRI, 1987 WS.

Cultivar	Seeding rate (kg/ha)	Weed control	With *R. cochinchinensis*		With *E. colona*	With *C. rotundus*		
			Grain yield (t/ha)	Height (cm) at 55 DAS	Grain yield (t/ha)	Grain yield (t/ha)	Height (cm) at 55 DAS	Light transmission ratio
IR43	100	Weedy	0.0 b	52 b	0.7 b	2.1 b	55 d	31.4 a
IR43	200	Weedy	0.0 b	61 ab	0.2 b	2.1 b	69 bcd	27.4 a
UPLRi-5	100	Weedy	0.0 b	74 ab	0.3 b	2.4 ab	78 ab	37.9 a
UPLRi-5	200	Weedy	0.0 b	79 a	0.6 b	2.4 ab	82 ab	27.4 a
IR43	100	Weed-free	2.6 a	65 ab	2.3 a	2.8 a	57 cd	36.4 a
IR43	200	Weed-free	2.9 a	68 ab	2.3 a	2.5 ab	71 bc	26.2 a
UPLRi-5	100	Weed-free	2.7 a	77 a	2.2 a	2.6 ab	68 bcd	37.0 a
UPLRi-5	200	Weed-free	2.8 a	73 a	2.4 a	2.5 ab	86 a	30.4 a

[a]Av of 4 replications.

The competitive effectiveness of rice with weeds at 60 DAS varied from 49 to 86%; that of weeds with rice from 26 to 79% (Table 37). At harvest, however, rice did not affect *E. colona* and *R. cochinchinensis* biomass (Table 36). Density increased the competitive ability of rice by 12% more than did the cultivar.

LTR was reduced by 7.8% with 200 kg seed/ha, though not significantly, as compared with 100 kg seed/ha. No difference in LTR was observed between cultivars. Rice density and cultivar did not affect grain yield (Table 38).

GROWTH BEHAVIOR OF A 2,4-D-RESISTANT WEED

To evaluate differential tolerance of *Sphenochlea zeylanica* strains to 2,4-D, their germination, growth behavior, and leaf morphology were compared in a collaborative experiment with the National Crop Protection Center and the University of the Philippines at Los Baños Agronomy Department. See the section on Cooperative Country Projects.

Water management

Water Management and Plant Breeding Departments

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DETERMINANTS OF RAINWATER STORAGE AND USE ON RAINFED RICE FARMS

Water Management Department

Storage of rainwater in farm reservoirs (FRs) for supplemental irrigation of wet season (WS) rice and for dry season (DS) crop production is economically attractive in the rainfed areas of Central Luzon, Philippines. FR users can increase cropping intensity on their farms and raise fish in the reservoirs to increase their incomes. Previous studies identified problems that need systematic research to make the technology sustainable and widely adoptable (Annual report for 1986).

The specific objectives pursued in the research reported here were 1) to establish a methodology for water balance analysis for FRs, 2) to identify the factors that most affect rainwater collection efficiency at each site, and 3) to identify specific management practices that will improve water productivity. The study was conducted at five FR sites selected to represent the diversity of physical and hydrologic conditions of reservoirs in Tarlac Province, Central Luzon, Philippines. Their major characteristics are shown in Table 1.

For each reservoir a 1:250 or 1:100 scale map was produced from survey data, showing elevation contours at 10-cm intervals to allow reservoir depth-area and depth-volume analyses. The catchment area for runoff contribution to the reservoirs was determined, and the areas that could receive reservoir water for irrigation by gravity flow and by pumping were delineated by using information from the parcellary map and topographic survey of the farm. The reservoir water depths, rainfall, and open pan evaporation rate were recorded daily.

Water balance procedure. Water flowing into and out of the FR is shown schematically in Figure 1. The reservoir water balance equation is

$$\text{Change in storage} = \text{inflow} - \text{outflow}$$

$$\text{Thus, } QS = (QD + QR + QA + QG) - (QL + QO + QE + QI)$$

where: QS = change in storage,

QD = direct rainfall into reservoir,
QR = runoff into reservoir,
QA = input from artesian well (if any),
QG = input from groundwater or interflow,
QL = combined seepage and percolation losses,
QO = water loss by overflow,
QE = evaporation loss, and
QI = irrigation (including land preparation) use.

QG, QL, and QO cannot be measured directly; they were estimated or calculated from conditions described in Table 2.

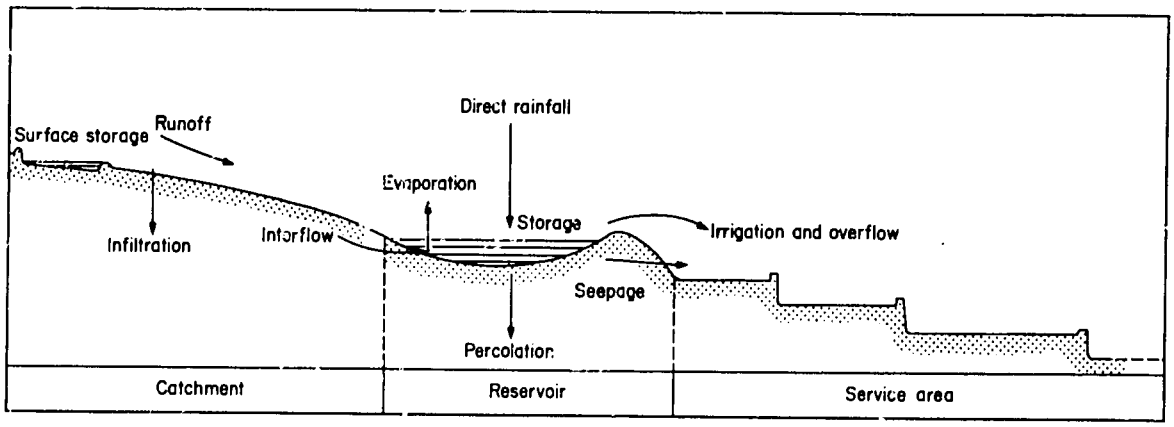
Reservoir inflows and outflows. A summary of the component inflows and outflows during 1987 is given in Table 3.

Reservoir inflows. Direct rainfall contributed an average 44% of the total input to the 4 reservoirs that were dependent on direct rainfall and runoff only. Significant contributions to the reservoirs were made by rainstorms of greater than 50 mm

Table 1. Physical and hydrologic characteristics of 5 selected farm reservoir sites[a] in Central Luzon, Philippines, 1987.

Item	Magday	Valdez	Ruz	E. Tolenada	A. Tolenada
Catchment area (ha)	5.8	2.6	0.8	2.0	4.4
Service area (ha)					
Wet season (1987)	0.75	2.08	0.87	0.55	0.62
Dry season (1988)	0.25	1.10	0.26	0.46[b]	0.36
Catchment area: service area					
Wet season (1987)	7.73	1.25	0.92	3.60	7.10
Dry season (1988)	23.2	2.36	3.10	4.35	12.2
Slope of service area (%)	4.6	5.0	1.6	2.8	2.5
Reservoir area, including dam (m^3)	3,600	4,100	1,400	1,900	500
Maximum reservoir storage volume (m^3)	2,872	3,997	1,016	1,139	287
Maximum reservoir depth (m)	1.7	2.1	1.8	1.6	1.0
Average reservoir depth (m)	1.1	1.3	1.1	0.95	0.76
Maximum reservoir depth: average reservoir depth	1.6	1.6	1.6	1.7	1.3
Storage ratio[c]	8.0	4.2	2.8	1.8	6.1

[a]All were built using a bulldozer except A. Tolenada's, which employed carabaos. [b]1987 DS area; no crop was grown in 1988 DS. [c]Ratio between maximum storage volume and volume of earthwork needed for reservoir construction.



1. Schematic representation of reservoir inflows and outflows. Central Luzon, Philippines, 1987.

Table 2. Truth table for calculation of reservoir inflows and outflows.[a] IRRI, 1987.

Rainfall	*Runoff*	*Overflow*	
0	0	0	Calculate seepage and percolation (S&P) loss
0	0	1	Estimate S&P Calculate from late runoff data or artesian well data
0	1[b]	0	Estimate S&P Calculate late runoff volume
0	1[b]	1	Estimate S&P Estimate runoff from previous data Calculate overflow
1	0	0	Calculate direct rainfall input Calculate S&P
1	0	1	Estimate S&P Calculate direct rainfall input Calculate overflow volume
1	1	0	Estimate S&P Calculate direct rainfall input Calculate runoff volume
1	1	1	Estimate S&P Calculate direct rainfall input Estimate runoff from previous data Calculate overflow volume

[a] 1 = present, 0 = absent. [b] Late runoff can occur up to 2 d after a heavy rain because of slow release of surface storage through seepage. Groundwater or interflow is assumed to be zero. Any contributions will decrease the calculated value of S&P.

depth irrespective of catchment size (Fig. 2). The A. Tolenada reservoir was maintained at a relatively constant volume by inflow from the artesian well throughout the year

Runoff flows depend upon antecedent rainfall, rainfall intensity and duration, catchment area, soil type, land use, and slope. Measured runoff flow and rainfall relationships were determined for 2 sites with contrasting catchment characteristics: one (Magday) with grassed soil and slopes between 2 and 7%, and the other (Valdez) with terraced rice plots and slope varying between 2 and 5%. For the Magday farm, the maximum runoff coefficient (RC) measured during the season was 0.25 for a rainfall intensity of about 50 mm. Higher runoff occurred during storms of more than 60 mm, but no measure of runoff could be made because the reservoir overflowed. Threshold rainfall—the minimum rainfall that causes runoff—was between 4.5 and 40 mm. Low thresholds were observed when a rainstorm closely followed a previous one.

In the second catchment (Valdez), RC values varied between 0 and 0.7 and were highly dependent on antecedent rainfall due to high surface storage in the rice plots. RC values of up to 0.7 with rainfall depths as low as 20 mm reflect low infiltration rates into the puddled rice soils in the catchment area or a nearly full surface storage condition maintained in the rice plots there.

Runoff volume contributed 35-62% of the total inflow in the 4 reservoirs that did not receive any artesian flow (Table 3); the average contribution was 53%.

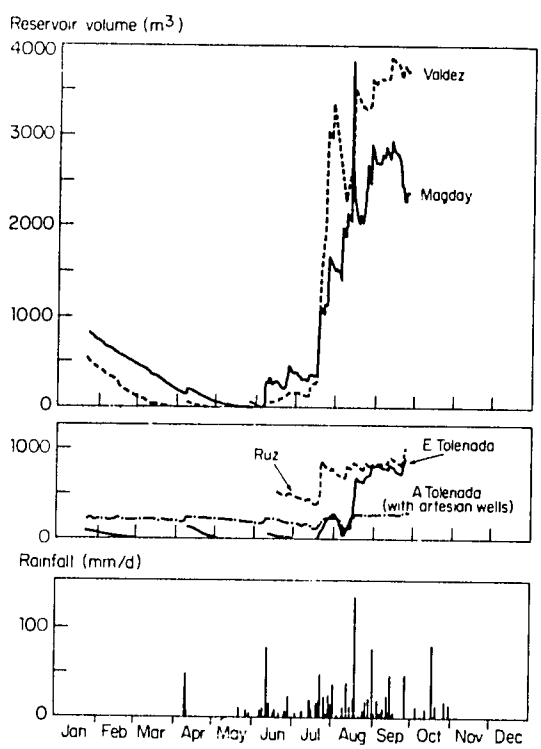
Reservoir outflows. Water use for land preparation and crop irrigation accounted for about 50%

Table 3. Components of reservoir inflow-outflow, Tarlac, Philippines, January-September 1987.

Component	Magday	Valdez	Ruz	E. Tolenada	A. Tolenada
Inflows (%)					
Artesian or external	–	–	11[a]	–	44[b]
Runoff[c]	62	61	35	56	32
Direct rainfall	38	39	54	44	24
Total	100	100	100	100	100
Total inflow (m^3)	5490	6950	1460	1610	1320
Outflows (%)					
Irrigation and land preparation	48	53	18	21	52
Evaporation	31	26	24	35	29
Seepage and percolation	20	21	58	44	19
Total	100	100	100	100	100
Total outflow (m^3)	3940	3770	960	800	1270
Change in storage[d] (m^3)	1550	3180	500	810	50

[a]160 m^3 of water was channeled to the reservoir from tubewells on a neighboring farm. [b]590 m^3 from artesian wells was channeled to the reservoir, and a further 600 m^3 was diverted past the reservoir. The diversion volume in not included in the irrigation volume. [c]Does not include runoff that was diverted past the reservoir or that contributed to overflow. [d]Difference between storage at the end of September and that at the start of data collection in January. Data collection for the Ruz reservoir did not begin until June.

of total water outflow from 3 of the reservoirs. The other 2 used about 20% of the total outflow for this purpose (Table 3). Evaporation losses were similar



2. Daily reservoir storage volume at 5 sites, Tarlac, Central Luzon, Philippines, 1987.

at all sites, accounting for 24-35% (av 29%) of the total water outflow in each reservoir. Average evaporation loss rates were 4.6 mm/d in DS and 3.1 mm/d in WS. For calculating these values, we used pan coefficients of 0.77 for DS and 0.83 for WS, as recommended by FAO for open water bodies less than 5 m deep.

Combined seepage and percolation (S&P) losses accounted for 20-58% (av 32%) of water outflow volume from the reservoirs, with daily losses varying between 1.6 and 6.5 mm. The Ruz reservoir, which was constructed in May 1986, had the highest S&P losses. The A. Tolenada reservoir, the only one that had the dam wall compacted during construction, had the lowest S&P losses (Table 3).

Practices that improve farm reservoir productivity. Any practice that leads to increased water storage, or a reduction in the water requirement of the DS crop, will enhance the productivity of a reservoir. The farmer can improve water collection efficiency by proper management of the catchment area and can conserve more water in the reservoir by taking specific measures to enhance water retention and improve the reservoir's functions. The farmer can increase the productivity of water in DS with improved on-farm practices. Good management practices currently used by some farmers in the reservoir, catchment area, and farm to meet these objectives are as follows:

Catchment area

- During the early part of WS there is a possible conflict of interest between 1) filling the reservoir as early as possible to plant part of the lower area to DS crops, and 2) conserving water in the catchment area itself to use for WS crop establishment. Since most of the catchment area is not topographically suitable for DS cropping with reservoir water, preference is given to early establishment of the WS crop in the area below the reservoir.
- When the crop in the catchment area is nearly ready for harvest, the bunds are cut to allow field drainage. The cuts are maintained to ensure maximum runoff to the reservoir during late WS rains.

Reservoir

- When the reservoir is full, runoff flows are diverted past it rather than through it to minimize siltation and the loss of nutrients used for fish production.
- Efficient flow of runoff into the reservoir requires an adequate inlet structure. Two of the reservoirs studied did not fill up in 1987 because their inlet structures were too small, and most of the runoff was diverted past the reservoir before it had filled. A 30-cm-wide cut in the bund of the adjacent ricefield was large enough to keep a 4,000-m^3 reservoir at full storage.
- Compacting the reservoir embankments during construction by driving the bulldozer up them makes them more resistant to slumping and erosion. Grass will protect the embankment from erosion caused by rainfall.
- Tree crops are often planted at the bases of downstream embankments to help support the embankment and reduce evaporation losses from the reservoir by acting as a windbreak. More importantly, they furnish extra income. Fish production in the reservoir can be profitable, while not conflicting with the use of the stored water for growing crops.
- Carabao cause major damage to reservoir embankments, but trampling and wallowing help seal the reservoir floor. Ideally, the reservoir should be fenced off and the animals led in and out at only one point.
- Animal manure, when applied directly to the water in the reservoir, increases fish production and helps seal the reservoir floor.

Service area

- The fields to be planted to the DS crop using reservoir water should not be drained before WS rice harvest to conserve water for DS land preparation and crop use.
- Turnaround time between WS and DS crops should be as short as possible to utilize residual soil moisture and reduce the time the DS crop must be supported with reservoir water.
- Partial irrigation of a crop of DS lowland rice is the most common use of stored water. On sloping land, irrigation water is applied in alternate plots to maximize the use of seepage water from higher to lower plots.
- Farmers in Padapada, Tarlac, have been successfully cultivating other crops such as eggplant, tomato, mungbean, and watermelon during DS. These crops are normally hand-watered, but one enterprising farmer planted rice and mungbean in alternate fields to utilize the seepage water from the ricefields.
- The frequency of DS rice irrigation is about once a week to once every 2 wk for rice when water is plentiful. If reservoir storage is too low for irrigation at this frequency, the water is saved and applied between the flowering and grain filling stages of the crop.

WATER MANAGEMENT FOR HIGHER FARM PRODUCTIVITY IN COASTAL IRRIGATED AREAS

Water Management Department

Coastal saline areas are increasingly being developed with irrigation facilities for rice production. A precondition to maintain the productivity of saline areas is preventing soil salinization by applying adequate, good quality irrigation water and protecting it from frequent drying and from flooding by seawater.

In the Bicol River basin in Camarines Sur, Philippines, where coastal salinity has been a large problem, the Inarihan River Irrigation System (IRIS) supplies irrigation water diverted from the

river to about 1,400 ha belonging to more than 1,100 farm families for growing 2 rice crops a year. Inadequate irrigation water deliveries to 30-40% of the service area allow salinity levels to rise and reduce rice yields as well as farm income (Annual report for 1986). A joint study with the National Irrigation Administration (NIA) in 1986-87 evaluated the effects of salinity on the productivity of the water-short, salinity-prone farms and the impact of introducing improved irrigation water allocation-distribution to those farms.

Farm water status and rice yield relationship. Water status was measured in terms of depth of the perched water table below the soil surface when there was no standing water in 84 plots distributed between saline farms (those whose root zone soils were found to have an electrical conductivity higher than 4.0 dS/m) and nonsaline farms. The water table depth was measured in an observation well consisting of a 100-cm-long, 2-cm-diameter polyvinyl chloride tube, with bottom 80 cm perforated for easy water movement, installed to 80 cm depth from the soil surface.

The deeper the perched water table inside the tube, the more severe was the water deficit on the farm. However, the duration over which the water table remained below the surface also contributed to the severity of the water deficit or stress on the plant. These two factors were combined by using them in the following equation to determine what was termed the water deficit index (WDI), defined as

$$\mathrm{WDI} = \sum_{i=1}^{n} \left(\frac{de.du}{2} \right)_i$$

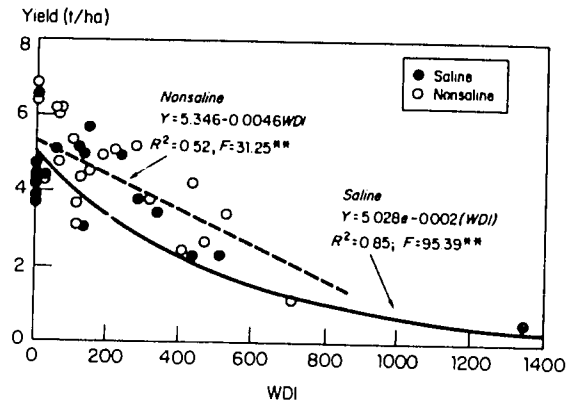
where de = maximum depth of water table below ground surface,

du = number of days water table remained below ground surface in one water deficit period,

n = number of water deficit periods during a season.

Regression analyses were made separately for the saline and nonsaline farms for 1986 DS and 1987 DS (Fig. 3). The subset of the sample used for this analysis consists of those farms whose rice yields were not affected by other problems such as insect infestation or Zn deficiency.

The results clearly show that water stress is much more detrimental to rice crops in saline than in



3. Water deficit index (WDI) and rice yield relationships. Inarihan River Irrigation System (IRIS), Camarines Sur, Philippines, 1986 and 1987 DS.

nonsaline (normal) soils. For example, a WDI of 200 caused about 0.5 t/ha yield reduction in nonsaline soil, but the reduction was about 3 times more in saline soil. The higher yield loss in saline soil was the accentuated effect on the plant of soil salinity created by water deficit. At WDI = 0, i.e., when there is no water deficit, the yield levels were nearly the same; but with increasing WDI, the yield reductions in saline soils were more drastic.

WDI is a more accurate measure of field water stress than stress-days, which has been often used to explain water stress effects in rice yields. For the saline farms in IRIS, stress-day as a variable explained only 26% of the yield variations in the sample, as opposed to 85% explained by WDI (Fig. 3). For the nonsaline farms, stress-day explained 34% of the yield variations compared with 54% explained by WDI.

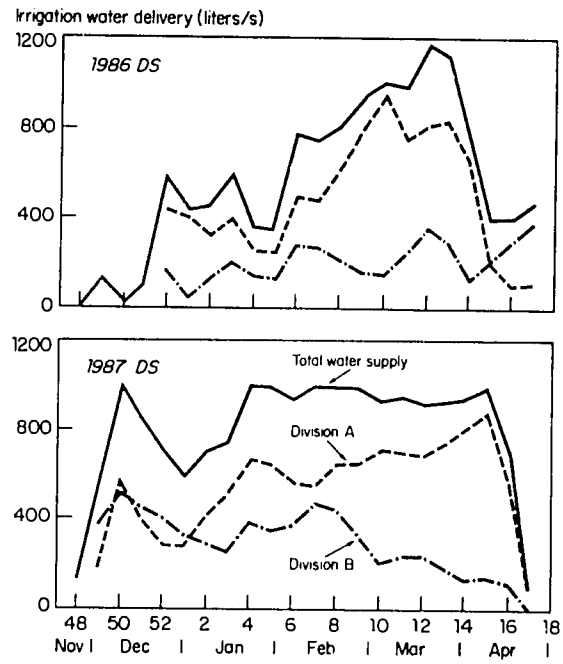
Effects of improved water allocation and distribution. In 1986 DS, water was allocated and distributed by the conventional "continuous flow method," in which water in all canals flows simultaneously and continuously; upstream Division A farmers diverted much more than their share of water through both the NIA-constructed turnouts and extra ones, causing serious water shortage and yield reductions in Division B farms. As a remedy, a "sectionwise rotation method" in the main canal was designed and implemented in 1987 through the NIA operation and maintenance personnel, with farmer group cooperation. Control gates were installed in 9 of the 11 extra turnouts in Division A to minimize uncontrolled, wasteful

diversion by advantageously located farmers; 2 others were closed. A minimum flow of 1,000 liters/s into the main canal was to be distributed to the various parts of Divisions A and B, each of which was divided into 2 sections with an assigned flow rate and time period for irrigation water delivery. Irrigation flow and farm-level water status were monitored throughout the season in 84 farmer plots selected on a grid basis. On half of these plots, field water requirements were measured with sloping gauges.

Irrigation water deliveries, use, and yields. Water deliveries in 1987 DS were better distributed between Divisions A and B, and fluctuated less than in 1986 DS. In 1986, for example, the daily irrigation flow in the main canal from February to March varied between 345 and 1,122 liters/s, with an average of 890 liters/s and a coefficient of variation (CV) of 37%. During the season, a significant amount of water in the river was allowed to spill over the dam, rather than to be diverted to the main canal through adjustment of the main gate. In contrast, the daily flow rate during the same period in 1987 fluctuated within a narrow range of 940-1,000 liters/s, with an average of 979 liters/s. Fluctuations of water delivery rate improved, as reflected in a lower CV of 10%.

The distribution of irrigation water between the two divisions improved significantly in 1987 DS over 1986 DS. In 1986, as water supplies from the dam increased through the season, most of the additional water was used in Division A (Fig. 4). Although Division A had an almost equal service area as Division B, it used on the average 77% of the total supply (789 liters/s) during February-March 1986. This inequity was due mostly to lack of physical control over water diversion by farmers through the official as well as extra turnouts, and to slack management. In 1987 DS, the average water diverted to Division A during December-February was about 56.5% of the total supply (490 liters/s), and the remaining 43.5% was used in Division B. But in the middle of February, after about a month of no significant rainfall, Division A farmers took advantage of their upstream location and diverted about 80% of the total supply. The improved equity of water supplies between Divisions A and B could thus be sustained by the farmers only in the first part of the season (Fig. 4).

The share of total planted area of Division B



4. Total water supply and its distribution between Divisions A and B. IRIS, Camarines Sur, Philippines, 1986 and 1987 DS.

increased from 43% in 1986 DS to 47% in 1987 DS. Irrigation water applied on the farm increased in 1987 DS by 38% in Division B and by 26% in Division A compared with 1986 DS. Despite a severe drought in 1987, average rice yields in 1987 DS were comparable to those in 1986 DS, but Division A farms produced on the average 0.7 and 1.3 higher yields per hectare than those of Division B in 1986 DS and 1987 DS. The higher water productivity values for Division B farms indicate that water was used more effectively there than on their counterparts in Division A (Table 4).

Within the entire service area, about 68% of the sample farms received adequate water during 1987 DS. Of these, about 58% of the farms that reported no other problems produced an average yield of 4.0 t/ha. About 13% of those with adequate water had significant pest and disease problems, and produced an average yield of 2.3 t/ha. About 29% of the farmers reported Zn deficiency problems, and 38% of those who applied ZnO to the seedlings obtained an average yield of 3.8 t/ha, which was about 0.6 t/ha higher than yields without Zn.

Farm productivity and income. The effects of improved irrigation water deliveries in 1987 on farm productivity and income were determined

Table 4. Area planted, water use, yield, and water productivity.[a] IRIS, Camarines Sur, Philippines, 1986 DS and 1987 DS.

Particulars	Division A	Division B	Total or average
Potential service area (ha)	646.5	743.1	1389.6
Area planted (ha)			
1986 DS	547.3	406.2	953.5
1987 DS	486.0	427.7	913.7
Total irrigation water (Ir) applied (mm)			
1986 DS	824.2	384.5	604.4
1987 DS	1040.1 (26%)	530.4 (38%)	785.2
Total rainfall (Rn) (mm)			
1986 DS	301.5	312.2	306.8
1987 DS	78.2	78.2	78.2
Total water use (Ir+ Rn) (mm)			
1986 DS	1125.7	696.7	911.2
1987 DS	1118.3	608.6	863.4
Average yield (t/ha)			
1986 DS	3.3	2.6	2.9
1987 DS	3.7	2.4	3.1
Water productivity (kg/mm)			
1986 DS	2.9	3.7	3.3
1987 DS	3.3	3.9	3.6

[a]Figures in parentheses indicate increased delivery in 1987 over 1986.

using "before-and-after" as well as "with-and-without" comparisons. For the before-and-after comparison, 1986 DS represented before and 1987 DS after. An adjacent area called the Bombon site, where water allocation and distribution in 1987 were not altered from the continuous flow method used during 1986, was used as the "without" site, and IRIS constituted the "with" site.

Low rainfall (78 mm in 1987 DS compared with >300 mm in 1986 DS) created a water shortage in the Bombon area; about 60% of the sample farmers reported water shortage in 1987 DS, compared with only 14% in 1986 DS. In contrast, 68% of the IRIS farmers sampled expressed satisfaction with their water status. The mean 1987 DS yield of saline farms with improved irrigation water delivery was significantly higher, about twice the yield of farms in Bombon (Table 5). On the nonsaline farms, the yield advantage of IRIS farmers over Bombon farmers was about 0.7 t/ha. The higher yields in the IRIS area could be attributed to improved water allocation and distribution, complemented by the operation of the flap gates at the mouth of a major drainage creek to control saltwater intrusion.

The production inputs used were similar at the two sites, except that at the IRIS site farmers used significantly more labor for hand weeding. In 1987 DS, both saline and nonsaline farms in IRIS showed significantly higher gross margins from rice production than Bombon farms. The difference was much higher for saline farms (Table 5).

The before-and-after comparison within IRIS

Table 5. Mean yields and farmers' gross margins on saline and nonsaline farms, with and without improved irrigation water deliveries.[a] IRIS, Camarines Sur, Philippines, 1987 DS.

Parameter	Saline			Nonsaline		
	With	Without	Difference	With	Without	Difference
Mean yield (t/ha)	2.4	1.1	1.3*	3.4	2.7	0.7*
Value of output ($/ha)	324	145	179*	461	368	93*
Total variable cost ($/ha)	239	189	50+	266	225	41*
Gross margin ($/ha)	85	(44)	129+	195	143	52+

[a]Exchange rate: $1 = ₱20. Differences were significant at the 5% (*) and 10% (+) levels by t-test.

indicates that the yields in 1987 DS were generally sustained at the 1986 level despite the low 1987 rainfall. The average yield of Division A nonsaline farms was significantly higher in 1987 (Table 6). The yield decrease of 0.6 t/ha on saline farms in 1987 can be attributed to the water shortage after February, and to pest and disease problems reported by more than 30% of Division B saline area farmers.

Inputs used during the 2 seasons were not significantly different, except for N, which was more used in 1987 in both saline and nonsaline farms of Division A (about 10 kg N/ha higher than in 1986). The gross margin of nonsaline farms increased significantly in 1987 DS compared with that in 1986 DS (Table 6).

The improved water management in 1987 DS allowed IRIS farmers to avoid a yield loss of about 1.0 t/ha that would have otherwise occurred from the combined effects of low rainfall, inequitable irrigation water deliveries, and related salinity problems.

FLOOD-PRONE ENVIRONMENT AND RICE PRODUCTION IN BICOL

Water Management and Plant Breeding Departments

Characterizing the flood-prone environment (*Water Management*). The Bicol River basin of the Philippines has an area of about 312,000 ha, of which about 30% is riceland. About 40,000 ha of low-lying areas in Camarines Sur Province, most of which is planted to rice, is subject to flooding. Farmers suffer crop losses due to generally unpredictable inundation. Despite high risks, rice farming is the main source of livelihood, and incomes are very low. Research in cooperation with the Bicol River Basin Development Program has aimed at developing a methodology to characterize rice areas under flood-prone conditions with respect to flooding hazard, both in terms of the area affected and the severity of inundation.

Flooding hazard categories. The Lake Baao and Bato sub-basins, which together cover around 12,000 ha of flood-prone area within the Bicol River basin, were studied to quantify the flooding hazard in rice culture. About 5,000 farmers cultivate the area. Data of 14 yr (1974-87), the Bicol River hydrograph at the Nabua gauging station, and records of flooding showed that significant flooding of the ricefields occurred at or above 7 m river stage. Flooding hazard was categorized as 1) *mild* with river stage between 7 and <8 m, 2) *extensive* with 8 to <9 m, and 3) *severe* with 9 m or above. On the average, about two floods are expected every year, although as many as four have occurred in a single year. Mild floods are more frequent than extensive or severe floods (Table 7). July is the most frequent month for mild floods, followed by August and November. More extensive floods occurred in November than in any other month. All severe floods occurred in September or later in the year.

Table 6. Mean yields and farmers' gross margins (at 1987 constant prices) on saline and nonsaline farms before and after improved water deliveries.[a] IRIS, Camarines Sur, Philippines, 1986-87.

Parameter	Saline		Nonsaline	
	Division A	Division B	Division A	Division B
	1986 DS (before)			
Mean yield (t/ha)	3.0	2.7	3.3	2.4
Value of output ($/ha)	425	368	439	328
Total variable cost ($/ha)	286	258	288	241
Gross margin ($/ha)	139	110	151	87
	1987 DS (after)			
Mean yield (t/ha)	3.2	2.1	3.8+	2.6
Value of output ($/ha)	431	267	523*	346
Total variable cost ($/ha)	268	230	290	228
Gross margin ($/ha)	163	37	233*	118

[a]Exchange rate: $1 = ₱20. Significant at the 5% (*) and 10% (+) levels by t-test.

Table 7. Number of floods based on 3 categories of peak water stage measured in the Bicol River at the Nabua gauging station, Camarines Sur, Philippines, 1974-87.

Year or month	Floods (no.) under each category[a]			Total (no.)
	Mild (7 m to <8 m)	Extensive (8 m to <9 m)	Severe (9 m or above)	
1974	3	1	0	4
1975	0	0	1	1
1976	1	0	1	2
1977	3	0	0	3
1978	2	1	0	3
1979	0	0	1	1
1980	0	1	0	1
1981	2	2	0	4
1982	0	1	1	2
1983	1	1	0	2
1984	1	0	0	1
1985	0	0	1	1
1986	2	0	0	2
1987	2	1	1	4
Total	17 (1.21)	8 (0.57)	6 (0.43)	31 (2.21)
May	0	0	0	0
Jun	1 (0.07)	1 (0.07)	0	2 (0.14)
Jul	4 (0.29)	2 (0.14)	0	6 (0.43)
Aug	3 (0.21)	0	0	3 (0.21)
Sep	2 (0.14)	1 (0.07)	2 (0.14)	5 (0.36)
Oct	2 (0.14)	0	1 (0.07)	3 (0.21)
Nov	3 (0.21)	3 (0.21)	1 (0.07)	7 (0.50)
Dec	2 (0.14)	1 (0.07)	2 (0.14)	5 (0.36)

[a]Numbers in meters indicate the range above mean sea level of the river stage associated with the flood category. Numbers in parentheses indicate annual frequency of occurrence.

Recurrence interval and area affected. From available data on extreme flood events recorded at the Nabua gauging station for the past 28 yr (1960-87), the recurrence intervals (RI) of the events were determined. The river stage at Nabua (RSN) and RI were related through the equation

$$RSN = 7.4426 + 2.614 \log (RI) \quad (r^2 = 0.88^{**})$$

The relationship between RSN and the floodwater elevations in the field (FWF) was examined for 1985-87, during which flooding depths were monitored at four sites and their elevations above mean sea level determined. The relationship between FWF and RSN is expressed by the regression equation:

$$FWF = -0.4897 + 0.9783 (RSN) \quad (r^2 = 0.98^{**})$$

The topographic map was used to delineate and measure the area that was submerged because of different FWFs. The equation relating area flooded (AF) with FWF is

$$AF = -6615.40 + 2307.22 (FWF) \quad (r^2 = 0.99^{**})$$

This area includes the DS residual areas in the Baao and Bato Lakes, totaling about 3,100 ha, which are mostly underwater and not used for cropping.

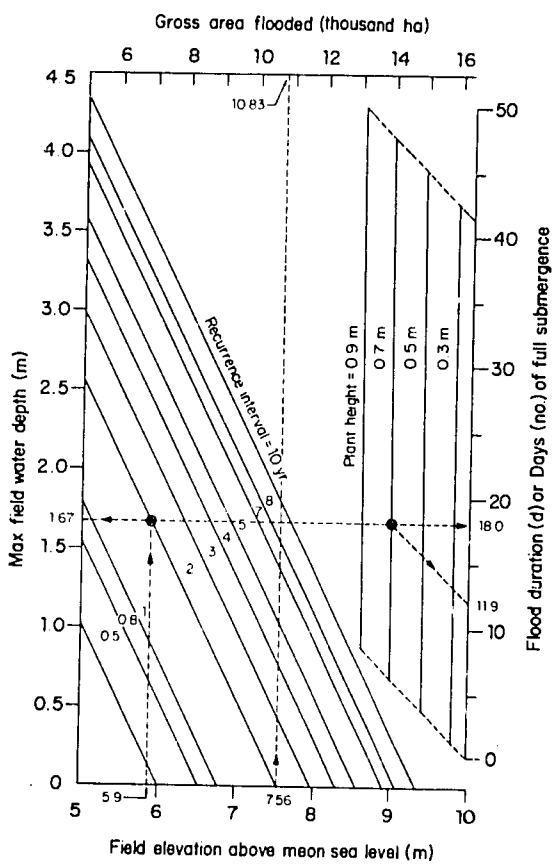
It was previously established that floodwater rise is generally sharp and closely follows heavy rainfall in the catchment area. The floodwater recession rate, which is of critical importance in determining the period of ricefield submergence and the degree of crop damage, was measured with staff gauges at four observation points during 1985-87. The average recession rates for the FWFs were 1) 8 m or higher, 8.2 cm/d; 2) 7 m to <8 m, 6.6 cm/d; 3) 6 m to <7 m, 7.2 cm/d; and 4) <6 m, 3.6 cm/d.

A predictive model. The above information and relationships were used to develop a computer

model for determining flooding depths and durations for different field elevations, areas, and periods of submergence of crops of given heights in the field for floods of varying severity. Using the model, a user nomograph was developed to estimate the effects of flooding (Fig. 5). For example, a flood with a 2-yr recurrence interval will cause the following:

- Field elevation affected = 7.56 m or lower
  Gross area flooded = 10,830 ha
- For a farm with field elevation of 5.90 m
  Maximum field water depth = 1.67 m
  Flood duration = 18.0 d
  If plant height is 0.70 m, the period of complete submergence = 11.9 d

Combining the information in Table 7 and the nomograph, the risk associated with rice cropping



5. Nomograph developed for determining the extent of flooded area caused by flooding of various recurrence intervals, maximum water depths, durations, and periods of crop submergence at chosen field locations. Bicol River basin, Philippines, 1987.

using various planting dates can be determined in areas of given elevation. The model can be used for other flood-prone areas by adjusting the basic parameters to local hydrologic conditions. It can also be expanded to estimate rice yield and production losses caused by flooding.

Performance of varieties under excess water conditions (*Water Management and Plant Breeding*). *Field testing of selected rices.* Several varieties and lines were tested under farmers' field conditions in the flood-prone areas of the Bicol River basin in 1986 WS (Table 8). Of the IR varieties and lines at the flooded sites (Group II farms), farmers' selections produced the highest average yield, 2.8 t/ha, followed by IR31142-14-1-1-3-2 at 2.5 t/ha; that indicates that farmers are skilled in choosing varieties for their conditions. At flooded site 4, varieties that were submerged fully for a total of 4 d—2 d at 43 d after transplanting (DT) and 2 d at 47 DT—and partially for 6 d gave the lowest yields. However, at this site with the worst submergence conditions, an IR breeding line (IR31142-14-1-1-3-2) bred for just such conditions was the best yielder among modern variety entries from IRRI.

Four varieties and lines that looked promising from the 1986 WS data were tested along with farmers' varieties in 1987 WS in Baao fields with varying elevations. Flooding occurred in mid-July, and crops were submerged at 32 DT to varying depths of floodwater depending on the elevation of the test site. With 0-4 d of full submergence and up to 3 d of partial submergence, most varieties did well. IR64 gave the highest average yield (4.8 t/ha): yields of farmers' choices averaged 0.5 t/ha less (Table 9). At the 5.83-m-elevation site, where the crops were submerged for a significant period but not long enough to completely destroy them, IR31142-14-1-1-3-2 performed best. But all varieties rotted in the field and produced no yield at the lowest-elevation site, where they were submerged completely for 6 d and partially for 2 d (Table 9). Crops submerged for longer (at elevations 6.06 m and lower) took up to 3 wk longer to mature. The 3 lines that produced average yields between 3.6 and 4.3 t/ha matured about 15 d later than the early-maturing IR64.

Crop-cut yields were taken from farmers' fields with elevations from 5.78 m to 7.04 m above mean

sea level, which were flooded in July 1987. As at the test sites, yields from sites that were completely submerged up to 4 d at 27-36 DT were comparable to yields at unflooded sites, but the yield of IR36 at 1 site that was completely submerged for 4.5 d and partially for another 3 d was only 1.7 t/ha (Table 10). When partial submergence occurred at a late stage, e.g., at 65 DT, rice yields were significantly lower than those after partial submergence at an earlier stage.

Experiment in controlled water regimes. The 1986 and 1987 WS observations and findings were used to design an experiment aimed at quantifying the relationships between rice yield loss and various

Table 8. Yield response (t/ha) of varieties and lines tested in flood-prone areas of Camarines Sur, Philippines, 1986 WS. Group I farms were not flooded during the season.

Parameter	Group I farms				Group II farms				
	1	2	3	Mean[a]	1	2	3	4	Mean[b]
Days (no.) of submergence									
Full	–	–	–	–	1	1,0	0	2,2	
Partial[c]	–	–	–	–	1	5,2	2	2,4	
Occurrence of flood (DT)[d]	–	–	–	–	26	42,98	41	43,47	
				Yield (t/ha)					
IR varieties									
IR36	2.0	2.2	3.5	2.6	2.8	0.8	2.5	[f]	2.0
IR64	2.3	1.5[e]	0.7	2.8	3.4	1.9	1.4	1.2	2.0
Submergence-tolerant breeding lines									
IR5853-198-1-2-1E-P1	2.9	1.0	3.7	2.5	3.1	1.4	3.0	0.7	2.0
IR21071-53-2-3-2E-P2	–	2.2	0.9[g]	1.6	2.1	1.4	2.1	0.7	1.6
IR26708-2-2-3-1-1	–	3.6	2.9	3.3	3.3	1.4	1.2	1.8	2.1
IR31142-14-1-1-3-22	2.9	5.9	7.4	5.4	2.7	1.6	3.3	2.3	2.5
IR31406-333-1	2.3	1.8	2.2	2.1	3.3	1.8	1.8	1.0	2.0
Farmer's variety[h]	1.8 (IR64)	2.7 (ES)	3.5 (ES)	2.7	3.1 (ES)	2.5 (S)	3.3 (IR64)	2.3 (IR58)	2.8

[a]Means of 2 farms not included. [b]Means not significantly different at the 5% level by DMRT. [c]Submergence began at full plant height and receded to 30% of plant height. [d]DT = days after transplanting. [e]100% lodging. [f]Damaged completely by rats. [g]Damaged by rice bugs. [h]ES = Early Senador, S = Sampaguita.

Table 9. Days of submergence[a] and yield response of varieties and lines[b] tested in Baao, Camarines Sur, Philippines, 1987 WS.

Parameter	Elevation (m above mean sea level)						Mean yield[c]
	7.01	6.56	6.55	6.06	5.83	5.64	
Submergence (d)							
Full	0	0	0	3	4	6	
Partial	0	2	2	2	3	2	
Entries			*Yield (t/ha)*				
IR64	4.5	5.1	4.2	5.4	4.6	0	4.8 a
IR5853-198-1-2-1E-P1	3.9	4.2	3.7	3.7	2.6	0	3.6 b
IR26708-2-2-3-1-1	3.4	3.8	3.8	3.5	3.7	0	3.6 b
IR31142-14-1-1-3-2	3.6	3.9	4.0	4.0	6.1	0	4.3 a
Farmers' variety	4.6 (IR60)	4.3 (RI10)	4.5 (77-d)	4.9 (RI10)	3.1 (RI10)	0 (RI10)	4.3 a
Mean[d]	4.0	4.2	4.0	4.3	4.0	0	

[a]Flood occurred at 32 d after transplanting. [b]Mean of 3 replications. [c]Excluding elevation 5.64 m yields. [d]No significant difference among means up to the 5% level by DMRT.

Table 10. Yields of farms adjacent to trial sites in Baao, Camarines Sur, Philippines, 1987 WS.

Elevation (m above mean sea level)	Variety	Days of submergence		Time of flooding (DT)[b]	Yield[c] (t/ha)
		Full	Partial[a]		
7.0	IR60	0	0	–	4.0
7.0	IR60	0	0	–	4.9
6.9	RI10	0	0	–	4.3
6.9	RI10	0	0	–	4.2
6.9	RI10	0	0	–	5.3
6.8	IR36	0	0	–	3.8
6.6	ES	0	2	27	3.5
6.6	IR32	0	2	24	2.6
6.6	RI10	0	2	34	4.9
6.6	RI10	0	2	32	5.2
6.5	RI10	0	2.5	34	4.6
6.4	IR36	0	3	34	3.3
6.3	RI10	1	2.5	32	4.6
6.3	RI10	1	3	36	4.4
6.0	IR60	2.5	3	65	2.3
6.0	RI10	3	3	36	4.6
5.9	IR60	3	3	65	2.1
5.9	RI10	4	2.5	36	4.5
5.8	IR36	4.5	3	36	1.7

[a]Submerged to 30% of plant height. [b]DT = days after transplanting. [c]Mean of two 5-m² crop-cut samples from each farm.

degrees of "mild" to "extensive" flooding that frequently occur in the Bicol River basin area. The experiment was conducted at IRRI in a concrete tank in the glasshouse, where water level was completely controlled. IR64 and IR31142-14-1-1-3-2 were grown August to November 1987, and subjected to varying degrees of excess water conditions (Table 11).

IR64 lost 74% of its potential yield when submerged for 4 d (1 d of rising water, 2 d of complete submergence, and 1 d of receding water) after the majority of tillers had flowered. In contrast, IR31142-14-1-1-3-2 lost about 45% of its potential yield (Table 11). For earlier occurrence of submergence in IR31142-14-1-1-3-2, the highest yield reduction (45%) occurred with 12 d of "fully submerged" condition starting at 30 DT. For IR64, it occurred with 8 d of the same treatment at 45 DT, with 51% yield reduction.

For most of the treatments, IR31142-14-1-1-3-2 outyielded IR64 (Fig. 6). Unlike those of IR64, yields of IR31142-14-1-1-3-2 were not significantly reduced by the various "half-submerged" treatments (Table 11). For "fully submerged" treatments, the results were mixed. Significant yield reductions occurred in IR64 when submerged for the various durations at 45 DT, 15 and 45 DT, and 30 and 45 DT. IR64 yield reductions were also significant with fully submerged treatments at 15 DT for 8- and 12-d durations and at 30 DT for a 12-d duration. For IR31142-14-1-1-3-2, no significant yield reductions occurred for any of the fully submerged treatments other than the 12-d duration treatments at all DT values and the 8-d duration treatment at 15 and 45 DT. This variety performed better than IR64 under submerged conditions. Under the no-submergence control condition, yields of both were very close (6.6 t/ha for IR64 and 6.4 t/ha for IR31142-14-1-1-3-2).

POLLUTION EFFECTS ON IRRIGATION WATER QUALITY AND RICELAND PRODUCTIVITY

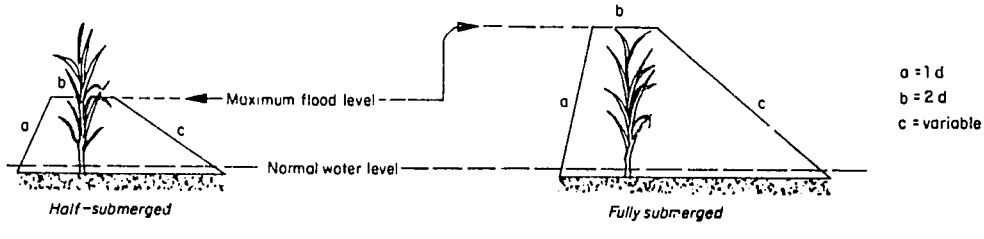
Water Management Department

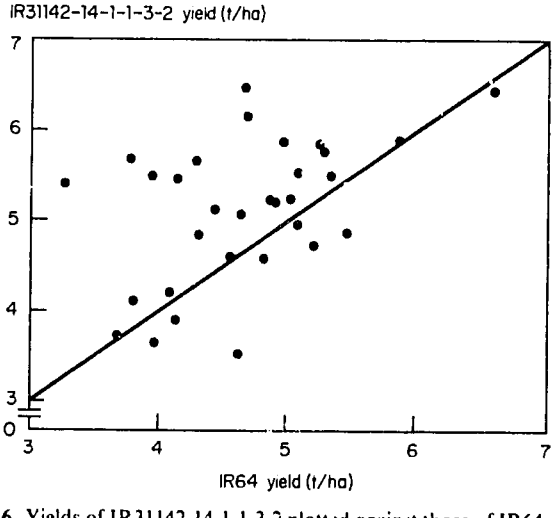
Mine tailings from several copper and gold mines in the Agno River watershed in northern Luzon, Philippines, have been known to pollute the river water. Detention dams are used to control inflow of the mine tailings into the river water diverted for

Table 11. Relative yields obtained from 2 rices at different levels of excess water conditions. IRRI, 1987.

Treatments		Relative yield[b]			
Crop stage (DT)[a]	Duration of submergence (d)	IR64	IR31142-14-1-1-3-2	IR64	IR31142-14-1-1-3-2
–	0	100.0	100.0	100.0	100.0
		Half-submerged[c]		*Fully submerged*[c]	
15	4	78	82	82	86
	8	73	71	67	77
	12	68	82	62	63
30	4	71	83	80	91
	8	89	94	83	77
	12	79	91	70	55
45	4	74	85	62	86
	8	80	73	49	85
	12	65	88	62	65
15 & 45	4	75	82	62	84
	8	58	89	58	64
	12	77	93	61	58
30 & 45	4	78	88	71	76
	8	72	106	78	78
	12	70	95	57	58
Flowering	4	–	–	26	55

[a]DT = days after transplanting. [b]Relative yield was based on actual yields of 6.6 t/ha for IR64 and 6.4 t/ha for IR31142-14-1-1-3-2 under nonsubmerged conditions. Least significant difference with respect to nonsubmerged yields was 22.8% for IR64 and 28.3% for IR31142-14-1-1-3-2. [c]"Half-submerged" and "fully submerged" treatments are described as follows:

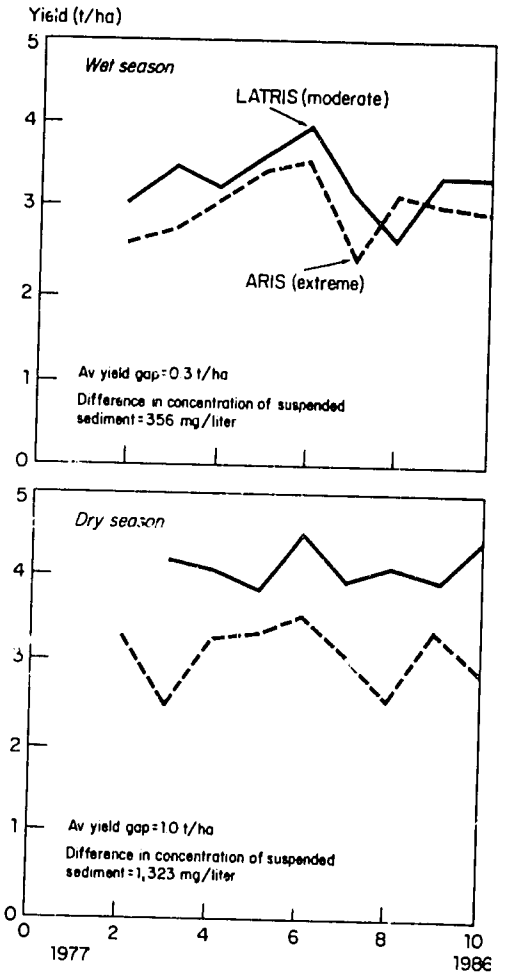




6. Yields of IR31142-14-1-1-3-2 plotted against those of IR64. IRRI, 1987 WS.

rice irrigation, but high concentrations of sediment, mixed with mine tailings, are deposited on the ricelands and canals of the Agno River Irrigation System (ARIS), which has a total service area of about 20,000 ha. The primary objective of this study was to assess the possible impact of continuous sedimentation on riceland productivity in ARIS. The study entailed a comparison of areas in ARIS with those in the adjoining Lower Agno-Totonoguen River Irrigation System (LATRIS), which also receives water from the Agno River, downstream of ARIS, but water mixed with clear water from the Totonoguen Creek; consequently, LATRIS (service area = about 7,500 ha) water has a low concentration of sediments.

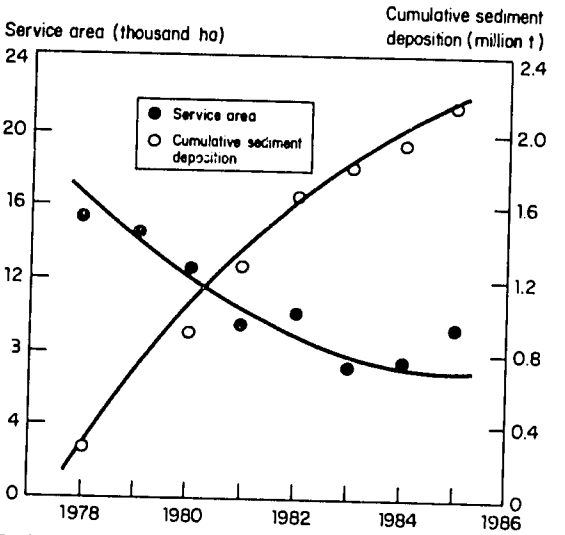
The irrigation waters from 1987 DS were analyzed for suspended sediments, salinity, alka-



7. Average rice yields in WS and DS in 2 adjacent irrigation systems receiving "extreme" and "moderate" concentrations of sediment pollution into their service areas, 1987. ARIS = Agno River Irrigation System, LATRIS = Lower Agno-Totonoguen River Irrigation System.

linity, B, and Cu. All values were within accepted safe limits for rice irrigation, except for the concentration of suspended sediments, which was 1,540 mg/liter in ARIS and 216 mg/liter in LATRIS waters. An acceptable value is about 100 mg/liter.

Because of the higher concentration of suspended sediments, the sediment deposition rates were much higher in the ARIS service area. In 1987, each hectare of ARIS ricefield received about 56.5 t of sediment. In contrast, LATRIS riceland received



8. Cumulative suspended sediment inflow and declining service area. ARIS, Pangasinan, Philippines, 1978-85.

only about 9.5 t/ha. The topsoil in the ARIS service area is relatively low in N (0.10%) but high in Cu (36.8 ppm) compared with the LATRIS deposits, which had 0.12% N and 0.7 ppm Cu. Higher Cu concentration in the ARIS soil is caused by a higher sediment concentration in the irrigation water. Cu concentration in the ARIS irrigation water (0.03 ppm) was 50% higher than that in the LATRIS water. LATRIS soil had higher P (8.4 ppm) than ARIS soil (1.3 ppm), but ARIS soil had about 2 times higher K (0.5 meq/100 g).

The high rate of sedimentation may be lowering the productivity of the ARIS service area. The yields of ARIS in both seasons are lower than those of LATRIS, but the difference is much greater in DS, when the concentration of suspended sediment is significantly higher in ARIS (Fig. 7).

The high sediment concentration in ARIS water caused continuously heavy depositions in the irrigation canals. Over the years, this process has caused reduced flow capacities in irrigation canals and abandonment of some. Consequently, the service area has significantly declined during the past several years (Fig. 8), despite the regular desilting work done through the annual maintenance schedule to clear the canals of sediments.

Soil and crop management

Soil characterization

Soils Department

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AMENDING AN ACID SULFATE SOIL

We studied the effect of topsoil leaching on soil solution kinetics and nutrient uptake of rice in an acid sulfate Sulfaquept soil (Table 1) from Aparri, Cagayan, Philippines. This factorial experiment in the greenhouse used 3 levels of leaching, 2 levels of P (25 and 50 kg P/ha), and 2 levels of lime (0 and 500 kg $CaCO_3$/ha).

Soil was soaked with either brackish or demineralized water and leached after 24 h. Leaching with brackish water was followed by leaching with demineralized water until the electrical conductivity (EC) of leached water was about 3.7 dS/m. The chemical properties of leached water appear in Table 2. Because of enhanced cation exchange, brackish water leached more Al, Fe, and Na than did demineralized water.

IR36 was planted in 16-liter glazed porcelain pots containing 3 kg of original air-dried soil overlain with 3 kg of treated soil. All treatments were presubmerged for 15 d. Lime was added before flooding, and P was applied 1 d before transplanting. Urea at 60 kg N/ha was added in 3 equal splits: basal, 15 d after transplanting (DT), and before panicle initiation.

Leaching and liming increased the soil pH (measured at 3-cm depth), but P application did not. Soil pH ranged from 4.5 to 5.1 at 12 wk after submergence. Initial soil solution pH (3.2) was not affected by any treatment but increased more rapidly (up to 5.4) in leached soils.

Soil Eh decreased to -88 mV by 12 wk after submergence but was not affected by the treatments. Soil solution Eh remained positive in all treatments, and only leaching lowered it.

The average EC of soil solution ranged from 7.1-7.5 dS/m at 1 d after submergence to 2.9-4.1 dS/m at 12 wk after submergence. The slow decline was caused by dilution and formation of metal ions and NH_4^+. The subsequent rapid decline might have been caused by the precipitation of metal ions, conversion of $RCOO^-$ to CH_4, and plant uptake. ECs of leached soils were lower. Lime and P application did not affect soil solution EC.

Fe in the soil solution was above the toxic level (300 mg/liter) throughout the experiment in all treatments. Water-soluble Fe increased sharply to 1900 mg/liter at 4 wk after submergence and declined rapidly to 500-900 mg/liter because of precipitation as sulfide and hydroxide. Leaching lowered Fe concentration. Water-soluble Mn was highest at 1 d after submergence (16 mg/liter) and declined gradually to 2.8-5.4 mg/liter by 12 wk after submergence. Leaching with either brackish or demineralized water reduced Mn faster than in the control. In all treatments, water-soluble Al^{3+} decreased sharply from 29 mg/liter to 3 mg/liter in the first 2 wk. At 12 wk after submergence, Al declined to 0.3 mg/liter.

SO_4^{2-} in the soil solution was highest immediately after submergence (5700 mg/liter). Gradual decline was related to the formation of S^{2-} and the precipitation of metal sulfides. Leaching lowered SO_4^{2-} to 1900 mg/liter at 12 wk after submergence. Lime and P application had no effect.

Zn in the soil solution decreased sharply from 1.9 to 0.1 mg/liter the first 4 wk and was as low as 0.02 mg/liter at 12 wk after submergence, probably because of the formation of Zn sulfides and hydroxides, reactions with soluble silica, and plant uptake. No treatment affected the kinetics of water-soluble Zn.

In all treatments, soil solution P decreased sharply the first 4 wk because of the high P-fixing capacity of the soil. Leaching lowered P throughout

Table 1. Properties of the topsoil (0-20 cm) of an acid sulfate soil from Dodan, Aparri, Cagayan, Philippines. IRRI greenhouse, 1987.

pH (H_2O 1:1)	3.0
EC_e (dS/m)	8.1
Organic C (%)	5.63
Total N (%)	0.43
CEC (meq/100 g soil)	53
Exchangeable Na (meq/100 g)	5.38
Exchangeable K (meq/100 g)	0.41
Exchangeable Mg (meq/100 g)	12.78
Exchangeable Ca (meq/100 g)	2.19
Exchangeable SO_4^{2-} (%)	0.74
Available P (Olsen) (mg/kg)	3.11
Available Zn (mg/kg)	4.3
Available Cu (mg/kg)	0.19
Available B (mg/kg)	6.5
Active Fe (%)	0.74
Active Mn (%)	0.014
Exchangeable Al (meq/100 g)	3.77
Exchangeable acidity (meq/100 g)	9.00

Table 2. Concentrations of elements in sequential leachates[a] of a Sulfaquept. IRRI, 1987.

Sequence	Concentration of elements											
	N	P	K	Fe	Al	SO_4^{2-}	Ca	Mg	Na	Zn	Mn	Cu
					Leaching by brackish water							
1st	5.27	0.05	12.5	102	16.04	3276	396	642	848	0.90	7.95	0.0
2d	6.44	0.05	11.7	175	33.30	2720	332	548	709	0.91	6.81	0.0
3d	6.15	0.03	10.3	166	6.89	2156	273	420	432	0.51	5.41	0.0
4th	5.47	0.03	8.3	146	4.54	1280	218	343	475	0.53	4.00	0.0
5th	3.92	0.02	6.4	110	2.25	1053	152	201	294	0.34	2.51	0.0
Total	27.25	0.19	49.14	700	63.02	10436	1371	2154	2759	3.19	26.68	0.0
					Leaching by demineralized water							
1st	6.38	0.07	10.9	87	13.80	2845	369	563	512	0.89	6.97	0.0
2d	8.09	0.07	11.3	18	9.58	2521	334	546	488	0.94	7.00	0.0
3d	5.91	0.03	8.3	157	5.78	2080	239	368	257	0.63	4.79	0.0
4th	5.50	0.03	7.4	126	4.14	1355	217	351	301	0.54	4.03	0.0
5th	4.46	0.03	5.9	114	2.39	1087	160	219	200	0.37	2.68	0.0
Total	30.34	0.22	43.8	502	35.64	9887	1319	2047	1759	3.37	25.47	0.0

[a]Mean of 12 replications.

the experiment. Lime and P application did not affect P concentrations in the soil solution.

NH_4^+ peaked at 24 mg/liter at 4 wk after submergence. Leaching resulted in lower peaks and faster decline.

Ca^{2+} and Mg^{2+} in the soil solution declined gradually, while Na^+ increased slightly during the first 2 wk, declined sharply until 4 wk after submergence, and decreased gradually thereafter. Leaching lowered Ca^{2+}, Mg^{2+}, and Na^{2+}, while lime and P application had no effect.

Soil solution kinetics revealed adequate nutrients for normal growth except for P deficiency and Fe toxicity. Leaching and high P application lowered N, P, and K in 6-wk-old shoots. At maturity, total uptakes of N, P, K, Mg, Ca, Na, and Zn were higher in leaching and high P treatments. Leaching and high P application gave the highest straw and grain yields. Brackish water leaching was not superior to leaching with demineralized water.

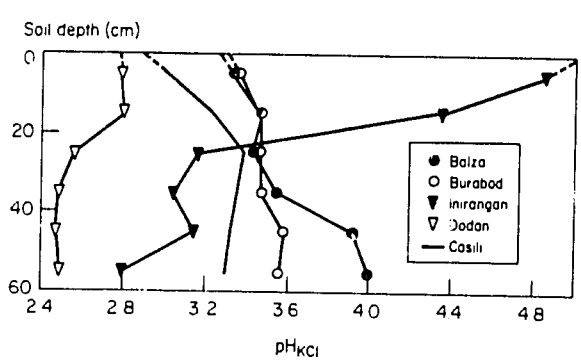
POTENTIAL FOR WETLAND RICE CULTIVATION ON PHILIPPINE ACID SULFATE SOILS

Field and greenhouse studies characterized the physical, chemical, and morphological properties of five Philippine acid sulfate soils (Figs. 1-7). The acid sulfate soils in Dodan (Sulfaquept), Casili (Sulfaquept), and Inirangan (Sulfic Tropaquept) developed in marine floodplains and tidal marshes, while those in Balza and Burabod (both Sulfaquepts) developed from sediments associated with volcanic S emanations.

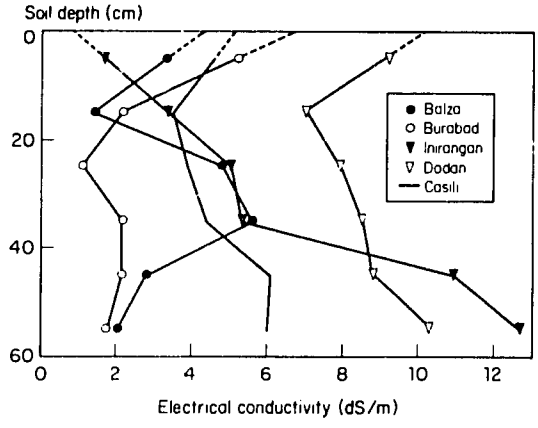
Topsoil textures vary from sandy to clayey, with clay contents of 8% in Balza, 16% in Burabod, 40% in Dodan, 55% in Inirangan, and 73% in Casili.

Field studies showed Al toxicity and P deficiency during the early vegetative phase of rice and Fe toxicity at maximum tillering. Plant analyses showed toxic levels of Fe and Al, high Fe:Mn ratios, and low P and N levels.

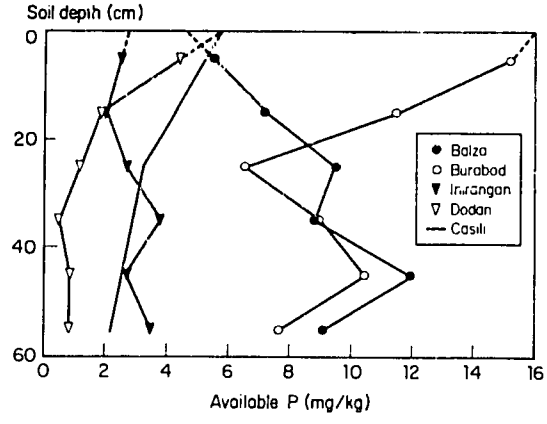
More severe plant injuries were observed in the wet season (WS) than in the irrigated dry season (DS), apparently because of extreme soil acidifica-



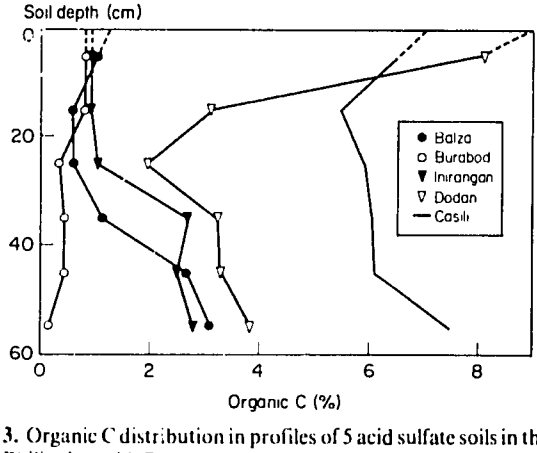
1. Soil pH at various mean depths of 5 acid sulfate soils in the Philippines, 1987.



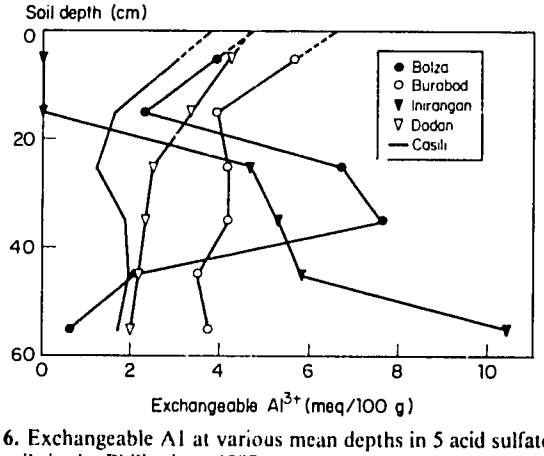
2. Electrical conductivity of soil saturation extracts at various mean depths of 5 acid sulfate soils in the Philippines, 1987.



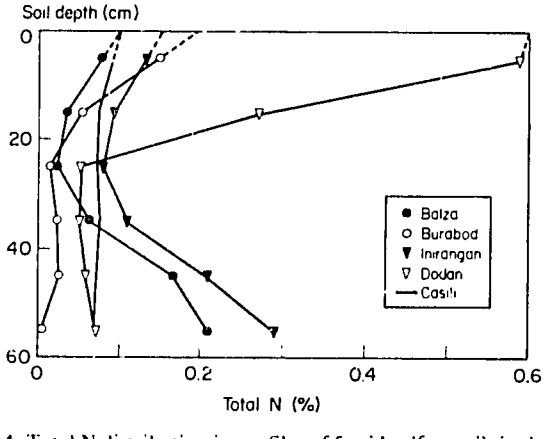
5. Available P (Olsen) at various depths in 5 acid sulfate soils in the Philippines, 1987.



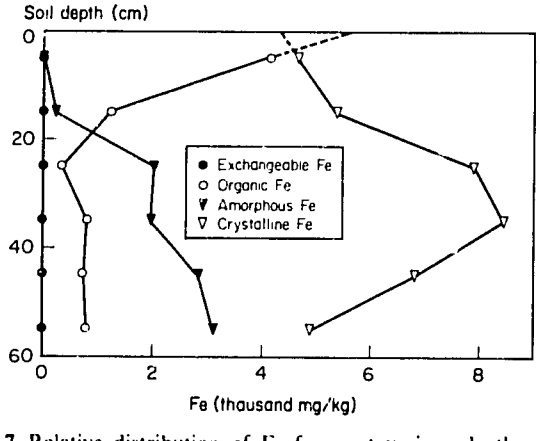
3. Organic C distribution in profiles of 5 acid sulfate soils in the Philippines, 1987.



6. Exchangeable Al at various mean depths in 5 acid sulfate soils in the Philippines, 1987.



4. Total N distribution in profiles of 5 acid sulfate soils in the Philippines, 1987.



7. Relative distribution of Fe forms at various depths of Dodan soil, 1987.

tion (pyrite oxidation) in dry periods preceding WS cropping.

Lime requirements based on incubation methods and total exchangeable acidity of the topsoil are 7-8 t/ha for Balza, 5-12 t/ha for Burabod, 13-18 t/ha for Dodan, and 11-16 t/ha for Casili. No lime amendment is needed in Inirangan (pH 5.5).

The following chemical and physicochemical properties of the soil solutions were observed:

- Topsoil solution pHs of the Sulfaquepts immediately after flooding were low (3.2-4.0) and increased only gradually to 5.6 by 14 wk after submergence. At 30-50 cm depth, pH remained almost constant except in sandy Balza soil.
- Soil solution Eh decreased gradually after submergence but was still above +100 mV at 14 wk after submergence. Except in Balza, the Eh decrease at lower soil depth was less than in topsoil.
- Water-soluble NH_4^+, K^+, Ca^{2+}, and Mg^{2+} increased in the topsoil up to 6 wk after submergence and decreased thereafter.
- Soil solution P, Al, and Zn decreased with submergence in the topsoil.
- Water-soluble Fe^{2+} in Balza, Dodan, and Casili increased to toxic levels (up to 1,800 mg/liter) in the topsoil after submergence. Increases in subsoils were less or delayed except in the Inirangan Sulfic Tropaquept. Mn concentration followed the Fe pattern but at much lower levels (0.5-10 mg/liter).
- Very high concentrations of SO_4^{2-} were observed. SO_4^{2-} increased up to 3,800 mg/liter in the Dodan topsoil at 4 wk after submergence. The concentration in the subsoil was 8,000 mg/liter at 14 wk after submergence.

The interaction of soil and variety was highly significant. Grain yields of IR42 were higher than those of IR36 in all soils except in Balza, where severe adverse soil factors killed IR42 during the vegetative phase. IR42 showed higher panicle number, grain yield, and straw yield, while IR36 had higher percentages for productive tillers and grain filling.

Yields reflected site-specific adaptabilities. IR8236-464-3-3 yielded >3 t/ha during WS, while IR9764-45-2-2 and IR19431-22-2 yielded >5 t/ha in DS in farmers' fields in Balza and Burabod.

Field amelioration studies in Balza and Burabod ascertained the beneficial effects of lime and MnO_2 on rice growth, nutrition, and yield. Residual effects of lime (5 t/ha) persisted for 2 consecutive croppings.

EFFECT OF CONTINUOUS CROPPING AND WATER QUALITY ON AVAILABLE ZINC IN ZINC-DEFICIENT SOILS IN THE PHILIPPINES

A 4 × 2 factorial experiment with 4 Zn-deficient soils (Table 3) as main plots and with varieties as subplots was set up with 4 replications in the greenhouse over a 10-yr period.

Two rice crops were grown each year in 10 kg of soil in 16-liter porcelain pots. Varieties were IR34 (tolerant) and IR26 (moderately susceptible). Soils were fertilized each season with 50 mg N/kg as urea, 25 mg K/kg as muriate of potash, and 25 mg

Table 3. Properties of Zn-deficient Philippine soils under field conditions. IRRI, 1987.

Property	Tiaong (Lipa clay loam)	Luna (clay)	Laguna (Lam-aw peat)	San Pablo (Lipa clay)
pH	7.9	7.7	5.8	6.8
Organic matter (%)	11.5	1.81	36.8	4.36
Total N (%)	0.47	0.14	1.96	0.24
Available P (mg/kg)	11	120	9	54
Exchangeable K (meq/100 g)	1.14	0.24	0.53	0.70
Exchangeable Ca (meq/100 g)	27.2	17.5	41.8	18.3
Exchangeable Mg (meq/100 g)	13.3	3.7	17.1	2.6
Exchangeable Na (meq/100 g)	2.5	0.5	0.6	1.0
Total Zn (mg/kg)	46	134	109	85
Available Zn (0.05 *N* HCl) (mg/kg)	0.12	0.26	0.44	0.16

P/kg as solophos. The soils were kept submerged with demineralized water and dried by evaporation between crops. Zn availability was monitored every 2 yr.

After 10 yr of continuous cropping, total Zn did not change significantly. HCl-extractable Zn was increased by extensive cropping except in the Lipa clay loam (Table 4). In the field, available Zn did not change. Ten years of double lowland rice cropping with dry fallow, returning stubble and roots to the soil, and irrigating with demineralized water lowered the soil pH (Table 5).

The pH decrease increased available Zn except in the Lipa clay loam. In the field, irrigation water salts likely kept the pH at higher levels, lowering Zn availability. Drying soils during fallow may have influenced pH and Zn availability.

Increased Zn deficiency in farmers' fields after double lowland rice cropping is caused, not by Zn depletion in soil but by insufficient drying between crops and prolonged irrigation with water high in bases.

KINETICS OF IRON AND MANGANESE IN FLOODED SOILS

To understand the transformations of Fe and Mn under flooded conditions, we studied the kinetics of the soil solutions of 4 soils planted to IR36 (Luisiana, Tropudult, pH [H_2O] 4.5, OC 2.4%, cation exchange capacity [CEC] 19.6 meq/100 g, clay; Maahas, Tropudalf, pH [H_2O] 6.6, OC 1.7%, CEC 35.7 meq/100 g, clay loam; Pila, Tropaquept, pH [H_2O] 7.6, OC 1.8%, CEC 44.9 meq/100 g, loam; Burabod, Sulfaquept, pH [H_2O] 3.9, OC 1.8%, CEC 12.8 meq/100 g, sandy loam). Ten kilograms of each soil was placed in a 16-liter glazed porcelain pot; soil solutions were sampled anaerobically by gravity every 2 wk. Basal applications of N, P, K at respective rates of 100, 50, and 50 mg/kg soil were added as ammonium sulfate, monocalcium phosphate, and potassium chloride.

Table 4. Changes in available Zn in soils at 4 Philippine sites due to intensive cropping and irrigation with demineralized water. IRRI, 1976-86.

Location	Available Zn (mg/kg)					
	1976	1978	1980	1982	1984	1986
Tiaong (Lipa clay loam)	0.05	0.05	0.05	0.05	0.05	0.05
Luna (clay)	0.2	0.2	0.15	0.1	0.5	0.6
Laguna (Lam-aw peat)	0.4	0.5	3.5	3.5	3.6	5.1
San Pablo (Lipa clay)	0.1	0.5	0.8	1.0	1.2	1.4

Table 5. Reduction in pH due to intensive cropping and irrigation with demineralized water. IRRI, 1976-84.

Location	pH		
	1976	1984	Reduction
Tiaong (Lipa clay loam)	7.9	7.5	0.4
Luna (clay)	7.7	6.5	1.2
Laguna (Lam-aw peat)	5.8	4.9	0.9
San Pablo (Lipa clay)	6.8	5.6	1.2

The decreased Eh after flooding corresponded to the reduction of Fe(III) and Mn(IV) oxides and hydroxides and the release of Fe^{2+} and Mn^{2+} into solution (Fig. 8, 9). The net reaction was oxidation of readily oxidizable organic C to CO_2 and reduction of Fe(III) and Mn(IV) to Mn^{2+} and Fe^{2+}

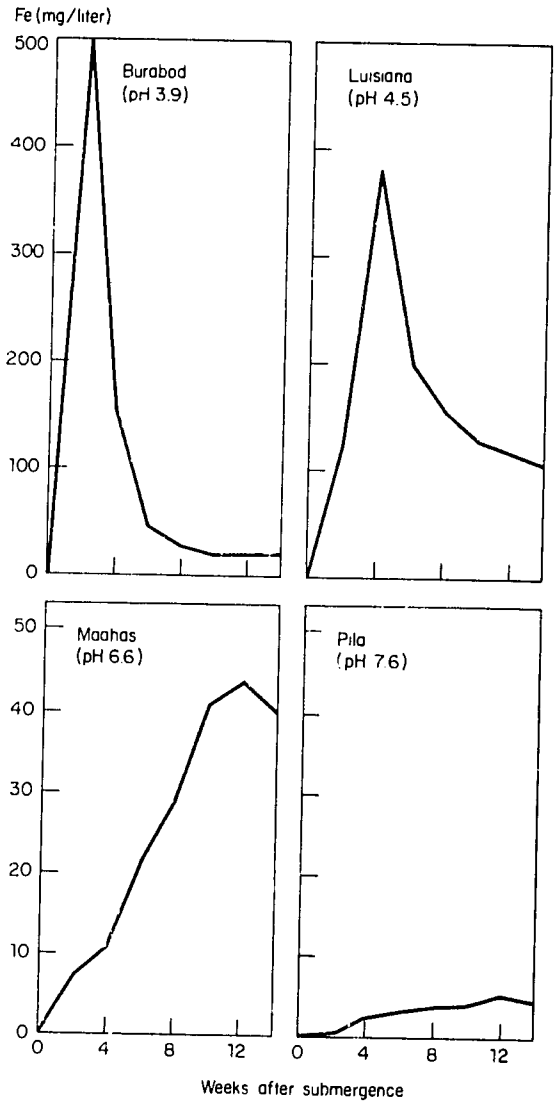
$$\tfrac{1}{4}C + Fe(OH)_3 + H_2O \rightarrow Fe^{2+} + 2OH^- + 3/2\ H_2O + CO_2$$
$$\tfrac{1}{2}C + MnO_2 + H_2O \rightarrow Mn^{2+} + 2OH^- + \tfrac{1}{2}CO_2$$

Because the reduction of Mn(IV) oxides can occur at a higher Eh than the reduction of Fe(III) oxyhydroxides, the Mn^{2+} concentration increases before Fe^{2+}.

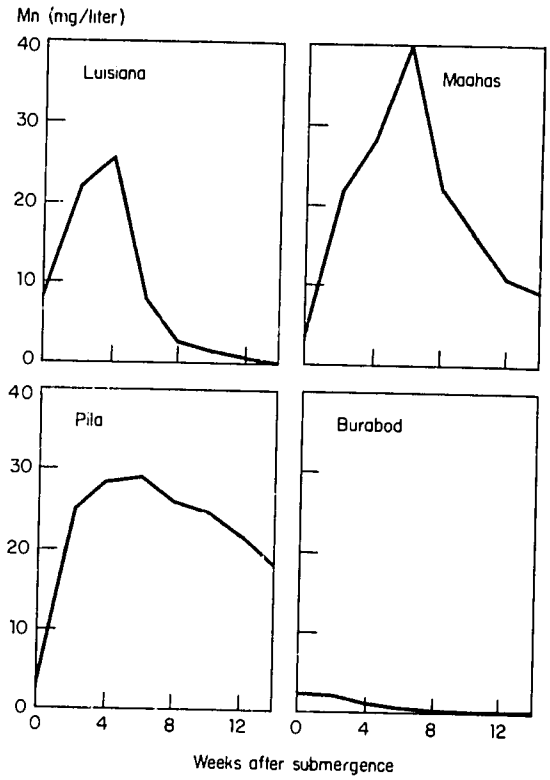
In this experiment, no fresh organic C was added. In other experiments with similar soils, adding organic substrates increased the rate of production of Fe^{2+} and Mn^{2+}.

Fermenting organic matter produces CO_2, influencing the pH of most flooded soils (except acid sulfate soils). The partial pressure of CO_2 increased until 4-6 wk after transplanting up to 45-55 kPa and sharply declined to 10-20 kPa. In the neutral Maahas clay loam and calcareous Pila loam, the partial pressure of CO_2 increased only to 17 kPa and stabilized at 12 kPa.

In calcareous soils, where pH is buffered by $CaCO_3$, the increase in partial CO_2 pressure lowers pH to near 7. The pH, however, is not determined by a simple carbonate solubility equilibrium. Calculated ion activity products for calcite (Ca^{2+}, CO_3^{2-}) show that soil solutions can be oversaturated more than 15-fold with respect to calcite solubility. The oversaturation, which pushes pH



8. Kinetics of water-soluble Fe^{2+}. IRRI, 1987.



9. Kinetics of water-soluble Mn^{2+}. IRRI, 1987.

values higher than predicted by solubility equilibrium, is likely caused by blockage of crystal growth sites through adsorption of very small amounts of soluble organic matter.

In acid soils, the production of OH^- increases pH. This increase is limited by the precipitation of Fe(II) and Mn(II) carbonates, occurring at about pH 7.

At the Eh and ionic concentration found, siderite ($FeCO_3$) and rhodochrosite ($MnCO_3$) control the solubility of Fe^{2+} and Mn^{2+} in the Luisiana, Maahas, and Pila soils. Pure siderite and rhodochrosite, however, are not likely to form.

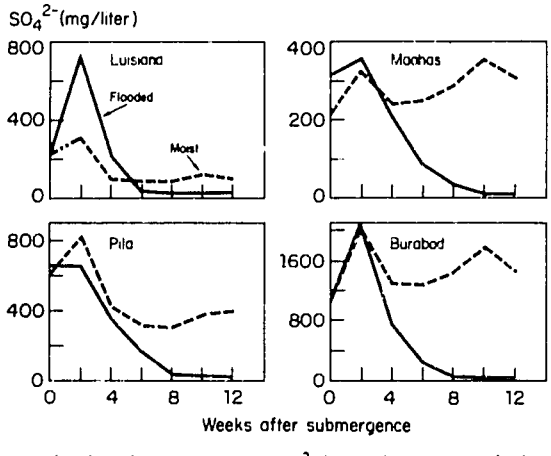
In the initial stages after flooding, reduction produces Fe^{2+} and Mn^{2+} faster than carbonate precipitation removes these ions from solution. This can produce high oversaturations of rhodochrosite and siderite. For the acid Luisiana, neutral Maahas, and calcareous Pila soils (Fig. 8, 9), oversaturations were 100-fold for siderite and 60-fold for rhodochrosite. After peaking, Fe^{2+} and Mn^{2+} decrease in concentration but remain well oversaturated, except Mn^{2+} in the acid Luisiana soil. Apparently, blocking of crystal growth sites by organic matter is important for Fe^{2+}-Mn^{2+} carbonates as well as for calcite. In the Luisiana soil, high in Fe and low in Mn, the coprecipitation of Mn into Fe-carbonates reduced the Mn^{2+} concentrations below the solubility of rhodochrosite. Such coprecipitation can lead to Mn deficiency when the Fe:Mn ratio and partial pressure of CO_2 are high.

Soluble Fe can be toxic to rice at concentrations observed in the Luisiana and Burabod soils. But the relationship between Fe concentration in the soil solution and Fe toxicity is complex. Symptoms

have been observed at Fe concentrations from 45 to 1,700 mg/liter. Fe toxicity apparently is often caused by nutrient imbalances and physiological disorders, rather than by increased Fe in the soil solution. Preflooding potentially Fe-toxic soils and/or organic matter amendments (higher partial pressure of CO_2) and planting after the decrease in Fe^{2+} due to $FeCO_3$ precipitation are recommended.

In the acid sulfate soil from Burabod, Fe and Mn in soil solution were controlled by mineral phases of FeS and MnS because pH increased too little for $FeCO_3$ precipitation. Sulfate, however, is reduced at a lower Eh than Fe(III) and Mn(IV), so Fe^{2+} and Mn^{2+} increased, then decreased because of FeS precipitation. The Fe^{2+} concentration in the Burabod soil decreased to less than 50 mg/liter because of a high initial concentration of soluble SO_4^{2-} (Fig. 10). More than 2,000 mg SO_4^{2-}/liter was available to supply S^{-}. Mn decreased to very low concentrations by precipitating as MnS or coprecipitating with FeS.

With drying, Fe and Mn carbonates oxidize to form oxides and hydroxides. Not much, however, is known about the mineral phases of Fe and Mn when flooded soils are oxidized. Pure $Fe(OH)_3$ and MnO_2 are not likely to form. At Eh values between those typical of flooded soils and those of well-aerated soils, the stable form of Fe(III) is $Fe_3(OH)_8$, containing Fe(III) and Fe(II). At higher Eh, $Fe_3(OH)_8$ is not stable, although some may persist in drained ricefield soils depending on the water regime, especially if the turnaround time for a second lowland rice crop is short. Under aerobic conditions, ferrihydrite, a poorly ordered species of $Fe(OH)_3$, forms. The oxides of Mn and Fe formed upon drainage and oxidation are likely to vary in composition and to crystallize poorly.



10. Kinetics of water-soluble SO_4^{2-} in 4 soils under moist but well aerated and flooded conditions. IRRI, 1987.

SOIL STRUCTURE EVALUATION IN LUZON, PHILIPPINES

Ensuring the productivity of upland crops after rice is difficult because soils differ in physical requirements for the crops. After rice, when excess water evaporates, ricefield soil is usually hard and blocky. This affects the upland crops' seed emergence, root penetration, and water availability. Soils of Luzon, Philippines, were inventoried to evaluate their suitability for upland cropping.

We sampled topsoils from 250 sites in the major Luzon rice-growing areas and analyzed their structure, linear shrinkage, and 1500-kPa water retention.

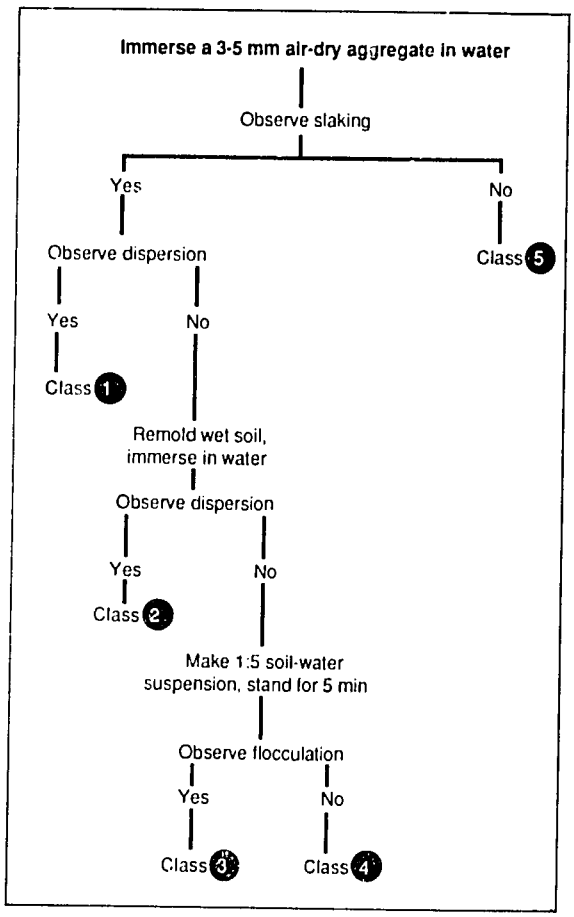
Water stability of aggregates. A water coherence test determined aggregate stability. The water coherence of soil aggregates is related to the intraparticle and interparticle bonds, which determine the reaggregation potential.

Five classes, based on the behavior of dry, wet, and remolded aggregates in water, indicate increasing stability from class 1 to 5 (Fig. 11).

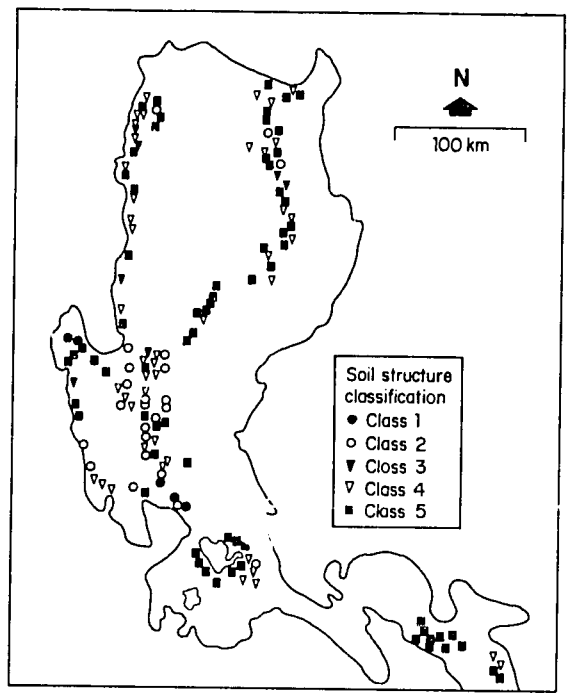
Soils of class 1 have a weak structure and tend to form an unstable dense soil mass. Tillage of class 1 soils is easy and can produce a favorable structure for a wide range of moisture content. But class 1 soils easily slake, so heavy rains can destroy their structure and erode them. Thin crusts may form, impeding seed germination.

For class 5 soils, tillage is easy only in a small range of soil moisture content (minute soils). Tillage at low moisture content requires high draft power and produces large clods, while high moisture contents cause only plastic deformation of the soil material. Root penetration might be limited for upland crops.

The soil aggregate stability for Luzon is shown in Figure 12. Class 1 soils occur only in coastal saline areas, where high Na content helps disperse particles. Class 2 and class 3 soils are found mainly in Central Luzon, while other areas have highly stable soils with high reaggregation potential.



11. Water stability test for aggregate classification (adapted from Greenland et al 1975, and Emerson and Foster 1985). IRRI, 1987.



12. Soil aggregate stability of rice soils in Luzon, Philippines, 1987.

On the IRRI farm, though soil aggregates belong to class 5, they easily disperse when irrigated with deep well water. The high Na content (up to 100 mg/liter) of irrigation water from some deep wells disperses particles on the surface, leading to thin silty crusts that hamper water penetration and seed germination.

Linear shrinkage. After equilibrating sieved soil at the equivalent moisture content of 33 kPa on ceramic plates, standardized aggregates were formed with a plastic mold. The length of a specimen was 125 mm with a semicircular diameter of 18 mm. After initial air and final oven drying at 110 °C, the linear shrinkage (LS) of each artificial aggregate was measured.

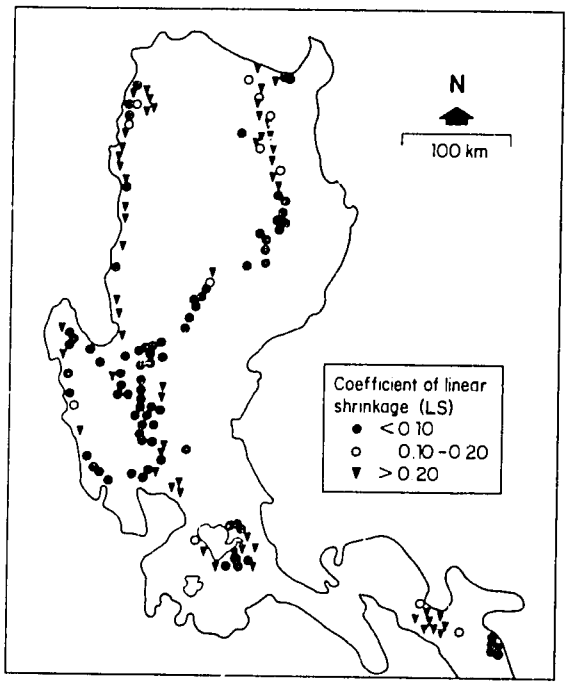
LS is related to clay mineralogy, clay content, and organic matter content. In these 250 samples, clay content was positively correlated (r^2=0.41) with LS.

The increasing clay content in the downstream direction of the Cagayan Valley matches increasing LS values (Fig. 13). LS coefficients of more than 0.20 were also found in Bicol, around Laguna de Bay, and in parts of Ilocos. These values indicate the development of structure by the segregation of soil particles; hence, the term "segregate" can indicate the processes involved for this particular kind of aggregate. These soils also have vertic and self-mulching properties.

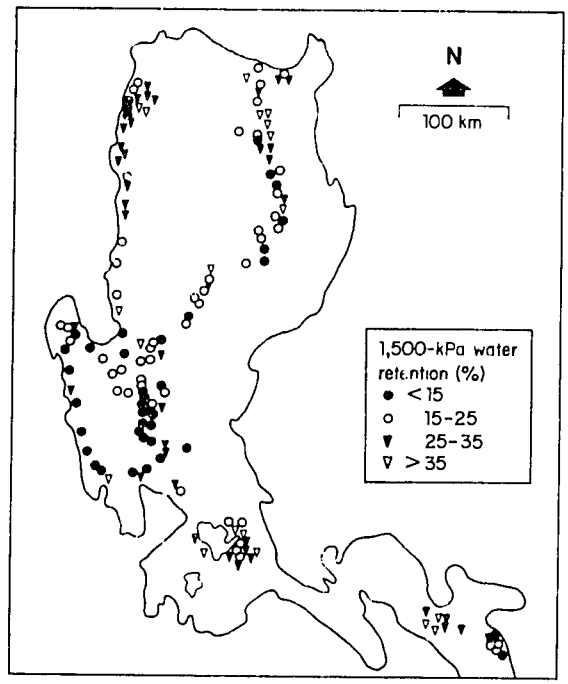
Moisture retention at 1500 kPa. The moisture retention at pF 4.2 as the lower limit of plant accessible water indicates the primary structure of soils unchanged by tillage. Low values indicate low content of fine-textured particles, mainly clays and organic matter.

In these 250 soils, moisture retention at pF 4.2 correlated (r^2=0.66) with clay content.

Figure 14 shows the distribution of soils according to water retention. Values of <25% water retention were found in Central Luzon, whereas values of >25% were prevalent in the



13. Linear shrinkage of rice soils in Luzon, Philippines, 1987.



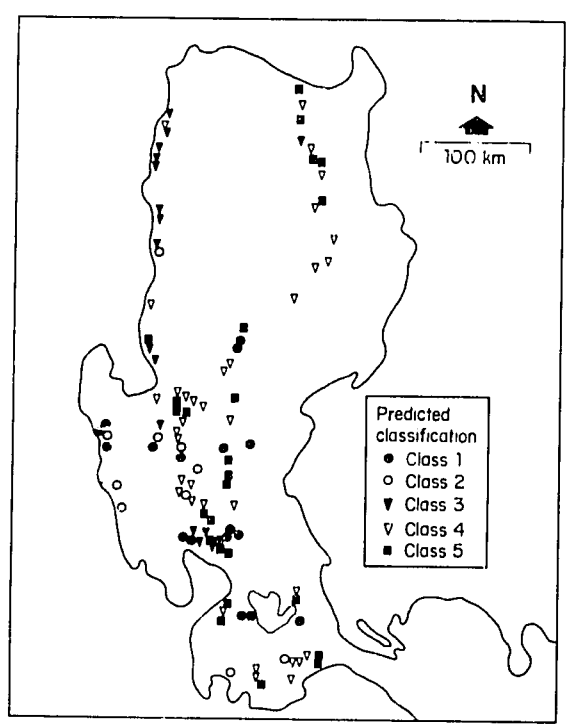
14. 1,500-kPa water retention of rice soils in Luzon, Philippines, 1987.

downstream area of the Cagayan Valley, the Bicol Region, and parts of Ilocos.

Computer modeling of soil structure. Of the 250 samples, 180 were analyzed for chemical and physical parameters. These data were used to establish a computer modeling system to predict the previously determined water stability of soil aggregates. Data on amorphous and crystalline Fe have not yet been included in this database, although they are effective cementing agents.

Discriminant analysis determined that the following data best delineate the aggregate stability classes:

- pH (H_2O)
- pH (1 N KCl)
- EC
- Organic C
- Total N
- Exchangeable cations
  - Na
  - K
  - Mg
  - Ca
- CEC
- Available P (Olsen)
- Available Zn



15. Predicted soil aggregate stability of rice soils in Luzon, Philippines, 1987.

Most parameters relate to the net charge, exchange capacity, exchangeable cations, and organic matter.

Soil texture (sand, silt, clay contents) has not been selected as a discriminating parameter. The median value for the clay content of the 180 soils is 35%. Above a certain clay content, difference in texture seems not to affect aggregate stability. The model predicts aggregate stability based on the water coherence classes, with a confidence limit of 70%.

The model was applied to data from soils compiled by the Agronomy Department from the same region but different sites. The results are shown in Figure 15. The pattern of structural classes is similar for both data sets (compare Figures 12 and 15). For Central Luzon, the Agronomy Department data generally indicate a lower class than do our data. The average clay content of Agronomy Department soils is higher than in our samples, while the pH, organic C, CEC, and exchangeable cations are lower.

This model for classifying soil structure can be used to assess sites for upland cropping.

Soil and crop management

Management of soil and fertilizer nitrogen

Agronomy Department

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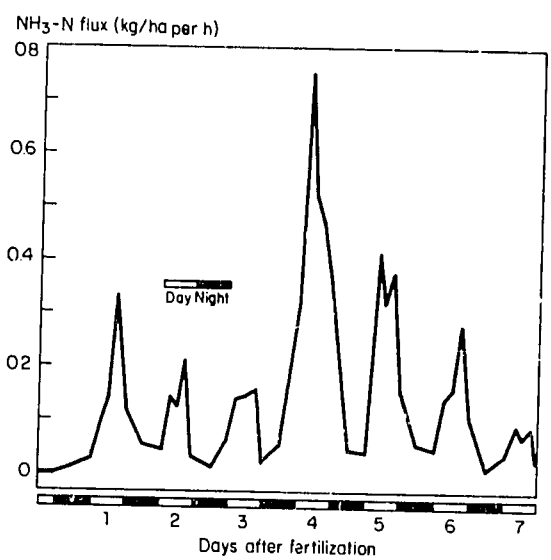
COMPARISON OF TOTAL NITROGEN LOSS AND AMMONIA VOLATILIZATION USING SIMPLE TECHNIQUES

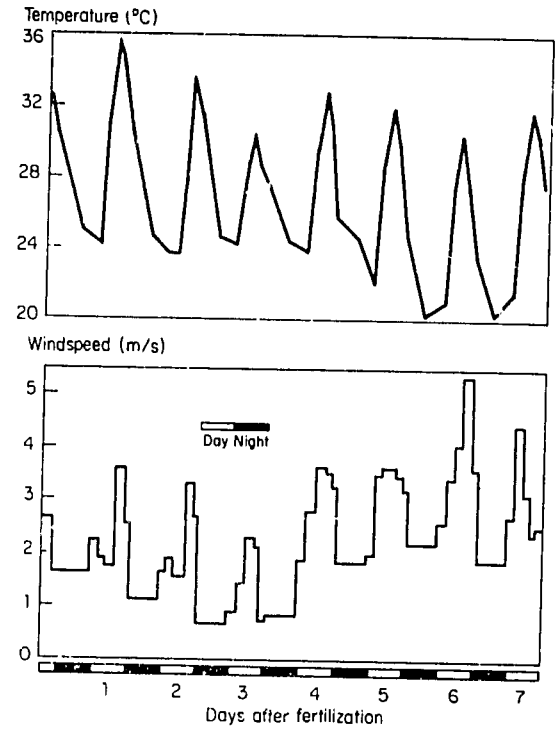
Data on NH_3 volatilization loss, determined from measurements of windspeed and excess NH_3 concentration over the background NH_3, and total N loss determined by ^{15}N-balance techniques were obtained in San Marcelino, Zambales, Philippines (very low cation exchange capacity [CEC], 5 meq/100 g soil, Angeles loamy sand soil), in the 1987 dry season (DS). The difference between total N loss and NH_3 loss was estimated as the nitrification-denitrification loss.

High NH_3 volatilization was recorded in San Marcelino between 1400 and 1600 h for 6 d after urea surface application at 80 kg N/ha into the floodwater (Fig. 1). NH_3 loss was 0.3 kg/ha per h on day 1, peaked on day 4, and lasted up to day 6. These periods coincided with daytime fluctuations in floodwater temperature (Fig. 2) and floodwater pH (Fig. 3). Maximum windspeed of 5 m/s was recorded on day 6 and 3.7 m/s on days 1-5. Total NH_3 flux determined by a simplified technique was 19%—15 kg N/ha out of 80 kg N/ha applied.

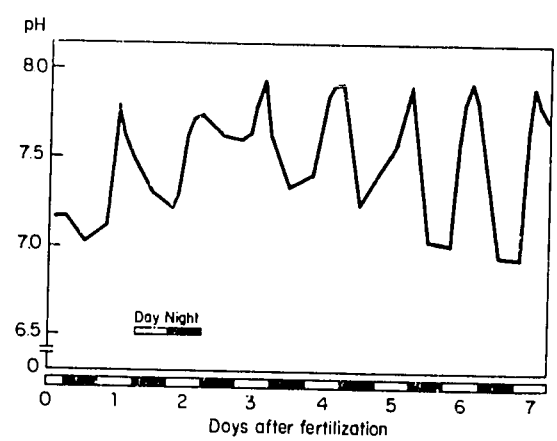
Measured NH_3 flux density was correlated with the product of windspeed and the difference between NH_3 concentrations in floodwater and in air. Highest cumulative NH_3 volatilization loss was



1. Ammonia fluxes from the circular plot as measured by micrometeorological technique. San Marcelino, Zambales, Philippines, 1987 DS.



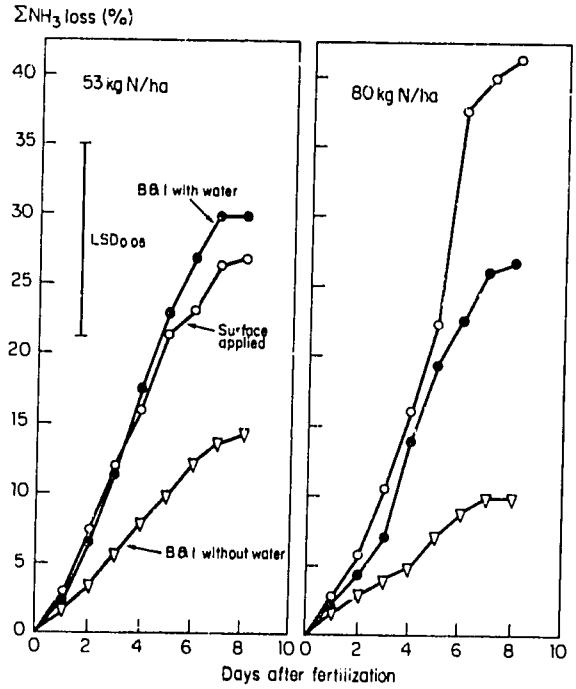
2. Diurnal fluctuations in windspeed and floodwater temperature in an unreplicated circular plot. San Marcelino, Zambales, Philippines, 1987 DS.



3. Diurnal fluctuations in floodwater pH in the circular plot. San Marcelino, Zambales, Philippines, 1987 DS.

with surface-applied urea (Fig. 4) and lowest with urea incorporated into the soil without standing water. At 53 kg N/ha, incorporation of urea into the soil with 5 cm water or surface application resulted in high NH_3 loss.

Total N loss was lowest (14%) with deep placement of urea supergranules (USG) in loamy



4. Cumulative NH_3 loss as affected by fertilizer management practices in San Marcelino, Zambales, Philippines, 1987 DS. B&I = broadcast and incorporated.

sand (Table 1). Total N loss was significantly lower (65-71%) with farmers' split surface-applied urea than with researchers' split urea incorporated into the soil (80-82%). Estimated nitrification-denitrification was maximum (50-56%) when urea was incorporated into the soil without standing water, followed by incorporation into soil with 5 cm water. Nitrification-denitrification loss was lowest (29-39%) when urea was surface-applied into water at 11 d after transplanting (DT). Surface-applied fertilizer, although producing high NH_3 volatilization losses, gave low nitrification-denitrification losses. USG deep placement was superior in minimizing N losses in loamy sand.

Total ^{15}N recoveries under different treatments at 30 DT showed that deep placement gave the highest total recovery (Table 2). Surface application or farmers' split gave higher total ^{15}N recovery (29-35%) than researchers' split (18-24%) because of the higher N uptake of the plant material excluding roots.

IR64 yield response to applied fertilizer over the no fertilizer-N treatment was 2.1 t/ha (Table 3). Researchers' split without water gave significantly higher yield than the two other application methods. Yield with deep placement of fertilizer was no better than that with researchers' split without standing water.

DIFFUSION MECHANISMS ASSOCIATED WITH AMMONIA VOLATILIZATION IN LOWLAND RICE

Molecular diffusion of ammonia from floodwater into the atmosphere. NH_3 diffusion rates into the atmosphere were estimated by micrometeorological techniques after applying 80 kg N/ha as urea into the floodwater in farmers' fields in Calauan, Laguna (1986 and 1987 DS); in Aguilar, Pangasinan (1986 DS); and in San Marcelino, Zambales (1987 DS). Diffusion coefficients were computed using diffusion rates and concentration gradients

Table 1. Relationship between total N loss and NH_3 volatilization. San Marcelino, Zambales, Philippines, 1987 DS.

Application method	N rate (kg/ha)	Water depth (cm)	Total N loss (%)	NH_3 loss (%)	Estimated nitrification-denitrification loss[a] (%)
Researchers' split[b]	53	0	76	14	62
Researchers' split[b]	53	5	80	30	50
Farmers' split[c]	53	5	65	26	39
Researchers' split[b]	80	0	80	10	70
Researchers' split[b]	80	5	82	26	56
Farmers' split[c]	80	5	71	42	29
Deep placement[d]	53	0	14	0	14
LSD 0.05	–	–	11	14	–
Farmers' split in circular plot[e]	80	5	79	19	60

[a]By difference. [b]2/3 basal + 1/3 at 5-7 d before panicle initiation (DBPI). [c]2/3 at 10 d after transplanting (DT) + 1/3 at booting. [d]Urea supergranules. [e]Unreplicated treatment.

Table 2. Recovery of ^{15}N-labeled urea at 30 d after transplanting (DT) in soil and plant as affected by application method and water depth. San Marcelino, Zambales, Philippines, 1987 DS.

Application method	N rate (kg/ha)	Water depth (cm)	Recovery (%) of ^{15}N-labeled urea			
			Plant	Total N + roots	Unaccounted for	Total
Researchers' split[a]	53	0	5	19	76	24
Researchers' split[a]	53	5	5	15	80	20
Farmers' split[b]	53	5	15	20	65	35
Researchers' split[a]	80	0	4	16	80	20
Researchers' split[a]	80	5	5	13	82	18
Farmers' split[b]	80	5	12	17	71	29
Deep placement[c]	53	0	6	80	14	86
LSD 0.05		–	4	10	11	11
Farmers' split in circular plot[d]	80	5	8	13	79	21

[a]Urea broadcast and incorporated (B&I) basally. [b]Urea topdressed at 11 DT. [c]Urea supergranules. [d]Unreplicated.

Table 3. Grain yields of IR64 as affected by N application method and water depth. San Marcelino, Zambales, Philippines, 1987 DS.

Treatment	N rate (kg/ha)	Water depth (cm)	Yield (t/ha)
No fertilizer N	0	–	2.8
Researchers' split[a]	80	0	5.0
Researchers' split[a]	80	5	4.5
Farmers' split[b]	80	5	4.5
Researchers' solit[a]	120	0	5.5
Researchers' split[a]	120	5	4.9
Farmers' split[b]	120	5	4.5
Deep placement[c]	80	–	5.2
LSD 0.05	–	–	0.6
Farmers' split in circular plot[d]	120	5	4.3

[a]2/3 basal + 1/3 at 5-7 DBPI. [b]2/3 10 DT + 1/3 at booting. [c]2/3 deep placement of USG + 1/3 at 5-7 DBPI. [d]Unreplicated treatment.

Table 4. Concentration profiles of fertilizer NH_4^+-N (treated-control) on different days (1-7) after urea application to floodwater. Zambales and Laguna, Philippines, 1987 DS.

Soil depth (cm)	NH_4^+-N[a] (µg/g soil)					
	1	2	3	4	6	7
San Marcelino (loamy sand)						
0 - 2.5	78	101	125	138	94	68
2.5- 5	10	18	17	17	22	37
5 -15	ND	ND	3	12	5	ND
15 -30	ND	ND	T	T	T	T
Calauan (clay)						
0 - 5	106	154	144	195		155
5 -15	40	7	18	13		24
15 -30	15	3	8	ND		ND

[a]ND = not detectable, T = traces.

across the wind-free layer contiguous to the floodwater.

Estimated diffusion rates were highest at midday and lowest in the morning and evening at all sites. Concentration gradients showed a similar trend. However, diffusion coefficients were lowest at around midday, when diffusion rates were highest.

Downward diffusion of ammoniacal nitrogen from floodwater into soil. Experiments in Calauan, Laguna (clay soil), and San Marcelino (loamy sand soil) in 1987 DS examined the influence of soil texture on the movement of NH_4^+-N from floodwater into the soil. The movement of applied fertilizer NH_4^+-N was investigated by monitoring the 2 N KCl-extractable NH_4^+-N concentrations in the soil profile until 7 d after applying 80 kg N/ha as urea to the floodwater.

NH_4^+-N movement, presumably by diffusion, was greater into clay soil than into loamy sand soil (Table 4). NH_4^+-N concentrations in the top 0- to 5-cm soil layer increased until 4 d after fertilizer application, and then decreased in both soils. Concentrations were either not detectable or only traces in the 15- to 30-cm layer of loamy sand soil until 7 d.

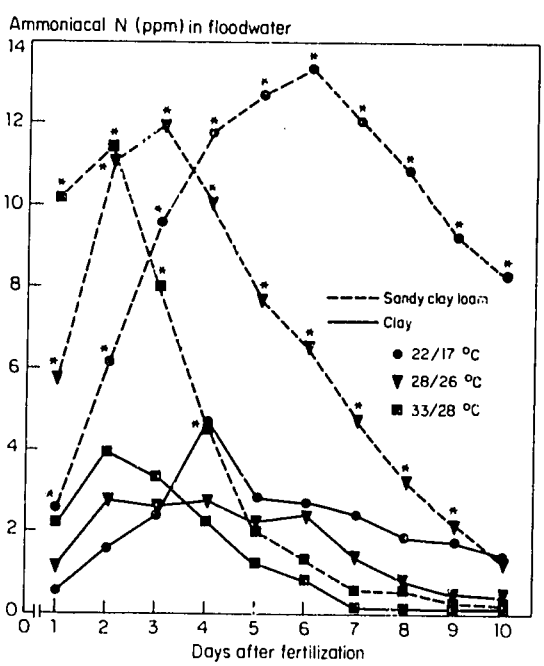
Upward diffusion of fertilizer ammoniacal nitrogen from soil to floodwater. The interaction effects of temperatures and soil textures on NH_4^+-N diffusion from the soil to floodwater were studied in the IRRI phytotron in 1987 DS. Ammoniacal-N concentrations in the floodwater

were monitored until 10 d after urea incorporation (80 kg N/ha as urea) into the top 0- to 5-cm soil layer.

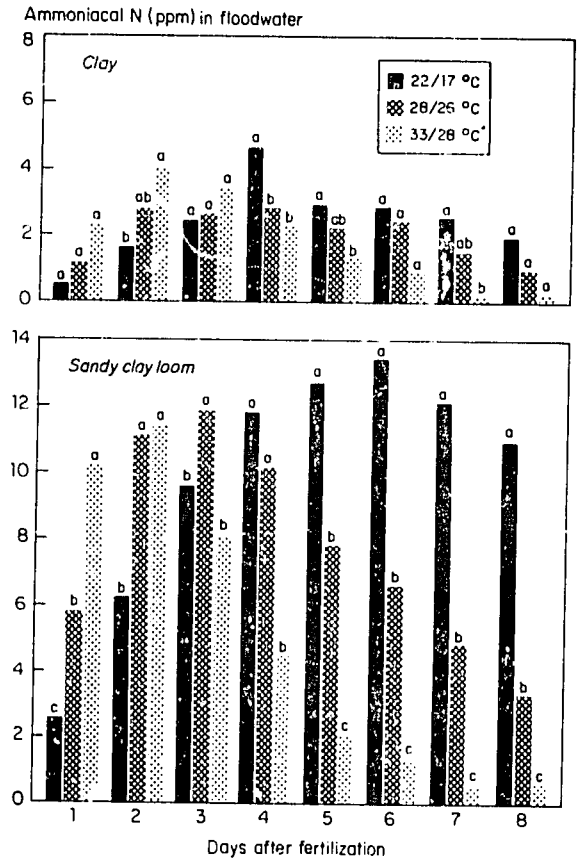
Soil textures (clay and sandy clay loam) and temperature regimes (22/17 °C, 28/26 °C, and 33/28 °C) showed strong interactions (Fig. 5, 6). Higher NH_4^+-N concentrations in the floodwater for sandy clay loam soil than for clay soil indicated greater upward diffusion rates from a coarse textured soil. However, this difference was not observed after day 5 at 33/28 °C. At 22/17 °C, NH_4^+-N in the floodwater gradually increased in clay, but was faster in sandy clay loam. At 33/28 °C, NH_4^+-N concentration in both soils peaked within 2 d, and then declined rapidly. Temperature differences were more apparent with sandy clay loam than with clay.

DIRECT FIELD MEASUREMENT OF DENITRIFICATION

Denitrification as a mechanism of N loss in flooded rice soils is difficult to measure directly because the atmosphere contains 78% N_2, the main end product of denitrification.



5. Effect of soil texture on ammoniacal N concentration in the floodwater at different temperature regimes, IRRI phytotron, 1987 DS. The asterisk means significantly different from clay soil values at the same temperature on the same day.

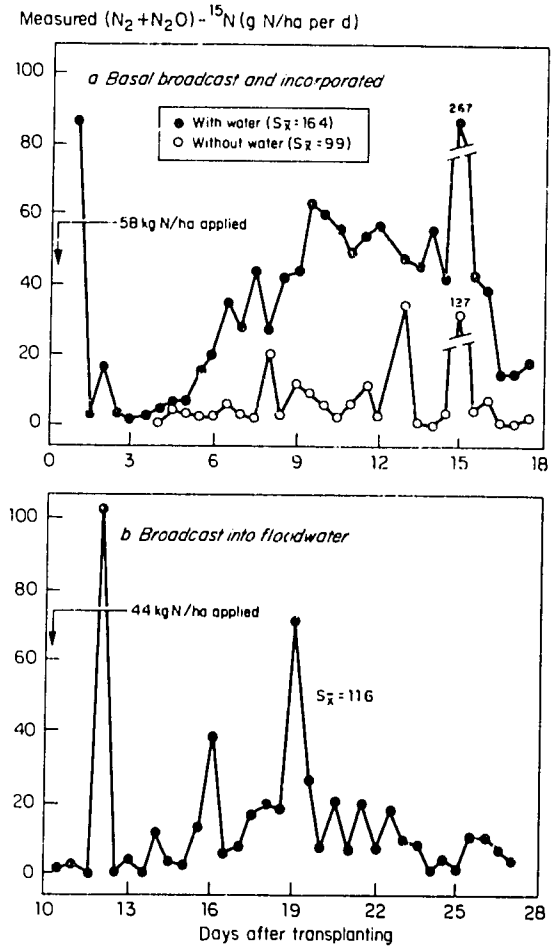


6. Effect of temperature on floodwater ammoniacal N concentration, IRRI phytotron, 1987 DS. Within a soil, bars on a given day with a common letter are not significantly different.

With International Fertilizer Development Center (IFDC) collaboration, field studies in DS at the Maligaya Rice Research and Training Center (MRRTC), Muñoz, Nueva Ecija, directly assessed denitrification in continuously flooded lowland ricefields. Highly enriched ^{15}N-labeled urea was applied to 40- × 40-cm microplots bordered by 40-cm-deep metal frames, with 10 cm of the metal border remaining above the soil surface to prevent runoff. The evolved N_2 and N_2O gases were collected from plexiglass chambers floating on the floodwater, then processed and analyzed for ^{15}N content using methods developed by IFDC.

The first experiment compared two methods of basal broadcast and incorporation (BB&I) of 58 kg urea-N/ha: 1) with 2 cm standing floodwater, and 2) without standing floodwater. The fluxes of (N_2 + N_2O)-^{15}N during the 17 d following urea application were less than 100 g N/ha per day for both

urea application methods, except for 1 sampling at 15 DT (Fig. 7a). The cumulative recovery of $(N_2 + N_2O)$-^{15}N was much smaller than the total ^{15}N loss as determined from unaccounted for ^{15}N in the ^{15}N balance after 18 d (Table 5). Whereas 40 and 26% of the urea N incorporated with 2 cm water and without standing water, respectively, were unaccounted for after 18 d, only 1.13 and 0.21% of the added urea N was recovered as $(N_2 + N_2O)$-^{15}N (Table 5). These recoveries corresponded to only 2.8 and 0.8% of the total ^{15}N loss.



7. Effect of urea application method on measured $(N_2 + N_2O)$-^{15}N flux. Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines, 1986 DS.

In a second experiment, N loss was measured from the equivalent of 44 kg urea-N/ha broadcast into 5-cm deep floodwater at 10 DT. The highest flux of (N_2+N_2O)-^{15}N during the 17-d period following urea application was 103 g N/ha per day (Fig. 7b). The cumulative recovery of $(N_2 + N_2O)$-^{15}N over this period was only 0.52% of the added N (Table 5), whereas total ^{15}N loss of applied urea N from the soil-plant-floodwater system was 46%. $(N_2 + N_2O)$-^{15}N recovery corresponded to only 1.1% of total ^{15}N loss.

DIRECTLY MEASURED DENITRIFICATION AND AMMONIA VOLATILIZATION LOSSES

With IFDC collaboration, denitrification and NH_3 volatilization were simultaneously measured in Calauan in 1987 DS. Urea was broadcast at 80 kg N/ha into 5 cm of standing floodwater at 11 DT. Ammonia volatilization was measured by the micrometeorological technique. Denitrification loss was measured by collecting the N gases (N_2 and N_2O) evolved from added 67 atom % ^{15}N-labeled urea and then analyzing the gases for ^{15}N content. A reference treatment with 22 atom % ^{15}N-labeled potassium nitrate broadcast in 3 doses of 10 kg N/ha was included to calibrate the denitrification measurement.

Table 5. Effect of urea application method on ^{15}N recovery 18 d after fertilization. Maligaya Rice Research and Training Center (MRRTC), Muñoz, Nueva Ecija, Philippines, 1986 DS.

Experiment no.	Urea application[a]	Unaccounted for ^{15}N[b] (% of applied N)	Direct recovery of $(N_2 + N_2O)$-^{15}N[b] (% of applied N)
1	BB&I with water	40	1.13
	BB&I without water	26	0.21
		(2.0)	(0.28)
2	10 DT	46	0.52
		(2.8)	(0.15)

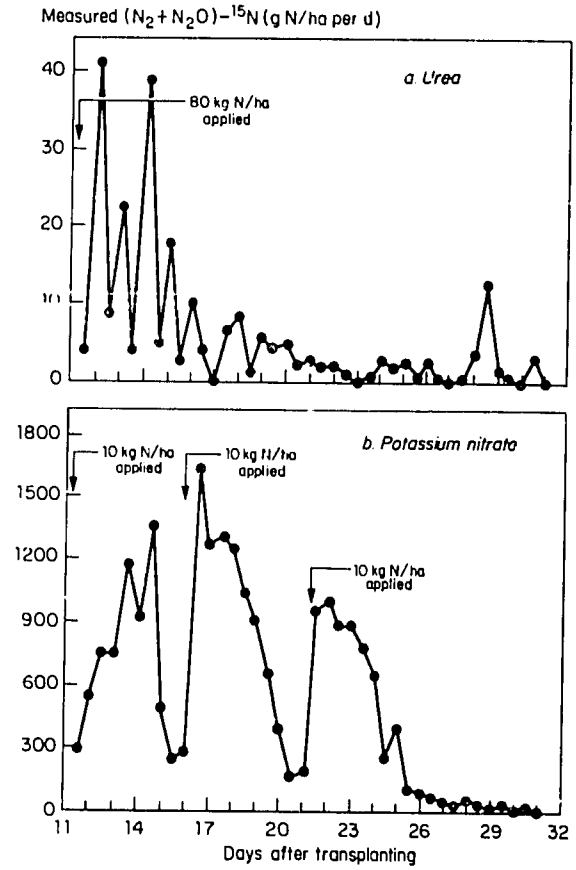
[a]BB&I = urea basal, broadcast and incorporated. DT = days after transplanting. [b]Numbers in parentheses are standard errors of mean.

The directly measured $(N_2 + N_2O)$-^{15}N flux from urea was very low and slightly exceeded 40 g N/ha per day only once during the 20 d following application into floodwater (Fig. 8a). Cumulative recovery of $(N_2 + N_2O)$-^{15}N was only 0.12% of the added urea-N (Table 6). In comparison, 45% of the added N was unaccounted for in the ^{15}N balance determined upon completion of flux measurements (Table 6).

Broadcasting potassium nitrate in the reference treatment gave a much higher $(N_2 + N_2O)$-^{15}N flux than that with urea, even though the application rate was lower (Fig. 8b). The highest measured $(N_2 + N_2O)$-^{15}N flux from added NO_3^--^{15}N was 1,650 g N ha per day. Nitrate-N was added in 3 equal increments at 5-d intervals to ensure a gas flux throughout the 20-d sampling period. The cumulative recovery of the added NO_3^--^{15}N as $(N_2 + N_2O)$-^{15}N was 38% (Table 6). In comparison, 80% of the added NO_3^--^{15}N was unaccounted for in the ^{15}N balance. Since leaching was apparently negligible and runoff loss was prevented by microplot borders, unaccounted for ^{15}N in the NO_3^- treatment was assumed to represent total N loss by denitrification. However, directly measured $(N_2 + N_2O)$-^{15}N represented only 48% of the total unaccounted for ^{15}N. These findings suggest that measured $(N_2 + N_2O)$-^{15}N underestimated total denitrification.

Ammonia volatilization loss measured with the simplified horizontal transport technique was 9% of the applied urea-N. A simultaneous ^{15}N balance revealed that total N loss as determined from unaccounted for ^{15}N was 43% of the applied urea N (Table 7). This agreed closely with the 45% total N loss obtained in microplots used for measurement of denitrification (Table 6). Denitrification loss estimated by difference between total N loss and measured NH_3 loss was 34% (Table 7), whereas denitrification estimated from direct recovery of $(N_2 + N_2O)$-^{15}N was only 0.12% (Table 6).

The results for the nitrate reference treatment (Table 6) indicate that the measured $(N_2 + N_2O)$-^{15}N flux underestimates total denitrification loss, presumably because of incomplete release of gases from the soil. Assuming that the measured $(N_2 + N_2O)$-^{15}N flux from urea represented only 48% of the total N loss by denitrification, as in the nitrate reference treatment, total denitrification loss from urea would still be less than 1%. The large



8. Effect of N source on measured $(N_2 + N_2O)$-^{15}N flux. Calauan, Laguna, Philippines, 1987 DS.

Table 6. Effect of N source on $(N_2 + N_2O)$-^{15}N flux and total N loss. Calauan, Laguna, Philippines, 1987 DS.

N source	N rate (kg/ha)	Total N loss (% of applied N)	Direct recovery of $(N_2 + N_2O)$-^{15}N (% of applied N)
Urea	80	45	0.12
Potassium nitrate	30	80	38

discrepancy between estimates for denitrification (Table 6, 7) emphasizes the need to improve techniques to measure N losses.

The NH_3 concentrations and windspeed obtained with simplified horizontal transport techniques were used to calibrate the bulk aerodynamic technique to estimate NH_3 losses from various urea fertilizer management treatments. Ammonia loss estimated by the bulk aerodynamic technique ranged from zero for deep-placed urea to

Table 7. Relationship between total N loss and NH_3 volatilization. Calauan, Laguna, Philippines, 1987 DS.

Application method	Rate (kg/ha)	Water depth (cm)	Total N loss (% of applied N)	NH_3 loss (% of applied N)	Estimated denitrification loss[a] (% of applied N)
Researchers' split[b]	53	0	39	10	29
Researchers' split[b]	53	5	56	18	38
Farmers' split[c]	53	5	45	27	18
Researchers' split[b]	80	0	50	7	43
Researchers' split[b]	80	5	50	15	35
Farmers' split[c]	80	5	55	16	39
Deep placement[d]	53	0	3	0	3
LSD (0.05)	–	–	9	3	–
Farmers' split[e] in circle	80	5	43	9	34

[a]By difference. [b]BB&I. [c]Broadcast at 11 d after transplanting. [d]Urea supergranules. [e]Unreplicated treatment.

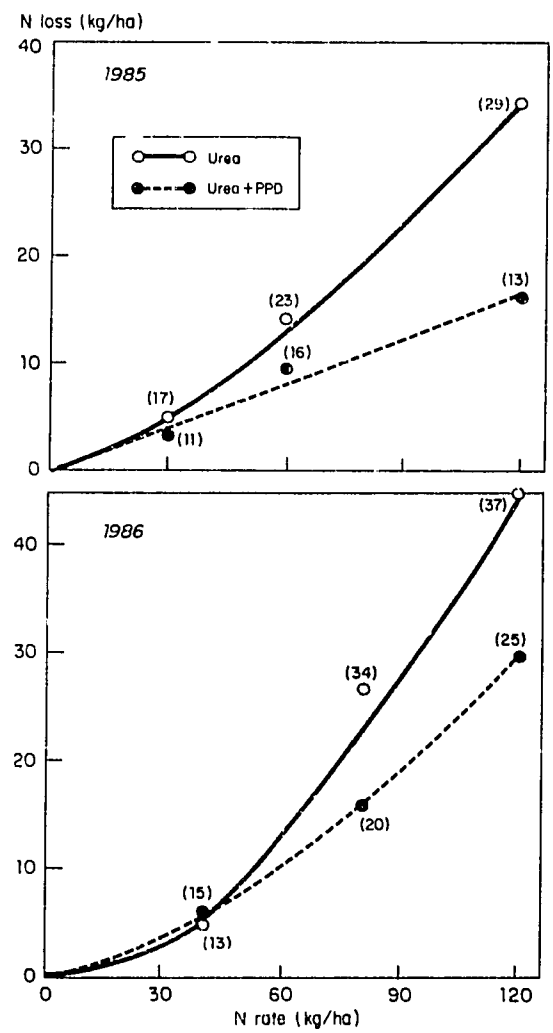
27% for 53 kg N/ha broadcast into floodwater at 11 DT (Table 7). The estimated denitrification losses obtained by differences between unaccounted for ^{15}N in ^{15}N balances and estimated NH_3 losses ranged from 3 to 43%. Except with 53 kg N/ha broadcast at 11 DT, the estimated denitrification loss was greater than the estimated NH_3 volatilization loss.

POTENTIAL YIELD INCREASE FROM ELIMINATION OF GASEOUS FERTILIZER-NITROGEN LOSS

Lowland ricefields can lose substantial amounts of urea-N by NH_3 volatilization and denitrification. Urease inhibitors could overcome NH_3 volatilization, and nitrification inhibitors could reduce nitrification-denitrification. However, no known inhibitor completely prevents all gaseous N loss of applied urea-N. Field ^{15}N balance studies with urea in Pila, Laguna, in collaboration with IFDC, examined the potential N savings and yield response with a hypothetical ideal inhibitor.

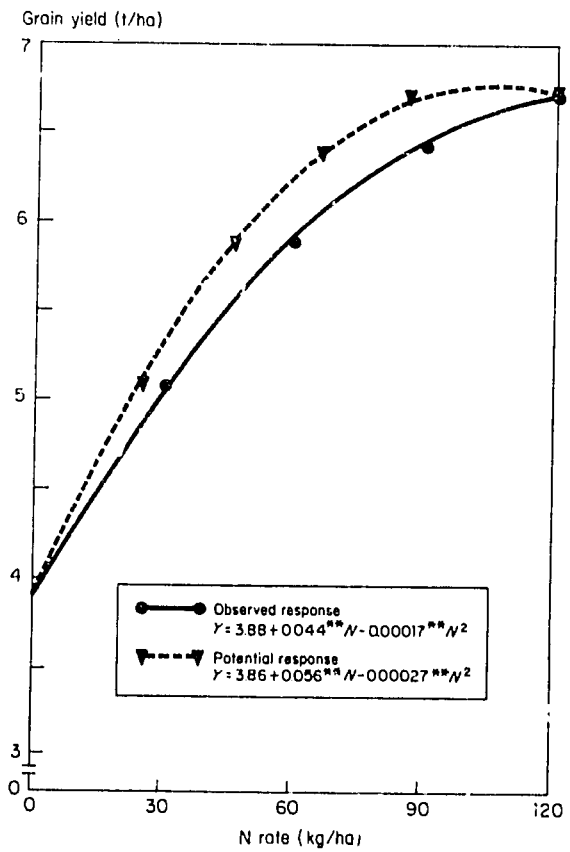
An ideal inhibitor would completely eliminate gaseous loss of applied urea-N with no effect on rice other than increasing the availability of fertilizer-N. The unaccounted for ^{15}N in ^{15}N balances with urea would represent gaseous N loss and hence the potential N savings, since runoff and leaching losses were negligible.

Figure 9 shows that the N loss and hence the potential savings in urea-N consistently increased with increasing N rate. In 1985, the potential urea-N savings were 17, 23, and 29% at 30, 60, and 120 kg N/ha, respectively. In 1986, they were 13,



9. Effect of N rate on the gaseous loss of urea N applied to lowland rice in Pila, Laguna, Philippines, 1985-86. PPD = phenyl phosphorodiamidate. Values in parentheses represent N losses in percent of applied N.

34, and 37% at 40, 80, and 120 kg N/ha, respectively. Amendment of urea with the urease inhibitor phenyl phosphorodiamidate (PPD) reduced but did not eliminate N loss (Fig. 9). In all cases, the urea was split broadcast into floodwater at 16 or 18 DT and at 5-10 d after panicle initiation (DAPI).



10. Comparison of observed yield response of lowland rice to applied N and potential yield response with complete elimination of gaseous N loss. Pila, Laguna, Philippines, 1985 DS.

Figure 10 illustrates the observed response and potential response estimated with elimination of the N loss from urea reported in Figure 9 for the 1985 experiment. The potential yield increase with complete elimination of gaseous N loss can be calculated as the difference between potential yield and observed yield at a specific N rate. In 1985 (Fig. 10), the maximum possible yield increase was 0.4 t/ha at 75 kg N/ha, or 6%. In 1986, the maximum possible yield increase was 0.5 t/ha, or 8%.

COATED UREA FERTILIZERS FOR LOWLAND RICE

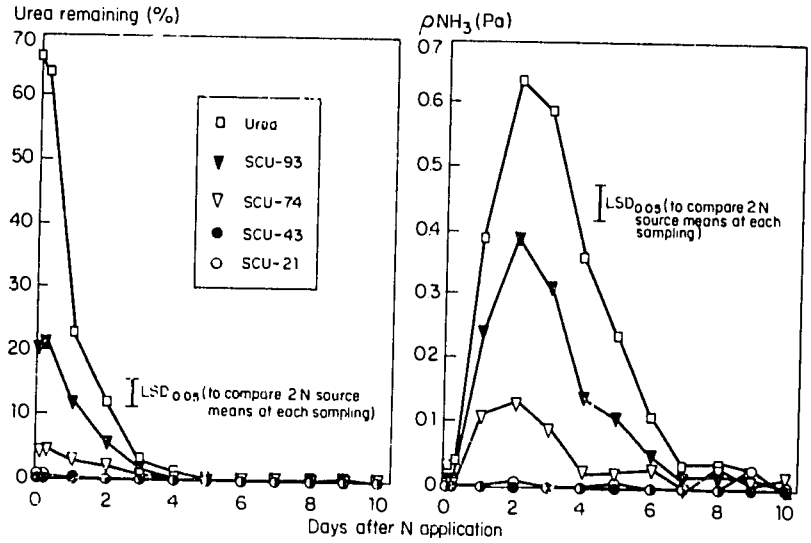
Sulfur-coated urea (SCU), an effective N fertilizer for rice, is expensive because it requires large amounts of S, sealant, and conditioner (20% by weight of urea). Increasing the urea granule size would decrease the quantity of coating per unit weight of urea.

Four SCU fertilizers prepared with 4.4-mm-diameter urea granules by IFDC (Table 8) were compared with conventional 2.0-mm-diameter granular SCU (designated SCU-21 because of its 21% 7-d release rate in water) and prilled urea (PU) in Muñoz, Nueva Ecija, Philippines. All SCU fertilizers reduced urea and NH_3 contents in the floodwater after basal incorporation with 2-cm standing floodwater (Fig. 11). SCU-43 and SCU-36 (not shown in Fig. 11) were as effective as conventional SCU-21 in completely eliminating the escape of urea to floodwater and the accumulation of NH_3 in floodwater. The negligible pNH_3 suggests that they completely eliminated urea-N loss by NH_3 volatilization. Since SCU-43, SCU-74, and SCU-93 essentially differed only in quantity of sealant and conditioner, the greater effectiveness of

Table 8. Properties of sulfur-coated urea (SCU) fertilizers prepared by the International Fertilizer Development Center (IFDC). MRRTC, Muñoz, Nueva Ecija, Philippines, 1986.

N source	Composition[a] (%)					Urea granule diameter (mm)	7-d release rate in water (%)
	N	S	Sealant	Conditioner	Total coating		
SCU-21	37	15.6	na	na	20.1	2.0	21
SCU-36	39	14.8	0	0	14.8	4.4	36
SCU-43	40	9.1	1.2	2.1	12.4	4.4	43
SCU-74	40	9.0	1.0	1.7	11.7	4.4	74
SCU-93	41	9.1	0	0	9.1	4.4	93

[a]na = not available.



11. Effect of sulfur coating on urea remaining in floodwater and partial pressure of ammonia (ρNH_3) after the application of 90 kg urea N/ha before transplanting. Muñoz, Nueva Ecija, Philippines, 1987 DS.

SCU-43 in preventing ρNH_3 (Fig. 11) suggests that sealant or conditioner may be essential to completely eliminate NH_3 volatilization when the S content is reduced to 9%.

Another way to decrease urea coating is to use lighter-weight coatings. Three polymer-coated urea (PCU) fertilizers with coatings from 3.3 to 6.0% by weight of urea were prepared with 4.4-mm-diameter urea granules by IFDC (Table 9) and included in the preceding experiment with SCU fertilizers in Muñoz. All 3 PCU fertilizers completely prevented urea and ρNH_3 buildup in the floodwater following basal incorporation at 90 kg urea-N/ha with 2 cm of standing floodwater. The results suggest that they completely eliminated urea-N loss by NH_3 volatilization.

The 3 PCU fertilizers (Table 9) were also compared at 3 N rates with SCU-21 and PU (2/3 basal incorporation + 1/3 at 5-7 DBPI) at IRRI in 1987 DS. Mean grain yield was 0.1-0.7 t/ha greater for PCU fertilizers than for PU. Quadratic responses in grain yield to applied N were used to calculate urea savings. Coating urea with polymer could dramatically reduce the quantity of urea required for desired grain yields of 3, 4, or 5 t/ha. Of the 3 PCU fertilizers, PCU-40, with only a 3.3% coating by weight of urea, was most effective. It was slightly superior to conventional SCU-21 in urea savings (Table 9).

NITROGEN EFFICIENCY IN LOWLAND RICE

The effect of N fertilizer application time and method on N uptake and ^{15}N balance in transplanted (TPR) and direct seeded (DRS) lowland

Table 9. Properties of polymer-coated urea (PCU) fertilizers prepared by IFDC and their effects on urea savings at 3 desired grain yields. IRRI, 1987 DS.

N source	Composition (%)		Urea granule diameter (mm)	7-d release rate in water (%)	Urea savings[a] (%) at		
	N	Total coating			3 t/ha	4 t/ha	5 t/ha
PCU-8	41	6.0	4.4	8	33	18	0
PCU-13	43	4.5	4.4	13	26	18	11
PCU-40	44	3.3	4.4	40	56	49	31
SCU-21	37	20.1	2.0	21	49	38	23

[a]Urea savings $= \frac{N_U - N_C}{N_U} \times 100$, where N_U = urea N (applied 2/3 basal + 1/3 at 5-7 DBPI) required for desired yield, and N_C = coated urea (applied all basal) required for desired yield.

rice was studied at MRRTC in 1987 DS. Urea was applied at 87 kg N/ha in all N treatments. A newly developed push-type injector for band placement of liquid urea solution was compared with conventional (BB&I) application and USG point placement. ^{15}N kinetics and efficiency and total N uptake by IR64 were established. ^{15}N uptake was determined on six sampling dates, and total N uptake was measured each week of growth.

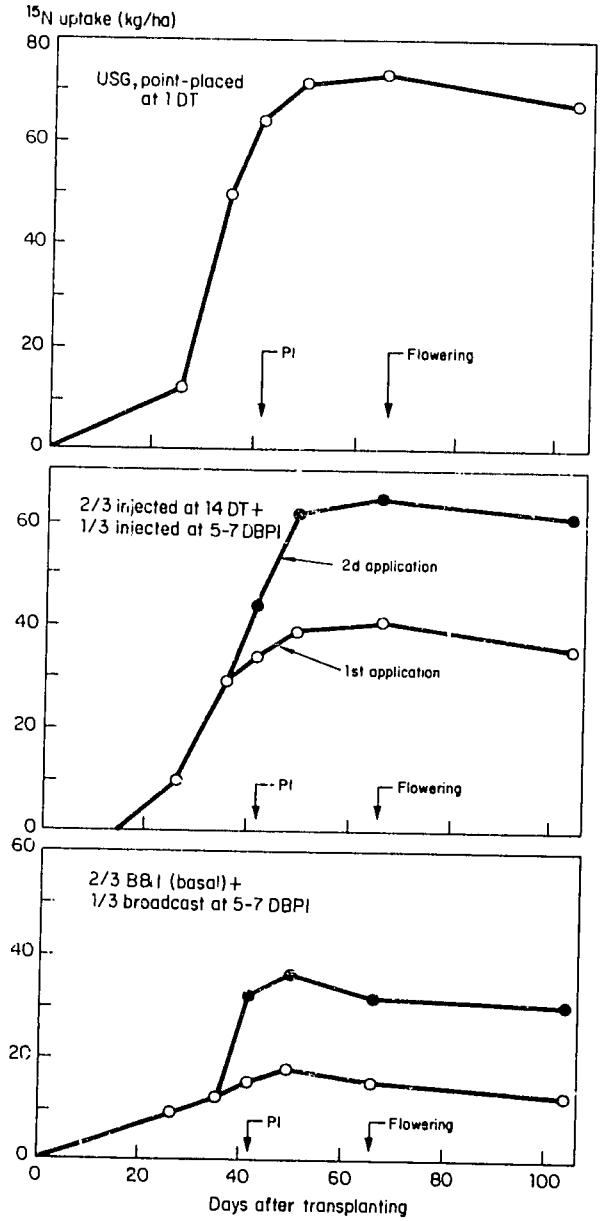
Grain yields with band placement were significantly higher than with BB&I in TPR and DSR. With band placement, a 1/3-2/3 split was better than a 2/3-1/3 split (Table 10). In contrast, the 2/3-1/3 split BB&I in DSR gave 0.5 t/ha more grain yield than did the 1/3-2/3 split. This indicates that, because of substantial losses and immobilization of applied N, a 1/3 dose BB&I was not sufficient to support early vegetative crop growth. Point placement of USG gave yields between those of BB&I and band placement.

Plant ^{15}N recoveries were highest with either band or point placement (Fig. 12, 13). The effect of higher fertilizer N uptake with band placement was

Table 10. Grain yield of transplanted and direct seeded (hill-wise dibbled and row seeded) IR64 rice as affected by N fertilizer (USG) application time[a] and method. Muñoz, Nueva Ecija, Philippines, 1987 DS.

N treatment	Grain yield (t/ha)
Transplanted	
No fertilizer N	3.3
2/3 BB&I + 1/3 at 5-7 DBPI broadcast	7.6
2/3 at 14 DT band-placed + 1/3 at 5-7 DBPI band-placed	8.0
1/3 at 14 DT band-placed + 2/3 at 5-7 DBPI band-placed	8.2
All USG point-placed at 1 DT	7.8
Direct seeded (hill-wise)	
No fertilizer N	3.3
2/3 BB&I + 1/3 at 5-7 DBPI broadcast	7.7
1/3 BB&I + 2/3 at 5-7 DBPI broadcast	7.2
1/3 at 20 DAS band-placed + 2/3 at 5-7 DBPI band-placed	8.5
All USG point-placed at 20 DAS	8.3
Row seeded	
No fertilizer N	3.3
1/3 BB&I + 2/3 at 5-7 DBPI broadcast	7.3
1/3 at 20 DAS band-placed + 2/3 at 5-7 DBPI band-placed	7.9
LSD (0.05)	0.4

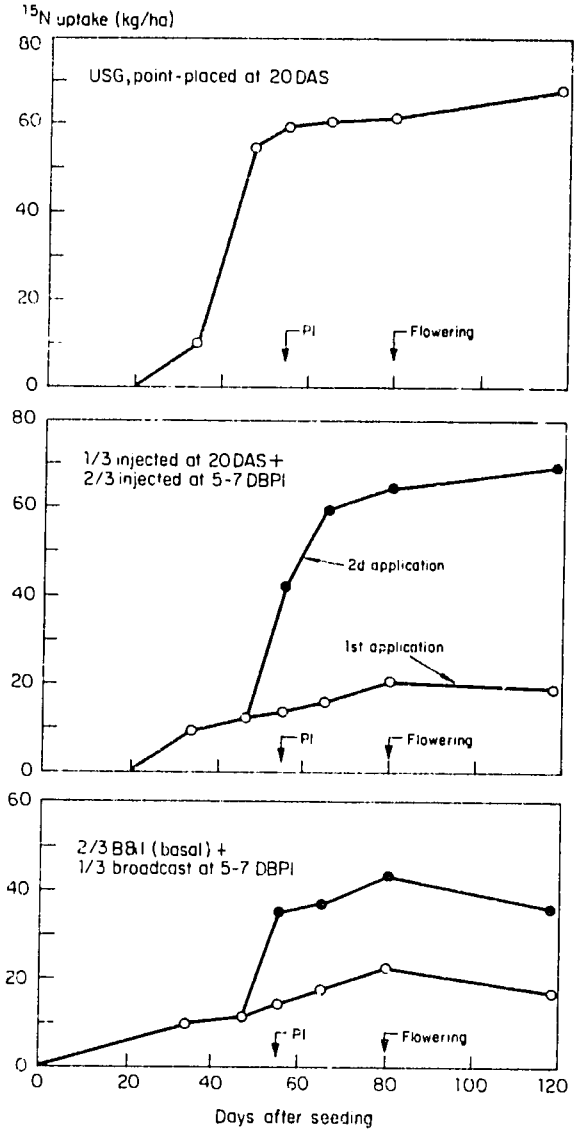
[a]DT = days after transplanting, DAS = days after seeding.



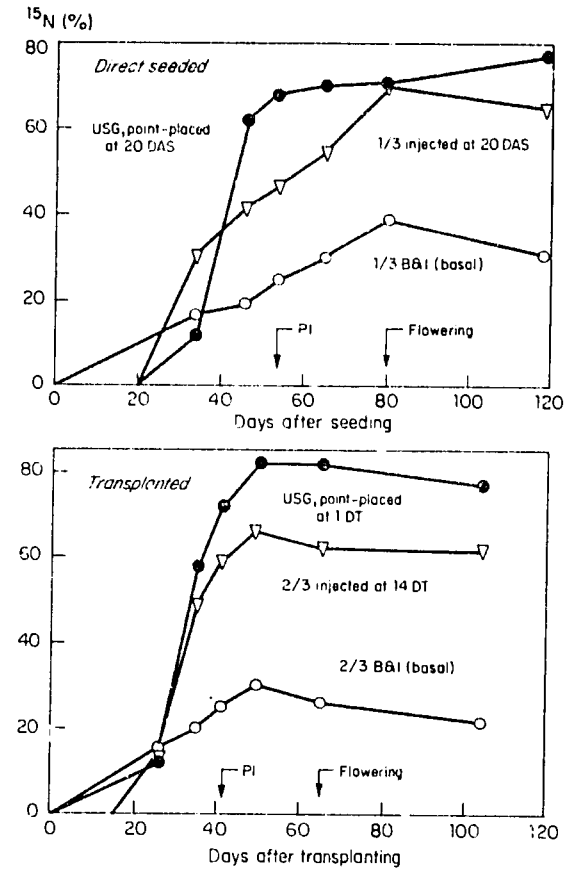
12. ^{15}N uptake by transplanted IR64 as affected by fertilizer application time and method at various growth stages, Muñoz, Nueva Ecija, Philippines, 1987 DS. DT = days after transplanting, B&I = broadcast and incorporated, PI = panicle initiation, DBPI = days before panicle initiation, USG = urea supergranules.

especially evident in the first N application (Fig. 14) at a growth stage (i.e., 14 DT or 20 d after seeding) when plants had developed enough sink strength to absorb N rapidly.

N application time and method also affected the total N uptake and N status of plants. While total N



13. ^{15}N uptake by direct seeded IR64 as affected by fertilizer application time and method at various growth stages, Muñoz, Nueva Ecija, Philippines, 1987 DS. DAS = days after seeding.

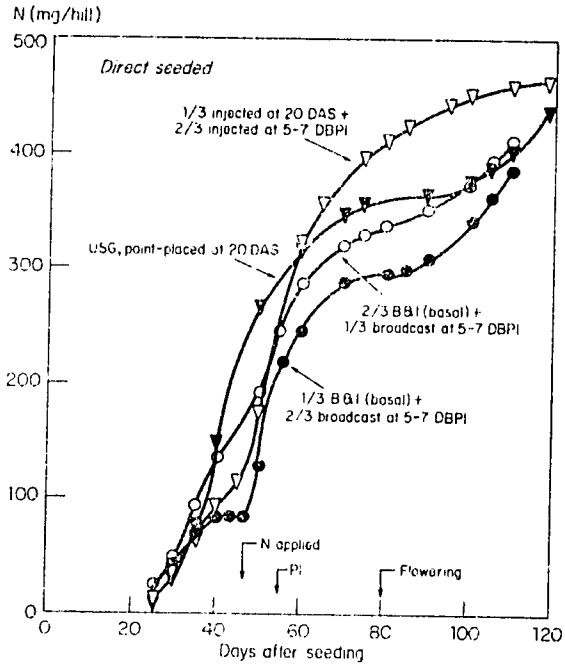


14. ^{15}N recovery in plants as affected by fertilizer application time and method at various growth stages of IR64, Muñoz, Nueva Ecija, Philippines, 1987 DS. DAS = days after seeding, DT = days after transplanting.

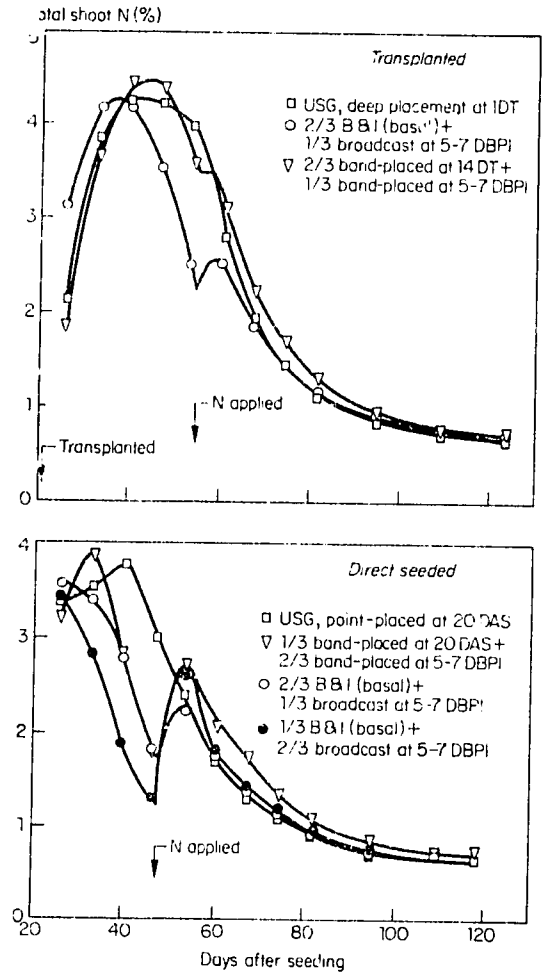
uptake with BB&I and point placement of USG were higher than with band placement during early growth, this was reversed at later growth stages, especially in DSR (Fig. 15). This produced marked differences in N content (N%) of plant shoots (Fig. 16). High N supply during early growth, as with point placement and BB&I, produced vigorous vegetative growth, diluting N within plant tissue and reducing yield potential through effects on panicle initiation (PI). In contrast, early band placement of 1/3 N and a subsequently high N dosage (2/3) before PI ensured balanced crop growth and maximum grain yield due to high N tissue content at PI and thereafter.

FATE AND EFFICIENCY OF ^{15}N-LABELED SESBANIA GREEN MANURE AND UREA IN LOWLAND RICE

Research on the effect of ^{15}N-labeled *Sesbania rostrata* green manure on the N dynamics and ^{15}N balance in lowland TPR was conducted at MRRTC in 1987 DS. Sesbania and urea were applied separately or combined at a rate of 90 kg N/ha. N as USG, and sesbania were applied basal at 90 kg N/ha. USG was hand point-placed at 10-to 12-cm soil depth at 1 DT. For other



15. Total N uptake at various growth stages of direct seeded IR64 as affected by fertilizer application time and method, Muñoz, Nueva Ecija, Philippines, 1987 DS. DAS = days after seeding.



16. N content in total shoot at various growth stages of transplanted and direct seeded IR64 as affected by fertilizer application time and method, Muñoz, Nueva Ecija, Philippines, 1987 DS. DT = days after transplanting, DAS = days after seeding.

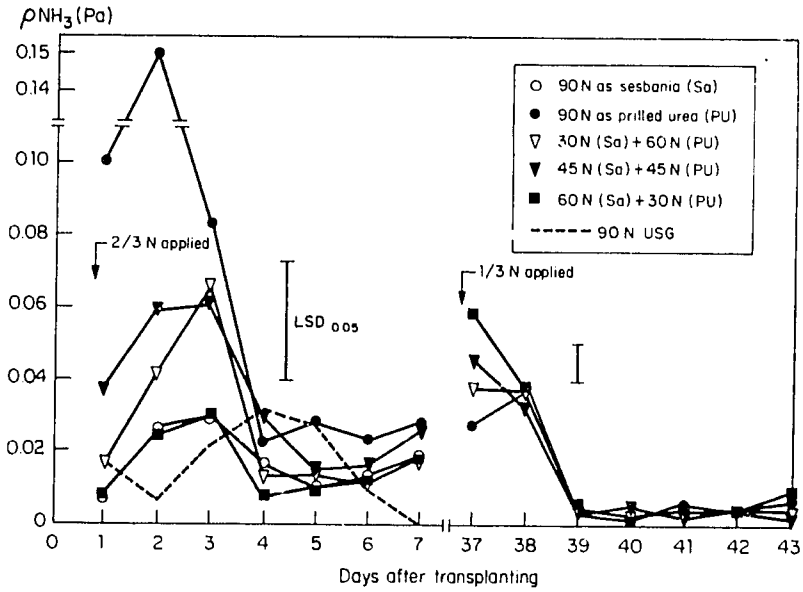
treatments, N was best split (2/3 N B&I into mud + 1/3 N at 5-7 DBPI).

Ammonia loss. The relative effect of the integrated use of sesbania and urea on NH_3 volatilization loss was calculated from the partial pressure (pNH_3) of NH_3 in the floodwater, which, at a given windspeed, is directly related to NH_3 volatilization. pNH_3 was calculated from the pH, temperature, and NH_4^+-N concentration of the floodwater (Fig. 17).

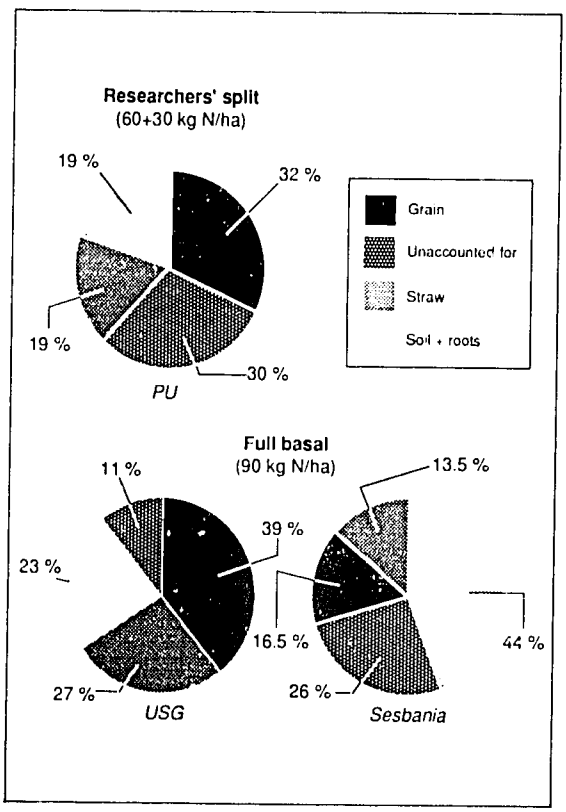
During initial fertilizer application, when floodwater properties highly favored NH_3 volatilization loss, sesbania applied with urea gave significantly lower pNH_3 than did urea applied alone. This was probably because decomposing sesbania produced enough CO_2 and increased the partial pressure of CO_2 (pCO_2) in floodwater. Since pCO_2 is inversely related to pH, reduced pH yields decreased pNH_3. On the other hand, the opposing process of mineralization-immobilization was prominent in combined application, which kept the floodwater NH_4^+-N level low. Thus, combined application of sesbania and urea can reduce NH_3 loss from floodwater.

^{15}N balance. The highest ^{15}N recovery by the plant was 66% (39% in grain + 27% in straw) with hand point-placed USG (Fig. 18). Replacing 30-45 kg of urea N with sesbania gave similar plant ^{15}N recoveries of 45-51% (Fig. 19). With 60 kg sesbania-N, plant ^{15}N recovery was 42%. Lowest ^{15}N recovery (30%) was obtained with sesbania applied alone.

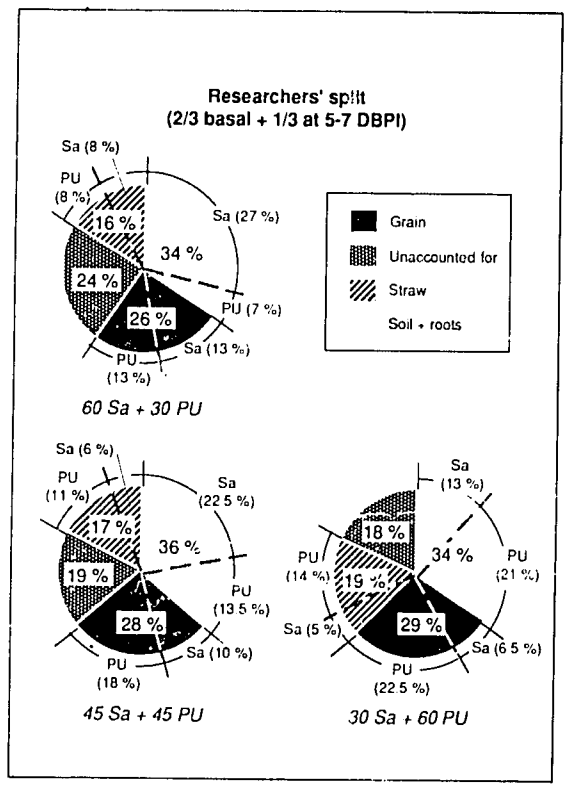
The estimated total N loss was lowest (11%) with USG. Urea applied alone accounted for 30% loss, highest among treatments. Basal incorporation of 90 kg sesbania-N accounted for 26% applied N loss. Combining 60 kg sesbania-N + 30 kg PU N



17. Partial pressure of ammonia (ρNH_3) in the floodwater at 1300-1400 h as affected by incorporation of *Sesbania rostrata* (Sa) and prilled urea (PU). MRRTC, Nueva Ecija, Philippines, 1987 DS.



18. ^{15}N balance of *Sesbania rostrata*, PU, and USG in IR64 at harvest. MRRTC, Nueva Ecija, Philippines, 1987 DS.



19. ^{15}N balance of *Sesbania rostrata* (Sa) and PU in IR64 at harvest as affected by combined applications of Sa and PU. MRRTC, Nueva Ecija, Philippines, 1987 DS.

resulted in 24% applied N loss. This higher loss associated with high sesbania-N is attributed to a nitrification-denitrification N loss mechanism. Combined application of sesbania and urea preserved more ^{15}N as residual N than did urea alone. The lowest residual N (19-23%) was recorded with urea and USG treatments.

Grain yield. Grain yield with combined sesbania and urea equaled that with urea and USG, but was significantly higher than that with sesbania alone (Table 11). However, sesbania as the sole N source produced a significantly higher yield (6.3 t/ha) than did the unfertilized control (4.8 t/ha). Urea and USG alone gave high straw yields, suggesting that combined treatments may have apportioned more dry matter to grains.

NITROGEN MANAGEMENT FOR EARLY-MATURING RICE

We evaluated the productivity, brown rice protein (BRP), and lodging resistance of early-maturing elite breeding lines as affected by N application method and rate during DS.

Promising line IR41993-131-2-3-1 gave the highest yield at 7.6 t/ha when SCU was applied at 116 kg N/ha. It also gave the highest average yield of 6.9 t/ha, and a productivity of 77 kg rough rice/ha per day. However, IR42000-211-1-2-2-3 had the highest BRP at 10%. BRP averaged 8.9% over all entries.

Grain yields did not differ with N application method or rate, with SCU, USG, and urea split at 116 kg/ha and urea split at 150 kg/ha. All yielded 6.3 t/ha, compared with an average 4.5 t/ha without N.

Table 11. Grain and straw yields of IR64 as affected by sesbania and urea applied alone or in combination. MRRTC, Nueva Ecija, Philippines, 1987 DS.

Fertilizer treatment[a]	Grain[b] (t/ha)	Straw[c] (t/ha)
No N	4.8 c	5.7 c
90 N as Sa[d]	6.3 b	7.9 b
90 N as prilled urea (PU)[e]	7.0 a	9.4 a
60 N (Sa) + 30 N (PU)[e]	7.0 a	8.2 b
45 N (Sa) + 45 N (PU)[e]	6.8 a	8.2 b
30 N (Sa) + 60 N (PU)[e]	6.9 a	8.9 ab
90 N as USG	6.9 a	9.5 a

[a]Sa = sesbania. Numbers indicate kilograms N/ha. [b]CV = 5%. [c]CV = 8%. [d]Full sesbania basal incorporated. [e]2/3 N B&I + 1/3 N at 5-7 DBPI.

ALTERNATIVE TECHNOLOGY FOR INCREASING EFFICIENCY OF APPLIED NITROGEN IN LOWLAND RICE

The tall traditional variety Binato did not respond to applied N. With the modern rice IR29723-143-3-2-1, the N response was at least 0.9 t/ha in both seasons. Without fertilizer N, IR29723-143-3-2-1 yielded 1.6 t/ha in DS and 1 t/ha in WS more than Binato. Averaging all application methods and rates, IR29723-143-3-2-1 averaged 6.9 t/ha and Binato 3.7 t/ha in DS. In WS, the modern line averaged 4.5 t/ha compared with Binato's 2.1 t/ha.

In DS, the recommended N application method (researchers' split) significantly increased the yield of IR29723-143-3-2-1 by 1 t/ha at 58 and 87 kg N/ha over the farmers' practice. The researchers' split yielded comparably with hand point placement of USG or with N deep placement by machines.

In WS at 29 kg N/ha, the researchers' split and deep-placed N by hand or machine did not significantly increase yields of IR29723-143-3-2-1 over the farmers' split. At 58 kg N/ha, deep placement of USG by hand significantly outyielded the researchers' and farmers' split application of PU. Machine-placed N gave yields comparable to that with researchers' split application.

EVALUATION OF MACHINES FOR DEEP PLACEMENT OF UREA IN LOWLAND RICE

Field experiments at IRRI compared the efficiency of N deep placement by machines with that of hand point placement of USG and farmers' and researchers' split application of PU in lowland rice. The effect of water depth on N fertilizer efficiency when N is deep-placed by hand or by machines was also evaluated. In DS, the test variety, IR64, was slightly affected by tungro. In WS, tungro-resistant IR66 was used.

In DS, the researchers' split of PU, currently the most effective N fertilizer application method in lowland rice, produced yields significantly higher

Table 12. Effect of urea source and application method on labor use during fertilizer application and grain yield of transplanted and broadcast seeded rice, IRRI, 1987 DS and WS.

Urea source	N applied (kg/ha) DS	N applied (kg/ha) WS	Application method	Water depth (cm) during basal fertilizer application[a]	Grain yield[b] (t/ha) DS	Grain yield[b] (t/ha) WS	Application time[a] (h/ha)
			Transplanted rice				
–	0	0	No fertilizer N	–	2.4 d	2.9 c	–
PU	87	58	Farmers' split[c]	5	3.6 c	3.7 b	10
PU	87	58	Researchers' split[d]	0	4.5 b	4.0 ab	10
USG	87	58	Hand point placement[e]	5	5.0 a	4.2 a	44
PU	89	59	Point placement by pneumatic injector[e]	5	5.0 a	3.8 ab	54
PU	87	58	Band placement by plunger-auger[e]	5	4.4 b	4.1 ab	25
			Broadcast seeded rice				
–	0	0	No fertilizer N	–	2.3 c	3.3 c	–
PU	87	58	Farmers' split[c]	5	3.2 b	3.9 ab	10
PU	87	58	Researchers' split[d]	0	4.0 a	4.3 a	10
USG	87	58	Hand point placement[f]	0	3.9 a	4.0 ab	42
PU	86	56	Point placement by pneumatic injector[f]	0	4.0 a	3.6 bc	50
PU	87	58	Band placement by plunger-auger[f]	0	3.8 a	3.7 bc	24

[a]Av of 2 seasons. [b]Under each planting method, means in a column followed by a common letter are not significantly different at the 5% level. CV = 6% for DS and 7% for WS. [c]1/2 at 15 DT or DAS + 1/2 at 10 DBPI. [d]2/3 B&I into mud before seeding or transplanting + 1/3 5-7 DBPI. [e]Applied at 5 DT. [f]Applied at 1 d before seeding.

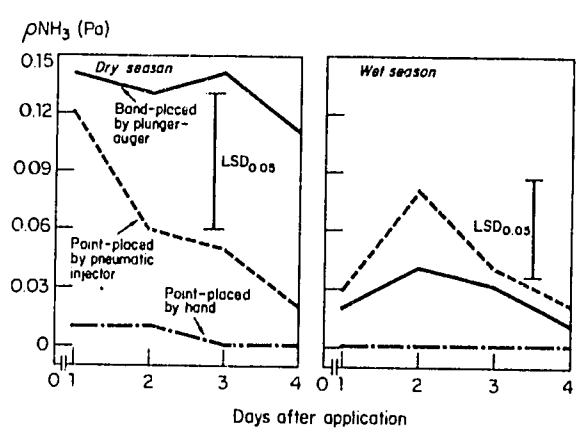
than the farmers' split with both crop establishment methods (Table 12). In TPR, deep point placement of PU by pneumatic injector machine and of USG by hand produced yields significantly higher than that with researchers' split. The deep placement methods did not prove superior to the researchers' split of PU in broadcast seeded rice (BSR).

In WS, only hand point-placed USG proved superior to farmers' split in TPR. In BSR, the researchers' split and N deep placement did not perform better than the farmers' N management practice, probably due to severe lodging of fertilized plants at the milk stage.

Deep placement of N by hand and machine required more labor than farmers' and researchers' splits (Table 12). Band placement of PU by plunger-auger machine was the least laborious deep placement method. Using the pneumatic injector took more time than did hand point placement of USG because the machine was moved manually. Fertilizer application times were similar for BSR and TPR

In DS, the partial pressure of ammonia (ρNH_3) in the floodwater after N deep placement in TPR was higher with the plunger-auger machine (Fig. 20). This indicates high NH_3 volatilization loss and low grain yield. In contrast, hand point placement of USG produced very low ρNH_3 values in DS and WS, indicating negligible NH_3 loss. In WS, deep point placement of PU by the pneumatic injector was less effective and produced slightly higher floodwater ρNH_3 values than did band placement by plunger-auger machine.

Deep placement of PU using the pneumatic injector gave yields comparable to those with hand



20. Partial pressure of NH_3 (ρNH_3) in the floodwater at 1300-1400 h after fertilizer N deep placement by hand and machine at 5 d after transplanting at IRRI, 1987 DS and WS. Bars represent $LSD_{0.05}$ for comparison each day.

placement of USG. Generally, both treatments gave yields significantly higher than farmers' split (Table 13). Deep placement of PU with 10 cm of standing water using the pneumatic injector did not reduce yields. But the average application time for DS and WS was less by at least 18 h/ha with or without 5 cm of standing water than with 10 cm of water. With 10 cm of standing water, poorer visibility hampered placing the fertilizer into the soil between hills.

In DS, deep placement of USG by hand with about 5 cm of water at 5 DT and by plunger-auger machine without standing water at 1 d before transplanting (DBT) or with 5 cm of water at 5 DT significantly increased grain yields by at least 0.8 t/ha over the farmers' N application method (Table 14). Yields from these treatments at 58 kg N/ha were comparable to that of researchers' split. Machine deep placement of N without standing water at 1 DBT was comparable to that with about 5 cm of water at 5 DT. The plunger-auger machine for PU performed better than the press wedge machine for USG, regardless of water depth during fertilizer application.

Table 13. Effect of urea source, application method, and water management on labor use during fertilizer application and on grain yield of transplanted rice. IRRI, 1987 DS and WS.

Urea source	N applied (kg/ha)		Application method[a]	Water depth (cm) during basal fertilizer application[b]	Grain yield[c] (t/ha)		Application time[b] (h/ha)
	DS	WS			DS	WS	
–	0	0	No fertilizer N	–	2.6 d	3.5 f	–
PU	87	58	Farmers' split[d]	5	4.0 bc	3.8 ef	12
PU	87	58	1/2 20 DT + 1/2 5-7 DBPI	0	3.7 c	4.4 abcd	11
PU	87	58	1/2 20 DT + 1/2 5-7 DBPI	5	4.0 bc	4.2 cd	10
PU	87	58	Researchers' split[e]	0	4.4 ab	4.4 abcd	11
PU	87	58	Researchers' split[f]	0	4.1 bc	4.1 de	11
USG	87	58	Hand point placement	0	4.6 ab	4.6 ab	41
USG	87	58	Hand point placement	5	4.8 a	4.7 a	46
PU	91	57	Point placement by pneumatic injector[g]	0	4.8 a	4.2 cd	46
PU	91	57	Point placement by pneumatic injector[h]	0	4.8 a	4.3 bcd	47
PU	91	55	Point placement by pneumatic injector	5	4.6 ab	4.3 bcd	52
PU	89	56	Point placement by pneumatic injector	10	4.8 a	4.5 abc	70

[a]All point placement application was done at 4 d after transplanting (DT). [b]Av of 2 seasons. [c]CV = 9.2% for DS and 5.8% for WS. [d]1/2 at 10 DT + 1/2 at 10 d after panicle initiation. [e]Reflooded 1 d after fertilizer incorporation before transplanting. [f]Reflooded 4 d after fertilizer incorporation before transplanting. [g]Reflooded immediately after fertilizer was applied. [h]Reflooded 4 d after fertilizer was applied

Table 14. Effect of urea source, application method, and water depth on grain yield of IR64. IRRI, 1987 DS.

Urea source	N applied (kg/ha)	Application method	Water depth (cm) during fertilizer application	Grain yield[a] (t/ha)
–	0	No fertilizer N	–	3.7 e
PU	58	Farmers' split	4.8	4.3 de
PU	58	Researchers' split	0	4.8 bcd
USG	58	Point placement by hand[b]	5.1	5.2 abc
PU	58	Band placement by plunger-auger[b]	4.8	5.2 abc
USG	48	Point placement by press wedge[b]	4.8	4.6 cd
PU	58	Band placement by plunger-auger (4-row)[c]	0	5.1 abc
USG	57	Point placement by press wedge (4-row)[c]	0	4.7 bcd
PU	87	Farmers' split	5.1	5.1 abc
PU	87	Researchers' split	0	5.4 ab
USG	87	Point placement by hand[b]	5.1	5.5 a

[a]CV = 8.3%. [b]Applied at 5 DT. [c]Applied at 1 d before transplanting.

MANAGEMENT OF FERTILIZER NITROGEN AND WATER IN LOWLAND RICE

The effect of water regime, N source, and various N application timing and methods on the grain yield of IR64 was evaluated during DS.

Grain yield did not significantly differ among water regimes, probably because of a high groundwater table. The researchers' split, the recommended N application method, significantly outyielded the farmers' practice in all water regimes (Table 15). The researchers' split yielded comparably with a single basal dose of slow-release SCU, all basal point-placed USG, and 2/3 point-placed USG + 1/3 topdressed PU at 5-7 DBPI. Results suggest that researchers' split application, deep placement of N, and slow-release SCU are better than the farmers' practice in rainfed areas with alternate wetting and drying of soil.

All N fertilized plots yielded significantly higher than nonfertilized plots.

NITROGEN FERTILIZER MANAGEMENT UNDER SIMULATED RAINFED LOWLAND CONDITIONS

Rice yield response to different N fertilizer management techniques using the line source sprinkler (LSS) system was again measured. There were five irrigation levels and three N treatments; P at 13 kg/ha and K at 25 kg/ha were basally applied to IR64, the test variety.

Fertilizers were applied and rice was transplanted on drained soil with no standing water. The first irrigation to about 2-cm water depth was at 3 DT. Irrigation level L1 represented continuously flooded rice; it received equal water from LSS as did L2, but surface irrigation was needed to maintain 5-cm continuous flooding. At 10 DT, the standing water in L2-L5 was allowed to dry. Irrigation by LSS, positioned between L1 and L2, started at 14 DT and was used 3 times a week up to 40 DT. L2-L4 received a decreasing amount of water from LSS during the stress period. L5, the most stressed treatment, did not receive water from LSS.

Pan evaporation was used to determine the water to be applied by LSS. The whole field was reflooded to about 5 cm from 43 DT to 10 d before harvest (DBH).

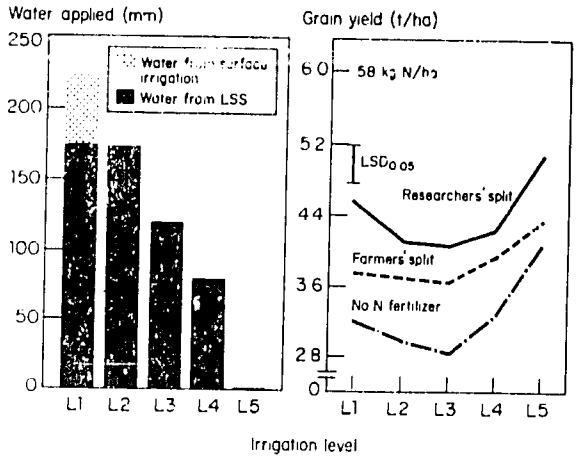
Continuously flooded plots received the most water (Fig. 21). L2, L3, L4, and L5 received 173, 120, 79, and 0 mm of water from LSS, respectively. The degree of soil cracking increased with increasing water stress. Alternate wetting and drying cycles occurred in L2-L4.

Under any water regime, the researchers' split of PU (2/3 B&I into mud + 1/3 at 5-7 DBPI) outyielded the farmers' split of PU (1/2 topdressed at 10 DT and 1/2 at 10 DAPI) by as much as 0.29 t/ha in L4 to 0.76 t/ha in L1 (Fig. 21). Regardless of N treatment, L5 produced higher yields than did L1. This may be the result of high mineralization of native N before and after reflooding, as evident from the response curve of the no-N fertilizer treatment at different moisture regimes. Lower yields in L3 were attributed to

Table 15. Effect of water management and N application method on grain yield of IR64. IRRI, 1987 DS.

N treatment	Grain yield[a] (t/ha)				N mean
	Continuously flooded	Nonflooded during maximum tillering	Nonflooded at PI to flowering	Nonflooded at flowering to dough	
No fertilizer N	3.0 d	2.7 c	2.6 c	3.1 c	2.8
PU, farmers' split	4.4 c	3.7 b	4.1 b	3.9 b	4.0
PU, researchers' split	5.3 ab	5.5 a	5.0 a	5.6 a	5.4
USG, hand point placement	5.7 a	5.4 a	5.0 a	5.4 a	5.4
2/3 hand point-placed as USG + 1/3 topdressed at 5-7 DBPI as PU	5.9 a	5.7 a	5.2 a	5.6 a	5.6
SCU, B&I	4.7 bc	5.3 a	5.2 a	5.8 a	5.3
Water mean	4.8	4.7	4.5	4.9	

[a]CV = 8%. Maximum tillering = 20-35 d after transplanting (DT) (15 d), PI to flowering = 41-67 DT (26 d), flowering to dough = 69-83 DT (14 d).



21. Total water applied from the line source sprinkler (LSS) and surface irrigation during the stress period, and grain yield of IR64 as affected by irrigation and N treatments. IRRI, 1987 DS. L1 = continuously flooded, L5 = the most stressed treatment.

alternate wetting and drying, which may have caused substantial N loss through sequential nitrification and denitrification. Besides denitrification, NO_3 leaching through soil cracks may have contributed to N loss.

The increasing yield trend in L4 and L5 was matched by increasing plant height, tiller number, and panicle number.

Results suggest that in areas of limited water supply and relatively fertile soil, withholding water temporarily can tap more native N for plant use. This practice increases water use efficiency.

RICE RESPONSE TO NITROGEN FERTILIZER MANAGEMENT AND WATER DEFICIT

The effects of fertilizer application time and method on lowland TPR were studied under varying degrees of water deficit. The researchers' split (PU, 2/3 B&I into mud + 1/3 at PI) was compared with USG hand-placed (at about 10-cm depth) at 1 DT. Six water management treatments were the main plots, and two N treatments were subplots in a split-plot design. IR64 was the test variety.

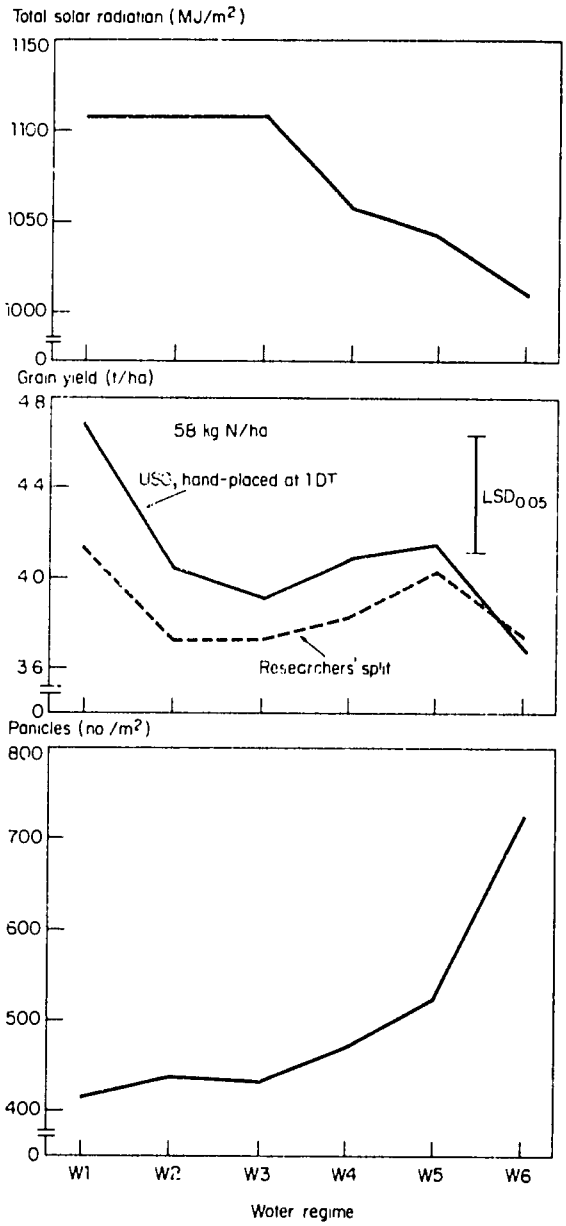
All plots were surface irrigated to about 2-cm water depth starting at 3 DT. Water regime W1 represented continuously flooded rice. At 10 DT, irrigation was withheld in W2, W3, W4, W5, and W6; the plots were rewatered only to 5-cm depth at desired growth stages after imposing 7, 14, 21, 28, and 35 stress days, respectively. Each main plot was surrounded with polyethylene sheets buried 50 cm into the soil to impound water and minimize seepage.

Except in W6, hand-placed USG at 1 DT consistently outyielded the researchers' split in all water regimes, especially under continuous flooding (W1). The mean yield (4.1 t/ha) of the USG N treatment across all water regimes was significantly higher than that of the researchers' split (3.8 t/ha). Yield increased in W4 and W5, perhaps because higher mineralization of applied and native N increased panicle number (Fig. 22). However, this was not reflected in yield higher than in W1, partly because of the lower total solar radiation at 55 DBH in W4, W5, and W6. Severe water deficit prolonged crop maturity, which coincided with low solar radiation. In W6, maturity was delayed by 13 d so that the total solar radiation at 55 DBH was only 1008 MJ/m^2 compared with 1102 MJ/m^2 in W1, a difference of 94 MJ/m^2 (about 2247 cal/cm^2).

Results indicate that deep-placed fertilizer proved advantageous under a wide range of soil moisture deficits during the vegetative phase.

WATER DEFICIT AND NITROGEN FERTILIZATION EFFECTS ON SIMULATED RAINFED LOWLAND RICE

The effects of water deficit and urea fertilizer timing on loss of applied N, crop development, and grain yield of IR64 were examined in a collaborative study with IFDC. The study was conducted in a farmer's field in Pila, Laguna, during 1986 and 1987 DS. The experimental design was a split plot with four replications. Main plot treatments were 3 water regimes: W1 = continuously flooded; W2 = vegetative phase water deficit, nonflooded from 15 to 35 DT; and W3 = reproductive phase water deficit, nonflooded from 41 to 63 DT. Subplot treatments were 3 N timings: N0 = no applied N; N1 = 80 kg urea N/ha, 1/2 B&I into mud before transplanting + 1/2 broadcast into 5-cm floodwater at 37 DT; and N2 = 80 kg urea N/ha, 1/2 broadcast into floodwater at 11 DT + 1/2 broadcast into 5-cm floodwater at 65 DT.

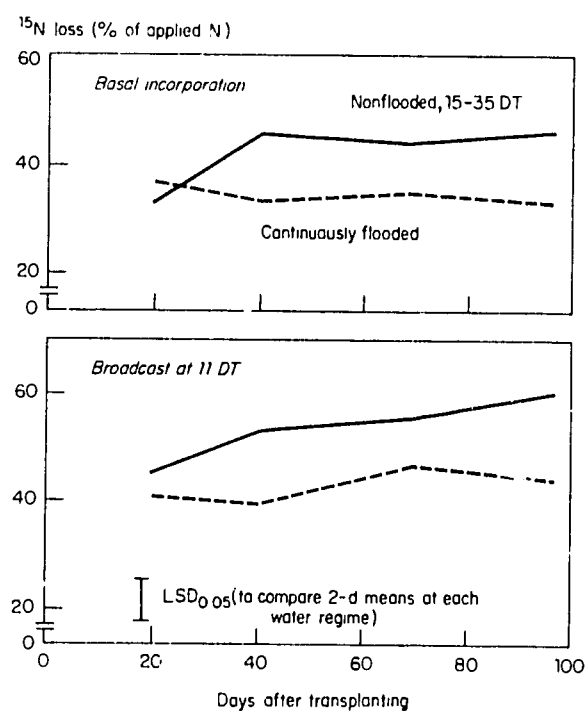


22. Grain yield and panicle number of IR64 as affected by water and N treatments and total solar radiation received by the crop at 55 d before harvest, IRRI, 1987 DS. DT = days after transplanting. W1 = continuous flooding, W2 = 7-d stress, W3 = 14-d stress, W4 = 21-d stress, W5 = 28-d stress, W6 = 35-d stress.

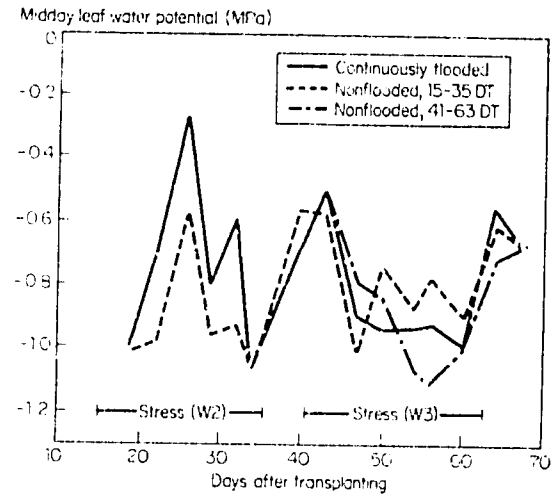
Loss of added nitrogen. The first application of 40 kg urea N/ha in treatments N1 and N2 was labeled with ^{15}N. Loss of added ^{15}N was determined from unaccounted for ^{15}N in ^{15}N balances at 20, 41, and 69 DT and at crop maturity.

Large losses of added N occurred soon after urea application. Figure 23 shows that 33 and 37% of the basal applied N was lost by 20 DT, whereas 41 and 45% of the N broadcast at 11 DT was lost by 20 DT, 9 d after N application. Under continuous flooding, no significant additional N loss occurred after 20 DT with either N application method. Water deficit during the vegetative phase (nonflooded 15-35 DT) produced a significant additional loss of applied N between 20 and 41 DT. Soil drying followed by reflooding, common in rainfed lowland ricefields, can increase the total loss of applied N over the cropping period. Measurements of soil nitrate, ^{15}N-labeled gas formation in the soil, and ^{15}N-labeled gas flux in this field experiment confirmed that at least some of the N loss in a period of water deficit was by nitrification-denitrification.

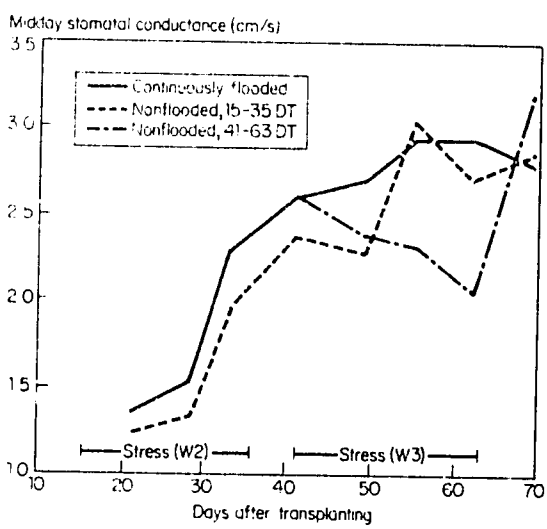
Plant water status. Although both vegetative (W2) and reproductive (W3) phase water deficits reduced leaf water potential (Fig. 24) and stomatal conductance (Fig. 25) compared with W1, stress levels were apparently mild. N fertilization effects



23. Effect of water regime and timing of urea application on loss of added N, Pila, Laguna, Philippines, 1986 DS. DT = days after transplanting.



24. Effect of water regime on midday leaf water potential of IR64 in Pila, Laguna, Philippines, 1987. DT = days after transplanting, W2 = vegetative phase, W3 = reproductive phase.

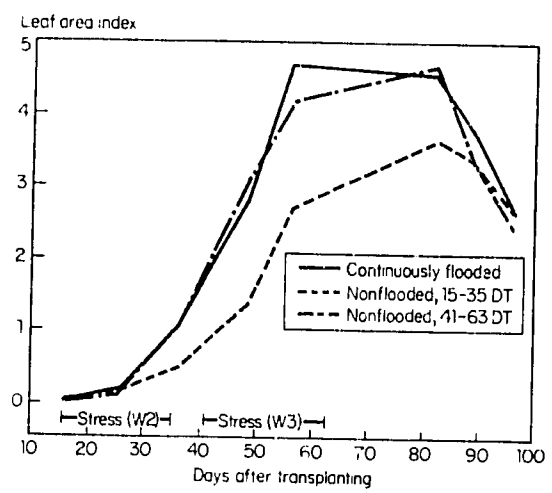


25. Effect of water regime on midday stomatal conductance of IR64, Pila, Laguna, Philippines, 1987. DT = days after transplanting.

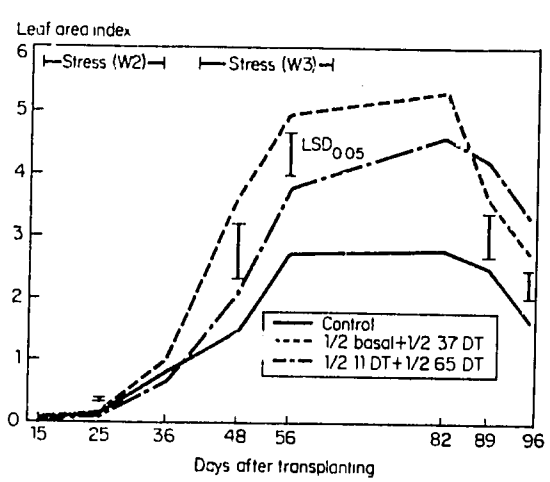
on water relations were small, but application of N reduced water deficit effects, and early N application (N1) seemed better than delayed N application (N2) during water deficit. Seasonal and crop growth stage factors had greater impact on leaf water potential and stomatal conductance than did water deficit and N fertilization treatments.

Leaf area index. Leaf area index (LAI) in W2 was about 50% that in W1 at 36 DT (Fig. 26), an effect that persisted even after reflooding. On the other hand, LAI in W3 was not affected by water deficit. N fertilization increased LAI (Fig. 27). LAI increased faster in N1 than in N2 but was maintained longer in N2. For N0, LAI never reached 3; therefore, full light interception was never reached.

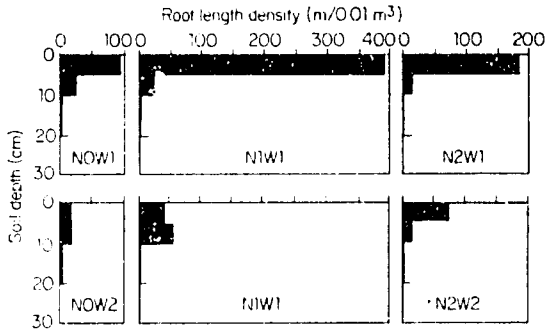
Root length. At the end of the vegetative phase water deficit, root length density (RLD) in the 0- to 5-cm soil layer was less in W2 than in W1 for all N treatments (Fig. 28). Water deficit had relatively less effect on RLD in deeper soil layers except for N1, where RLD of W2 was greater than that of W1 in the 5- to 10-cm soil layer. Addition of N



26. Effect of water regime on leaf area index of IR64, Pila, Laguna, Philippines, 1987. DT = days after transplanting.



27. Effect of N fertilization on leaf area index of IR64, Pila, Laguna, Philippines, 1987 DS. DT = days after transplanting.



28. Effect of N fertilization and water regimes on root length of IR64 at 36 d after transplanting, Pila, Laguna, Philippines, 1987 DS. N0 = no fertilizer, N1 = early N application, N2 = delayed N application, W1 = continuous flooding, W2 = vegetative-phase water stress, W3 = reproductive-phase water stress.

fertilizer, especially early application, enhanced root elongation and growth, which may have conferred resistance to water deficit.

At 63 DT, RLDs in W2 treatments had not recovered to the levels in W1 treatments, and RLDs in W3 treatments were reduced to about the same levels as those in W2 treatments (Fig. 29). In W1, N fertilization increased RLD in the 0- to 5-cm soil layer, but not in deeper soil layers (Fig. 29). In W2 and W3, RLD in the 0- to 5-cm soil layer was greatest in N1.

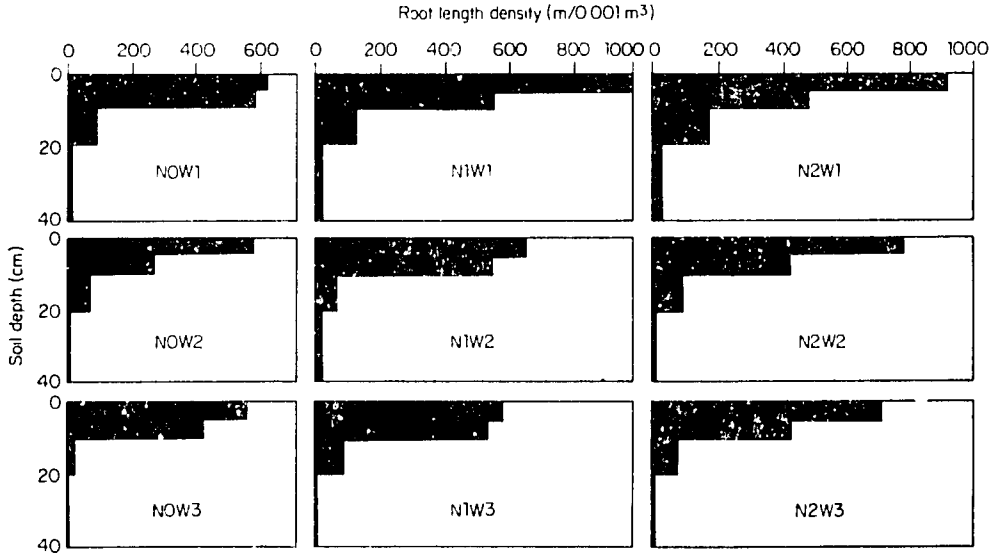
Grain yield and nitrogen accumulation. Water deficits reduced grain yield and N accumulation by the plant (Table 16). Reductions were greater with water deficit during the vegetative phase (nonflooded 15-35 DT) than during the reproductive phase (nonflooded 41-63 DT).

Grain yield and N accumulation by the plant increased with applied N (Table 16). Early N application (1/2 basal + 1/2 at 37 DT) gave 0.4 t/ha greater grain yield than delayed application (1/2 at 11 DT + 1/2 at 65 DT). However, the timing of N application did not significantly (P =

Table 16. Effect of water regime and urea fertilizer timing on grain yield and plant N of IR64, Pila, Laguna, Philippines, 1987 DS.

Treatment	Grain yield (t/ha)	Plant N (kg/ha)
Water regime (W)		
Continuously flooded	3.9	87
Nonflooded 15-35 DT	3.2	63
Nonflooded 41-63 DT	3.6	83
N timing (N)		
No applied N	2.4	54
1/2 basal + 1/2 at 37 DT[a]	4.1	84
1/2 at 11 DT + 1/2 at 65 DT	3.7	88

[a]There were 8 replications for this treatment and 4 replications for all others. DT = days after transplanting.



29. Effect of N fertilization and water regimes on root length of IR64 at 63 d after transplanting, Pila, Laguna, Philippines, 1987 DS.

0.05) affect N accumulated by the plant. Lower grain and straw yields with delayed N were compensated for by higher % N concentration of the grain and straw.

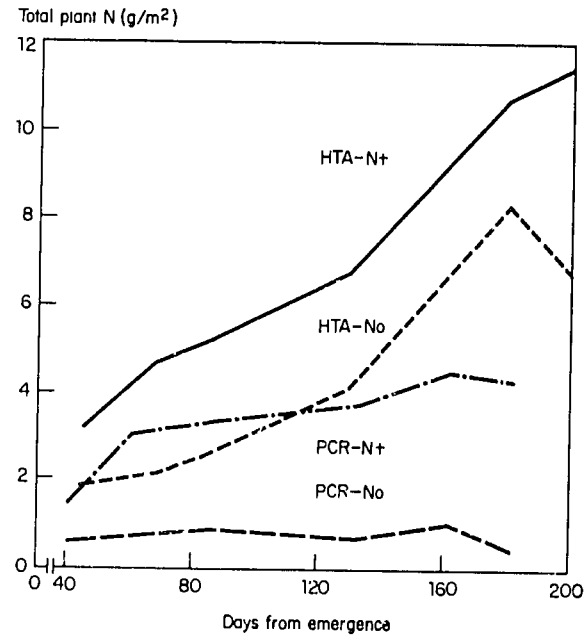
Reproductive phase water deficit, before flowering, was less detrimental to leaf water potential, stomatal conductance, LAI, N uptake, and grain yield than vegetative phase water deficit. Early N application enhanced root growth to enable plants to better withstand water deficit.

NITROGEN UPTAKE OF DEEPWATER RICE

Calculating the N fertilizer requirements of deepwater rice (DWR) is complex because of the crop's long growth duration, periods of drought and flood, the movement of N with floodwater, and the unknown contribution of N from floodwater and by biological fixation. To better understand the N responses, we conducted experiments in Thailand on an acid sulfate soil in Prachinburi and on a less acid soil in Huntra in 1986 WS.

Grain yields did not show clear differences between treatments in Huntra, but in Prachinburi the check was low and there was a wider spread of yields (Table 17).

However, samples for determination of dry weight and N concentration taken on six occasions from the start of flooding showed markedly different patterns of growth and N uptake between fertilized and unfertilized treatments and between sites (Table 17, Fig. 30). The check treatment in



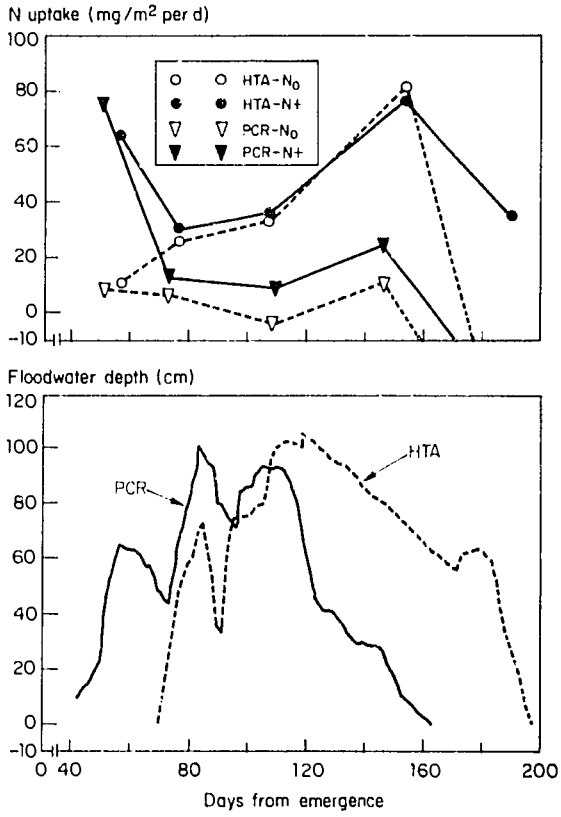
30. Total N uptake for mean of treatments with 75 kg N/ha in 2 applications (treatments 3, 4, 6, and 7) and for check treatments at Prachinburi (variety RD19) and Huntra (SPR7270-18), 1986 WS. HTA = Huntra, PCR = Prachinburi.

Huntra had a much higher N uptake than the fertilized treatments in Prachinburi. At both sites, the rate of N uptake in the fertilized plots decreased as the water level rose (Fig. 31), but in Huntra the check and the fertilized treatments increased in N uptake to about 80 mg/m^2 per day as the water rose to a maximum. In Prachinburi, the plants

Table 17. Treatments, dry matter production, and grain yields in N uptake experiments with deepwater rice in Prachinburi (RD19 variety) and Huntra (SPR7270-18), Thailand, 1986 WS.[a]

Treatment no.	N (kg/ha)				Dry weight (t/ha) at 181 DE		Yield (t/ha)	
	B&I[b]	Broadcast (DE)	Broadcast preflood	USG[c] at 5 cm water	Prachinburi	Huntra	Prachinburi	Huntra
1	–	–	–	–	1.0 e	11.4 b	1.33 b	2.91 ab
2	37	–	–	–	5.8 cd	13.5 ab	2.11 ab	3.06 a
3	37	–	37	–	6.3 bcd	13.9 ab	2.58 a	2.90 ab
4	37	–	–	37	10.2 a	13.5 ab	2.99 a	2.86 ab
5	–	37	–	–	4.9 d	14.3 ab	2.13 a	2.98 a
6	–	37	37	–	8.8 ab	16.4 a	2.88 a	2.42 b
7	–	37	–	37	8.2 abc	14.1 ab	2.79 a	2.87 ab
8	–	–	–	37	4.4 d	11.5 b	1.96 ab	2.98 a

[a]DE = days after emergence. [b]B&I = basal, incorporated. [c]Urea supergranules. Other treatments used prilled urea. All treatments received 8 kg P/ha.



31. Rate of N uptake for plots with 75 kg N fertilizer/ha and without N fertilizer, in relation to water level changes. Prachinburi and Huntra, Thailand, 1986 WS.

were younger at flood commencement, and check plots were completely submerged by the rapid increase in water level 75 d after seedling emergence. Even the fertilized plots were reduced to a N uptake of about 10 mg/m^2 per day, with only a slightly higher rate later in the season, and dry matter production was low.

The high rate of N uptake in Huntra late in the flood period was associated with high dry matter production, and could be a result of a high level of N-fixing activity in the floodwater or of a ready uptake of N from the submerged soil. High N uptake associated with high dry matter production and lack of grain yield response to N fertilizer indicates that N requirements of DWR could be estimated from the production of dry matter unfertilized fields.

Soil and crop management

Nitrogen fixation and azolla management

Soil Microbiology and Training and Technology Transfer Departments

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BACTERIAL NITROGEN FIXATION

Soil Microbiology Department

Nitrogen fixation by rice seedlings inoculated with free-living and symbiotic bacteria under gnotobiotic conditions. The ability of free-living N_2-fixing azospirilla and symbiotic rhizobia to fix N in the root zone of rice was studied using rice seedlings grown aseptically under light. Bacterial inoculation was made 2 d after seedling transfer, and acetylene-reducing activity (ARA) was measured 8 d after inoculation.

Seedlings of IR42 showed substantial ARA when inoculated with *Azospirillum lipoferum* 34H, an isolate from wetland rice roots (365 nmol C_2H_4 plant per 24 h), or *Azorhizobium caulinodans* ORS 571, an isolate from stem nodules of *Sesbania rostrata* (368 nmol C_2H_4 tube per 24 h). *Azospirillum brasilense* Sp7 from *Digitaria* showed significantly higher ARA (51 nmol C_2H_4 tube per 24 h) than the uninoculated control (3 nmol C_2H_4 tube per 24 h). Rhizobia isolated from *Sesbania aculeata*, *S. sesban*, *Trifolium* sp., or *Vigna unguiculata* showed negligible ARA.

Growth and yield responses of rice to inoculation with various root-associated diazotrophs in the presence of combined nitrogen under greenhouse conditions. We studied root and shoot growth and grain yield responses of rice variety IR42 to inoculation with 23 strains of N_2-fixing bacteria belonging to *Herbaspirillum*, *Azospirillum*, *Pseudomonas*, *Klebsiella*, *Enterobacter*, and *Azorhizobium*. The soil was amended with powdered rice straw at 5 t/ha, incorporated 12 d before transplanting, and fertilizer was applied. Bacteria-inoculated seeds were germinated, and seedlings were transplanted. Before transplanting, 5 ml of bacterial suspension (10^8 colony-forming units [CFU]/ml) pot was thoroughly mixed into the soil.

Plant growth was not affected significantly by inoculation at maximum tillering. At harvest, eight strains—*Herbaspirillum* HS; *Azospirillum lipoferum* AT; *Enterobacter* EUF 26-11, EUF 26-12, IR5-6; *Pseudomonas diazotrophicus* H8; *P. saccharophila* PD; and *Azorhizobium caulinodans* ORS 571—affected plant growth or yield. Root-to-shoot ratio, plant height, or shoot dry weight was increased significantly by ORS 571 and IR5-6. Significant grain yield increases of 23% and 42% were obtained only in treatments inoculated with IR5-6 and H8.

Agronomic and cultural practices affecting plant-associated nitrogen fixation. *Effect of inorganic and organic fertilizers.* We measured N_2-fixing activity (measured by ARA) associated with rice plants obtained from several field experiments with different inorganic N and organic fertilizers. Grain legume green manure (GM) (*Vigna radiata* mungbean and *Dolichos lablab* lablab), nongrain legume GM sesbania and crotalaria, inorganic N fertilizer (urea), nonlegume GM azolla, and rice straw and farmyard manure were compared. We correlated the average N applied in each treatment with increases in ARA and plant dry weight over those of controls.

Table 1 summarizes the data on ARA per plant, ARA/g of plant dry weight, and plant dry weight at heading. ARA per plant increased in all treatments. ARA/g of plant dry weight seemed slightly lower in all treatments except in the grain legume GM treatment, which increased an average of 27%. On the other hand, plant dry weight increased in all treatments, suggesting that applying inorganic N and organic fertilizers enhanced either plant growth or N_2 fixation per plant.

Effect of rice spacing and nitrogen source. In an experiment of the Multiple Cropping Department (1985 dry season [DS]), the second IR64 crop had the following treatments with 4 replications: 1 main factor consisted of 1) control (no N), 2) 60 kg N/ha as $(NH_4)_2SO_4$, and 3) *S. rostrata* incorporation. Another factor was rice plant spacing: 10 × 10, 12.5 × 12.5, 15 × 15, 20 × 20, and 25 × 25 cm. Rice plant-associated ARA and plant biomass were measured at 28 and 43 d after transplanting (DT) and at heading.

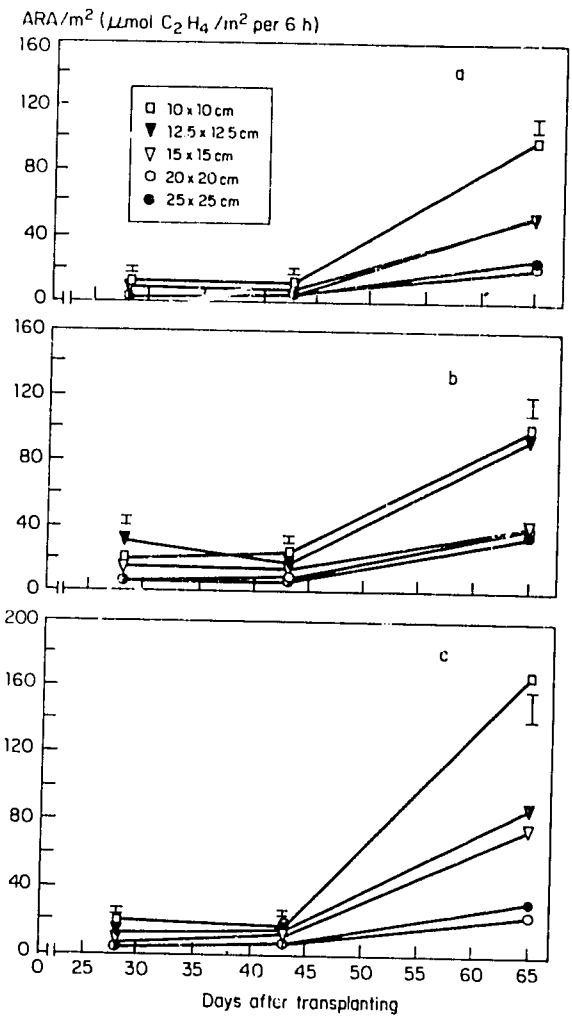
ARA per plant was not affected much by spacing. Total dry weights of aboveground material and roots per hill were significantly affected by spacing only at 28 and 43 DT. However, spacing on an area basis significantly affected these measures. Plant ARA/m^2 was at least 4 times higher at 10- × 10-cm spacing than at 25- × 25-cm (Fig. 1).

Varietal differences in associative nitrogen fixation. In 1986 DS, we measured N_2-fixation (measured by ARA) associated with the rice plant and the N uptake of 50 rice varieties and lines

Table 1. Effects of inorganic N and organic fertilizers on rice plant-associated acetylene-reducing activity (ARA) at heading.[a] IRRI, 1987.

N-incorporating treatment	Trials (no.)	N applied (kg/ha)		Increase (%) over control					
				ARA/plant		ARA/g plant dry weight		Plant dry weight	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
Grain legume GM	3	90	7.1	64	29.8	26.6	5.9	30.2	17.1
Nongrain legume GM	8	129	15.2	50.8	16.5	- 2.6	7.6	45.7	8.7
Urea	17	77	8	28.0	6.8	- 8.8	2.8	37.8	7.7
Nonlegume GM	3	100	7	12.2	14.6	-16.4	16.1	41.6	16.6
Rice straw and farmyard manure	5	83	18	4.4	8.6	- 4.6	10.0	15.4	8.1

[a]GM = green manure, SE = standard error of mean.



1. Effect of rice spacing on acetylene reducing activity (ARA) associated with rice grown with a) no N, b) inorganic N (60 kg N/ha), and c) *Sesbania rostrata* incorporation. IRRI, 1987.

grown in a wetland field without N fertilizer. The ARA of each variety was measured in 18 replicated plants for 3 consecutive days at heading.

Significant differences in ARA per plant and N uptake were observed among the short-, medium-, and long-duration groups. Among 23 short-duration varieties, C5444 and KNIB-361-1-8-6-10 ranked highest in ARA per plant—higher than IR50, which performed best in the previous seasons. Among 16 medium-duration varieties, Kulu and BR-51-46-1-C-1 exhibited the highest ARA per plant similar to IR19672-140-2-3-22, which gave the highest ARA per plant during the 1985 DS trial. Among 11 long-duration varieties, Pelita-I-1 and Intan ranked highest—higher than in previous seasons.

N uptake ranged from 283 to 496 mg N/plant in the short-duration group, 260 to 613 mg in the medium-duration group, and 365 to 528 mg in the long-duration group. The highest N uptake was exhibited by IR32453-20-3-2-2, followed by IR21820-154-3-2-2-3—both medium-duration varieties.

PHOTODEPENDENT NITROGEN FIXATION

Soil Microbiology Department

Blue-green algae collection. Trials of conservation by desiccation showed that 10 dried and powdered blue-green algae (BGA) cultures prepared 5 yr ago and 37 soil-based monostrain inocula prepared 3 yr ago had retained their viability. Among 135 cultures deposited on small paper strips and dried

at room temperature, 30 were lost after 16 mo of storage. Losses increased linearly with time. Conservation on paper strips is convenient for short-term conservation, including mailing of the strains, but currently is not suitable for long-term conservation.

Standardization of methods for field studies. *Bias in microbiological counts by plating.* We analyzed 1,215 plate counts of soil BGA by 4 independent operators and found that counts with a low value for the first digit (1-5) were more frequent than those with a high value (5-9), whereas an equal probability of values from 1 to 9 is expected.

This bias exists because dishes with more than 50 colonies are usually excluded from the lower dilution counts and are counted at the next higher dilution; however, the ratio between counts at 2 consecutive 10-fold dilutions was found to be about 6:1 (av of 589 data). As a result, counts on plates with 60 to 100 colonies are replaced by counts at the next dilution, on plates having 6 times fewer colonies, i.e., 10 to 17, which leads to more counts whose first digit is 1.

Standardization of ARA measurements. Experiments to determine the conversion rate from acetylene reduced to N_2 fixed for ARA measurements of photodependent N_2-fixation of soil core samples showed that the composition of the atmosphere of incubation used during measurement of ^{15}N incorporation strongly influences specific $^{15}N_2$ fixation of BGA. In 14 trials, specific ARA ranged from 0.65 to 2.45 nmol C_2H_2 mg algal protein per min, agreeing with previous measurements. On the other hand, specific $^{15}N_2$ fixation exhibited very large variations from 0.02 to 0.57 nmol N_2/mg algal protein per min. Replacing part of $^{15}N_2$ by Ar to utilize less $^{15}N_2$ and increasing CO_2 concentration markedly decreased the specific $^{15}N_2$-fixing activity, possibly because of a lower solubility of $^{15}N_2$ at its low partial pressure.

An average factor of 4.7, close to the theoretical value of 4, was obtained when partial pressures of N_2, O_2, and CO_2 used for incubation with $^{15}N_2$ were similar to those used for incubation under acetylene.

Occurrence of nitrogen-fixing blue-green algae in rice soils. A survey of BGA in 10 rice soils from Madagascar (pH 4.5-6.4, 2-11 ppm Olsen P) and 12 Egyptian soils from the Nile Delta (pH 7.6-8.1, 5.2-51 ppm Olsen P) recorded N_2-fixing strains in all soils. In Madagascar soils, BGA densities ranged from 4×10^3 to 2×10^4 and were correlated with soil pH and available P. In alkaline Egyptian soils collected in dry fields, densities ranged from 9×10^3 to 2×10^5 and were not correlated with pH or available P of the soil.

Method of application of phosphorus and blue-green algae growth. The effect of the method of P fertilizer application on the productivity and N_2-fixing activity of BGA was studied in a greenhouse microplot experiment. Split surface application increased BGA production 6 times more than incorporation and 1-2 times more than basal surface application. N-balance measurements after 30 d showed too large variability of the soil N among replications to allow conclusions. The maximum ratio between N accumulated and P applied was 3.2 after 1 mo.

Effect of straw on photodependent biological nitrogen fixation. A DS experiment studied the effect of incorporation and surface application of straw on pH and dissolved O_2 in the floodwater, photodependent ARA, and BGA populations. Straw application reduced O_2 concentration (av of −12%) and pH in the floodwater. Reduction was greater when straw was incorporated than when surface applied. BGA biomass was consistently lower in plots where straw had been incorporated. The highest biomass (19 t fresh weight/ha), recorded at 42 DT in plots where straw was surface applied, did not significantly differ from that in the control without N (15 t fresh weight/ha).

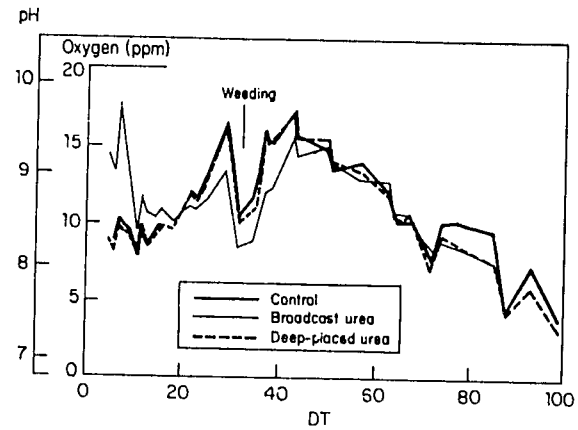
Straw application had no effect on the composition of the BGA biomass. ARA was higher in the treatment where straw was surface applied and in the control with no basal N than in the treatment where straw was incorporated and in the control with basal N. Large populations of aquatic snails (*Limnea* sp.) developed in plots where straw was surface applied. Photodependent ARA became negligible in all the treatments after urea broadcasting at panicle initiation.

Characterization of the photosynthetic aquatic biomass. We studied the ecology of the photosynthetic aquatic biomass (PAB) during DS in 65 plots 4 × 4 m in size (5 replications) receiving partial combinations of 4 treatments: urea (none, 55 kg N/ha split broadcast, 55 kg N/ha deep-placed), P fertilizer (control without P, 13 kg P in 3

splits in all treatments), BGA inoculation (none, 20 kg inoculum/ha), and neem seed to control algal grazers (none, 100 kg/ha).

O_2 concentration, pH and N and P contents of the floodwater, biomass of algae, aquatic macrophytes and weeds and their composition, and photodependent N_2-fixing activity (ARA) were measured at intervals during the crop cycle, which was marked by three major events:

- Surface application of urea caused a rapid blooming of unicellular green algae at 4-5 DT, increasing the O_2 content of the floodwater to 20 ppm and its pH to 10 at noon (Fig. 2). Resulting high losses of N by NH_3 volatilization are reflected in the absence of yield response to broadcast urea (Table 2).
- Irrigation water was passing through a cooling plot where a spontaneous growth of mucilaginous N_2-fixing BGA (*Aphanothece*, *Nostoc*, *Gloeotrichia*) provided a continuous reinoculation of the plots with indigenous BGA. This, together with N losses, established BGA at 35 DT in plots where urea had been broadcast (Fig. 3), whereas in 2 previous crops in the same field, split urea almost completely inhibited BGA. Dense blooms of mucilaginous BGA became established early in the control and in the treatment where urea was deep-placed.
- Azolla that spread from surrounding plots started to grow at 72 DT. It grew better in the plots where urea was broadcast.

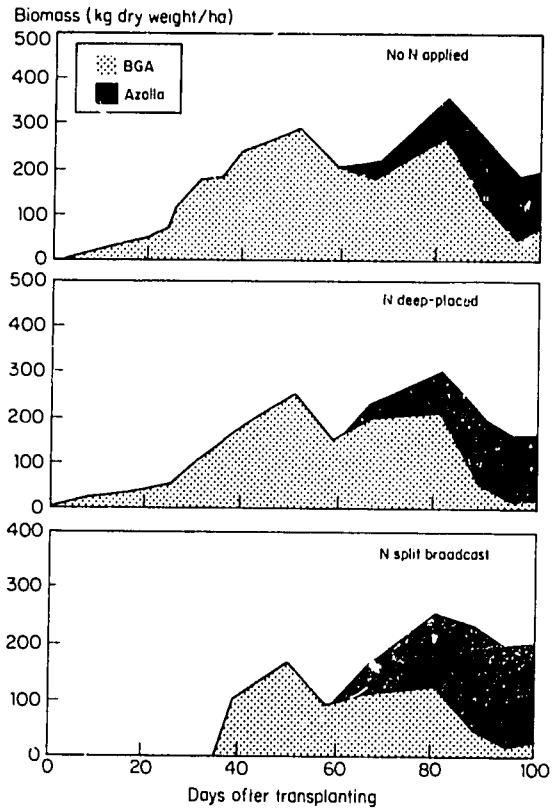


2. Dynamics of O_2 concentration and pH of the floodwater at 1300 h according to N fertilizer status. IRRI, 1987.

Table 2. Effects of blue-green algae (BGA) inoculation, neem seed application, and N fertilizer management on grain yield and photodependent ARA, and maximum N content of the photosynthetic biomass. IRRI, 1987.

BGA	Neem seed	N	Yield (t/ha)	Average ARA (μmol C_2H_2/m^2 per h)		Maximum biomass (kg N/ha)	
				1-120 d[a]	1-72 d[b]	All	BGA
–	–	0	3.8 bc	250 abc	238 abc	11.2 bcd	8.2 bcd
–	–	Split	3.9 bc	210 bc	182 bc	8.4 d	6.3 cde
–	–	Deep-placed	5.4 a	268 abc	223 abc	11.9 abcd	8.0 bcd
–	+	0	4.2 b	290 ab	301 a	11.2 bcd	9.2 abc
–	+	Split	3.6 bc	240 abc	174 c	9.0 cd	3.6 e
–	+	Deep-placed	5.2 a	311 a	297 a	11.1 bcd	7.6 bcd
+	–	0	3.5 c	188 c	207 abc	10.8 bcd	9.2 abc
+	–	Split	3.8 bc	208 bc	143 c	12.1 abc	6.3 cde
+	–	Deep-placed	5.5 a	265 abc	221 abc	9.5 cd	8.0 bcd
+	+	0	4.1 bc	278 abc	285 ab	14.9 a	11.3 a
+	+	Split	4.3 b	190 c	153 c	10.9 bcd	5.7 de
+	+	Deep-placed	5.5 a	231 abc	136 bc	13.6 ab	10.1 ab
No N			3.9 b	251 a	268 a	12.0	9.5 a
N split			3.9 b	212 b	163 b	10.1	5.5 b
N deep-placed			5.3 a	268 a	232 a	11.5	8.4 a
Noninoculated			4.4	261	236	10.4	7.2
Inoculated			4.4	227	199	12.0	8.4
No neem seed			4.4	231	202	10.7	7.7
Neem seed applied			4.4	257	232	11.8	7.9

[a]Includes biological N fixation by BGA and azolla. [b]BGA were the only photodependent N_2 fixers.



3. Effect of N fertilizer management on the dynamics of blue-green algae and azolla populations. IRRI, 1987 DS.

The floating and submerged components of PAB were mostly mucilaginous N_2-fixing BGA for about 70 DT and then azolla and BGA (Fig.3). Other components were rooted, emersed weeds collected at 30 and 52 DT. The N content of the 2 weed harvests ranged from 3 to 19 kg/ha and averaged 8 kg N/ha.

N fertilizer management had effects on grain yield, maximum biomass of N_2-fixing BGA, and photodependent biological nitrogen fixation (BNF). The highest yield was recorded where urea was deep-placed.

ARA was higher in the control and when N was deep-placed (250-260 μmol C_2H_2/m^2 per h). Surface application of urea decreased the ARA of BGA by 45% and their maximal biomass by 42%. Because azolla grew better in plots where urea was broadcast, maximum PAB N was reduced only by 17%, and average ARA during the crop by 16% (Table 2).

P application increased ARA by 80% and grain yield by 480 kg/ha.

Because indigenous BGA grew spontaneously in almost all the plots, algal inoculation had no significant effect (Table 2).

Neem application increased photosynthetic activity the first 2 wk in the control and in the plots where N was deep-placed. Its marginal effect on BNF was at least partly due to growth of mucilaginous BGA, resistant to grazing, since the crop started.

Photosynthetic activity in the floodwater (Fig. 2) increased in the first 6 wk of the crop cycle and was affected by weeding. Surface application of urea enhanced photosynthetic activity early by favoring the growth of unicellular green algae that rapidly disappear as grazers establish. Thereafter, these plots had less algal growth until 50 DT. After 6 wk, O_2 in the floodwater decreased in all plots.

N content of the floodwater reached 50 ppm urea and 8 ppm NH_4 after urea broadcasting and decreased within 4 d to negligible values. As long as photosynthetic activity in the floodwater was increasing, the N content of the floodwater remained negligible in all treatments. Between 60 and 100 DT, when BGA started to decay, the NH_4 content of the floodwater ranged between 0.2 and 1 ppm, exhibiting variations negatively correlated with variations in BGA biomass.

Average ARA per plot (65 values) showed values equivalent to 2-42 kg N/ha per crop (mean 24 kg N/ha per crop, CV 31%).

A positive correlation was found between average ARA in the 65 plots and grain yield, which agreed with the high ARA and yields observed in plots where urea was deep-placed, and lower yields and ARA in plots where urea was broadcast.

No correlations were found between ARA levels and N treatments. This may result from the relatively low range of variation of average ARA values in each set of data but may also indicate that N fixed by the PAB was little utilized by the crop.

Analysis of BGA and azolla (Table 3) shows higher ash and N contents in BGA than in aquatic macrophytes. Average P content was higher in azolla than in BGA, probably because azolla was analyzed when actively growing, partly at the expense of the nutrients released by decaying BGA. P contents of BGA and azolla growing in the same

Table 3. Composition and nutrient content of the standing photosynthetic biomass when photodependent N_2-fixers are dominant. IRRI, 1987.

Component	Source	Data (no.)	Minimum	Maximum	Average	Median	Variance	CV (%)
				Composition				
Ash (%)	BGA	400	36.4	73.6	52.8	52.5	52.8	13.8
	Azolla	115	12.8	35.4	24.0	24.0	15.4	16.4
N (%), ash-free	BGA	400	3.3	7.2	5.0	5.0	0.5	13.9
	Azolla	112	2.7	6.0	4.1	4.0	0.3	13.0
P (%), ash-free	BGA	400	0.10	1.46	0.46	0.43	0.05	47.9
	Azolla	112	0.16	0.87	0.54	0.54	0.02	26.9
C (%), ash-free	BGA	400	16.8	45.7	33.8	34.3	15.5	11.6
	Azolla	110	30.3	45.3	37.8	38	8.1	7.5
C:N, ash-free	BGA	400	4	10.8	6.9	6.7	1.5	17.8
	Azolla	110	6.9	14	9.3	9.3	1.6	13.7
				Nutrient content (kg/ha)				
N	BGA	400	0.2	16.8	4.6	4	8.5	63.4
	All[a]	318	0.2	17.1	6.3	6.1	8.9	47.7
P	BGA	400	0.02	2.0	0.45	0.37	0.11	71.5
	All	318	0.02	2.0	0.63	0.60	0.2	55.0
C	BGA	400	1.15	132.4	30.8	30.0	345	60.3
	All	318	2.20	122.0	49.6	47.4	602	49.5

[a]Biomass comprising both BGA and azolla.

plots were positively correlated (% P in BGA = 0.68 % P in azolla + 0.17).

Records of the standing PAB (including ash) ranged from 0.2 to 17 kg N/ha, with an average of 6.3 kg N/ha (Table 3). Average biomass N was higher when BGA and azolla were present (6.3 kg N/ha) than when only BGA were present (4.6 kg N/ha).

The average ratio from estimated N_2 fixed to maximum N in standing PAB was about 2 to 1, indicating an average residence time of half a crop cycle.

AZOLLA

Soil Microbiology Department

Azolla collection and distribution. Through collaboration with the Université Catholique de Louvain (UCL) in Belgium, we secured 150 accessions from Van Hove's collections, bringing the total accessions to 353 in 1987 (Table 4). Among them, 20 are artificial strains. To accommodate more than a hundred accessions in one species code, we added another digit to the code numbers. The numerical codes to identify species (0-8) are assigned in the 1st digit. For example, previous accession no. 418 is now 4018 (species digit=4). Accessions from UCL were numbered from 501 in each species.

Table 4. Azolla collection as of 6 Nov 1987. IRRI, 1987.

Species	Code	Accessions (no.)		
		IRRI	UCL[a]	Total
A. pinnata var. *imbricata*	0	86	31	117
A. filiculoides	1	37	44	81
A. mexicana	2	5	0	5
A. caroliniana	3	18	26	44
A. microphylla	4	39	9	48
A. nilotica	5	1	0	1
A. rubra	6	5	4	9
A. pinnata var. *pinnata*	7	15	31	46
Unclassified	8	1	1	2
Total		207	146	353
Hybrids				20

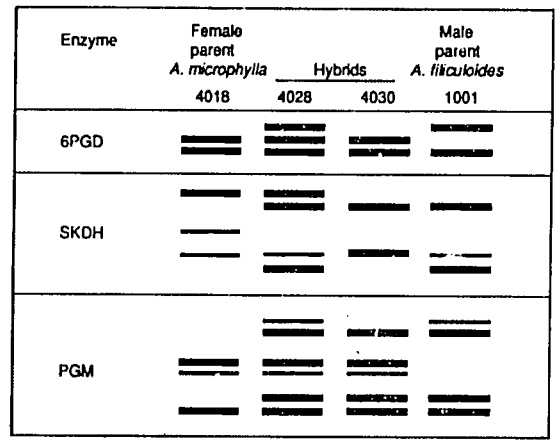
[a]UCL (Université Catholique de Louvain) strains similar to those in the IRRI collection are not included.

In response to requests, 243 accessions were sent to 27 people from 10 countries. *A. microphylla* was most requested.

Biochemical classification. To classify and identify species and strains, biochemical classification is useful. In collaboration with T. Lumpkin of Washington State University in the USA, polyacrylamide gel electrophoresis for isoenzymes of the azolla leaf was standardized. Fifteen enzymes were tested. Among them, shikimic dehydrogenase (SKD) and 6-phosphogluconate dehydrogenase (6 PGD) were most useful for separating accessions. Because zymograms (electrophoresis patterns in isozymes) of roots were different from those of leaves including stems, roots were removed from the azolla samples. Zymograms of *Anabaena*-free azolla were similar to those of corresponding symbiotic azolla, indicating that the enzymes in the algae are not extracted. The effects of physiological conditions of azolla on zymograms were also small. Zymograms of *Rhizosperma* and *Azolla* were distinctly different. Zymograms of *A. microphylla* strains showed great geographical variability.

Hybridization. Sexual hybridization was successful. After emasculation (manually removing massulae attached to megasporocarps), massulae of another species were mixed with megasporocarps. *A. filiculoides* (1001) and *A. microphylla* (4018) were used as male or female parents. When *A. microphylla* was used as a female parent, many albino sporophytes appeared among 765 crossed megasporocarps, but only 3 strains survived. Among them, one strain (4029) was *Anabaena*-free. Zymograms of hybrids (4028, 4030) were compared with those of the parents (Fig. 4). The enzyme bands common to the parents appeared in the hybrids, confirming the hybridization. The hybrid plants showed red pigments in the field, but *A. microphylla* 4018 did not. During cooler season in Los Baños, the hybrids developed longer stems than *A. microphylla*, but slightly shorter than *A. filiculoides*. Elongated stems are characteristic of *A. filiculoides*. No megasporocarps, but only microsporocarps were formed on the hybrids. There are no or few septa in the glochidia of the massulae of the hybrids, as in *A. filiculoides*.

Screening for high temperature tolerance. *Stepwise increase of temperature.* An azolla strain grown for 5 d at 22 °C (26 light/18 dark) was transferred to a small cup (6.3 cm diameter) and kept under controlled light (30 klx, 12/12 h light-dark period with 8 °C difference between periods).

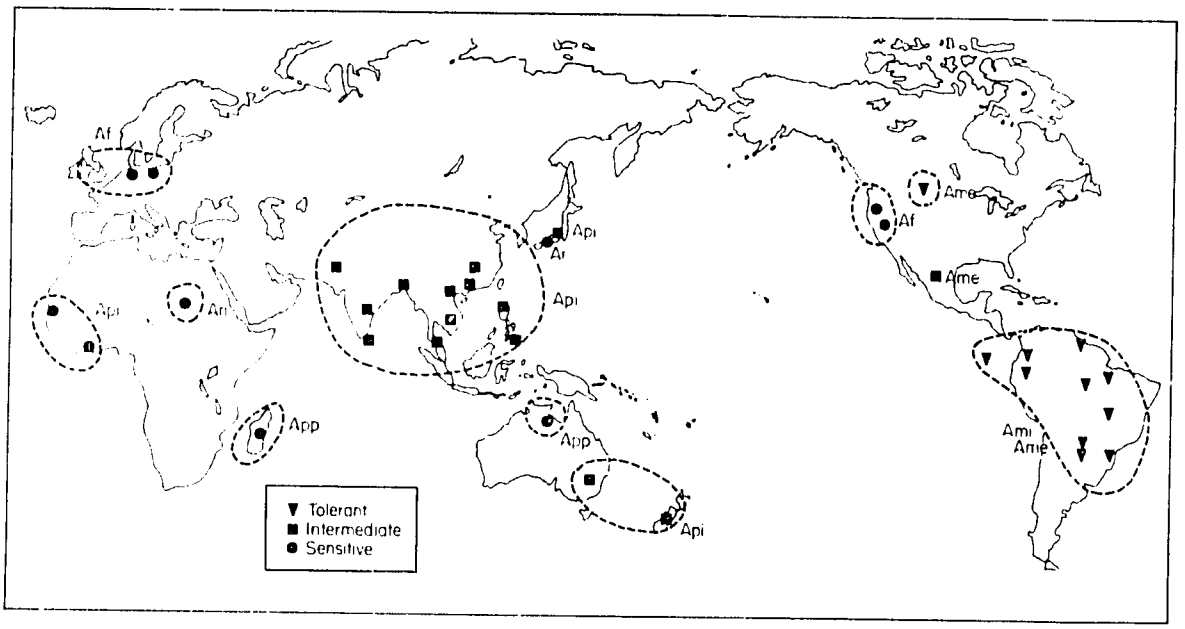


4. Zymograms of azolla hybrids, IRRI, 1987.

Temperature was increased stepwise: 1 d at average 28 °C (32 light/24 dark); 1 d at 30 °C; every 2 d at 32, 34, 36 °C; and, finally, 5 d at 38 °C. Scores of temperature, color, and coverage were recorded. After the 38 °C treatment, final fresh weight and, in some cases, N content were determined.

Generally, high temperature-sensitive strains showed yellowing and necrosis at 38 °C and produced less biomass. But *A. pinnata* var. *pinnata* remained green despite biomass reduction at high temperature. From the fresh weight after treatment, azolla strains were classified as tolerant, intermediate, or sensitive. All the tolerant strains were from Latin America (Colombia, Brazil, Guyana, and Paraguay). *A. pinnata* var. *pinnata* strains from Africa and Australia were sensitive. Figure 5 shows the geographical distribution of the collection sites of tolerant, intermediate, and sensitive strains.

Response of azolla with Anabaena from another species. *Anabaena* from *A. filiculoides* was introduced into *A. microphylla* and vice versa. *A. microphylla* is more tolerant of high temperature than *A. filiculoides*. Azolla was grown at 33 °C with 8 °C day and night temperature difference. *A. filiculoides* (1034) stopped growing after 2 wk, but *A. filiculoides* with *Anabaena* from *A. microphylla* (1035 and 1038) continued to grow. However, it produced still less biomass than *A. microphylla* (4031). The growth of *A. microphylla* with *Anabaena* from *A. filiculoides* (4033) was less than *A. microphylla* (4031). This finding shows that the response to temperature was controlled by the host

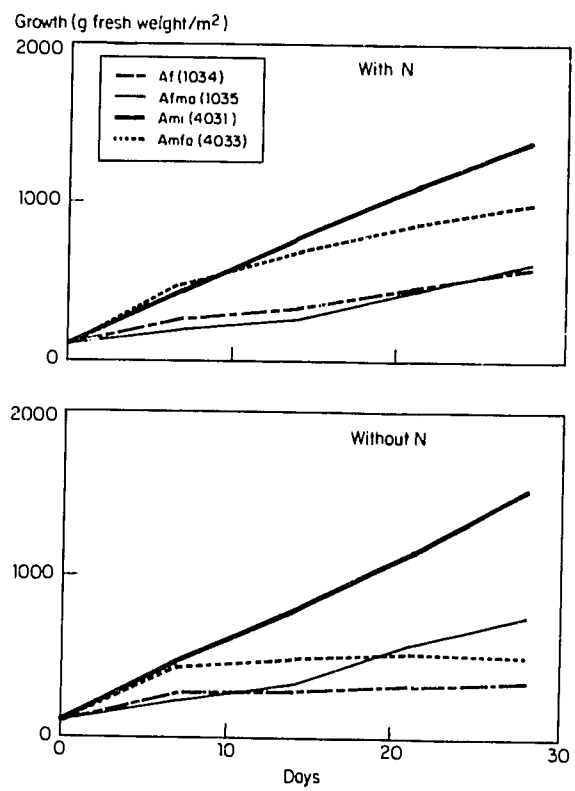


5. World distribution of temperature-tolerant and -sensitive azolla, 1987. Af = *A. filiculoides*, Ame = *A. mexicana*, Ami = *A. microphylla*, An = *A. nilotica*, Api = *A. pinnata* var. *imbricata*, App = *A. pinnata* var. *pinnata*, Ar = *A. rubia*.

and by the corresponding *Anabaena*. Both fern and *Anabaena* of *A. filiculoides* were sensitive to high temperature. In the presence of combined N, the growth difference was controlled mostly by the fern (Fig. 6).

Growth and nitrogen fixation of the hybrids. The hybrid was grown in the phytotron at 33 °C in N-free condition. The biomass and N contents at 28 d show that hybrid growth was intermediate between *A. filiculoides* and *A. microphylla*, but N content was similar to that of *A. microphylla* or higher (Table 5). Higher or similar N content was consistent with higher or similar N fixation activity. Hybrid vigor in N fixation was also suggested.

Phosphorus nutrition of azolla. *Soil-available phosphorus and phosphorus contents of azolla.* In surveys of azolla in the Philippines, soil samples were taken from a third of the sites. The average Olsen P of 70 samples was 24.4 mg P kg. This value seems higher than the Philippine average (about 8-10 mg P kg), probably because soils where azolla was grown were already high in available P. The correlation coefficient between available P of soils and P contents was 0.3 or 0.39 (ranking). When coverage of azolla in the fields was less than 10%, the correlation coefficient was significant ($r = 0.53$ or ranking $r = 0.60$).



6. Growth of azolla and heterologous *Anabaena*, IRRI, 1987. Af = *A. filiculoides*, Ami = *A. microphylla*, Afma = Af with *Anabaena* from Ami, Amfa = Ami with *Anabaena* from Af.

Table 5. Biomass and N contents of azolla hybrids and their parents at 28-d growth at 33 °C (37/29 °C) in N-free condition. IRRI, 1987.

Strain	Trial 1		Trial 2	
	Biomass (g/m^2)	N content (%)	Biomass (g/m^2)	N content (%)
4018 (parent)	1360	3.7	1100	3.5
1001 (parent)	330	1.4	145	2.4
4028 (hybrid)	1090	4.8	800	3.9
4030 (hybrid)	1140	5.0	800	4.1
4052 (hybrid)[a]	1124	4.8	852	3.3

[a]From China. Female parent was *A. microphylla* and male parent was *A. filiculoides*, but strains were different from 4018 and 1001.

Growth of azolla species after phosphorus deficiency. *A. pinnata* (5), *A. pinnata* var. *pinnata* (7001), *A. mexicana* (3010), *A. filiculoides* (1001), and *A. microphylla* (4018) were grown in P-deficient media, then inoculated into flooded soils that received 0, 40, or 80 mg P/kg. Soils in small pots received P fertilizer 1 wk before azolla inoculation. *A. microphylla* and *A. filiculoides* grew poorly in soils without applied P. Other species could multiply in soils without P application, but their P contents were below 0.1%. In soils with 40 mg P/kg, growth and P absorption were larger in *A. pinnata* and *A. pinnata* var. *pinnata* than in *A. caroliniana*. The application of 80 mg P/kg inhibited the growth of *A. pinnata* var. *pinnata*.

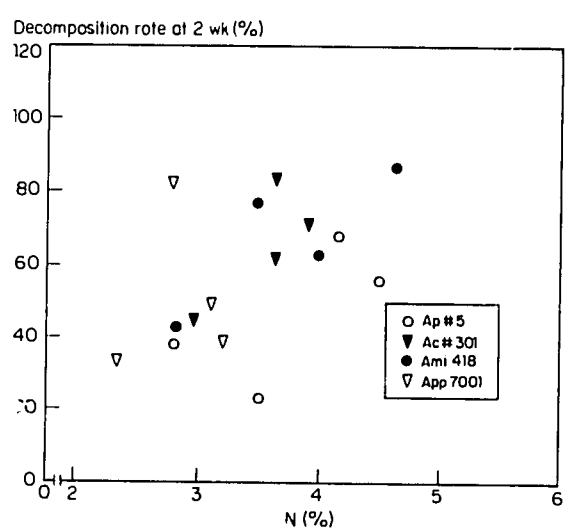
Thus, *A. microphylla* and *A. filiculoides* seem more sensitive to P deficiency. *A. pinnata* (2 strains) seems more efficient in absorbing P under P-deficient conditions.

In the field plots, P fertilizer was applied after growing *A. pinnata* (5), *A. pinnata* var. *pinnata* (7001), *A. mexicana* (3010), and *A. microphylla* (4018) under P-deficient conditions for 21 d. P contents were 0.1% or less when P was applied. The growth of *A. pinnata* (5) recovered first. The recovery of growth and the increase of N content were slowest in *A. microphylla* despite the greatest ARA and N content at their peak. The results of both experiments suggest that *A. microphylla* is sensitive to P deficiency.

Effect of diammonium phosphate on azolla. Diammonium phosphate (DAP) contains 18% N and 21% P. The application of DAP at 7 kg P/ha was split 12 times. Urea and triple superphosphate (TSP) at the same quantity of N and P as applied by DAP were also applied. After 4 wk, fresh weights of *A. microphylla* were 1.1, 1.2, 3.0, and 3.0 kg/m^2 in the control, urea, TSP, and DAP treatments. Thus, DAP was as effective as TSP. N gain in DAP-treated azolla over urea-treated azolla was 42 kg N/ha, meaning that 1 kg of DAP application stimulated N gains equivalent to 2.8 kg of urea. DAP can be used as P fertilizer to stimulate azolla growth.

Availability of nitrogen to the rice plant. *Decomposability of azolla as affected by nitrogen content.* After incorporation of azolla, its decomposition made N available to rice. The mineralization of four strains of azolla under flooded conditions was studied. The N content of azolla was changed by changing its P content, because N content decreases as P content decreases. Mineralization rates (mineralized N/total N in azolla) after 2-wk incubation were plotted against N content of azolla (Fig. 7). Except for *A. pinnata* (7001), decomposability decreased as N content decreased. At 3.5% N, decomposability was about 50%.

Utilization of azolla nitrogen by rice. Recoveries of ^{15}N in the second crop of rice and ^{15}N balance after 2 crops of rice were studied. Labeled azolla or



7. Mineralization of azolla under flooded conditions, by N content, IRRI, 1987. Ap = *Azolla pinnata*, Ac = *A. caroliniana*, Ami = *A. microphylla*, App = *A. pinnata* var. *pinnata*.

Table 6. Balance sheet of labeled azolla N and urea for 2 rice crops, IRRI, 1987.

Treatment		^{15}N recovery (%)			
1 d before transplanting	42 d after transplanting	1st rice	2d rice	Soil	Unaccounted for
^{15}N azolla	^{14}N azolla	39.3	4.4	43.5	12.8
^{14}N azolla	^{15}N azolla	63.0	4.0	31.3	1.7
^{15}N urea	^{14}N urea	27.3	4.1	41.9	26.7
^{14}N urea	^{15}N urea	48.0	2.9	18.3	30.8
^{14}N urea	^{15}N azolla	56.1	3.8	38.8	1.3

urea was applied 1 d before and 42 d after transplanting rice. The result after the first crop of rice was reported in the Annual report for 1986. Recoveries of ^{15}N from azolla were higher than those from urea (Table 6). No differences were found in the recovery of ^{15}N in the second crop of rice, indicating that azolla N was not decomposed during the first crop of rice, but utilization in the second crop was negligible.

AZOLLA APPLIED RESEARCH

Training and Technology Transfer and Soil Microbiology Departments

Because the survey of azolla N and P content and soils showed the higher P status in the Bicol Region (Albay, Camarines Sur, Camarines Norte, and Sorsogon Provinces, Philippines), the growth and use of azolla were monitored in the region. The growth of some azolla strains was tested at some sites (Table 7). At most sites, *A. pinnata* (5) and *A. mexicana* (3010) produced higher biomass than other strains. Biomass production of *A. pinnata* var. *pinnata* (7001) varied less with site, though it was low. Three split applications of P at a total of 7 kg P/ha increased biomass of all azolla strains, but the effect on strain 7001 was minimal. The application of DAP was effective in improving azolla production and its P content in farmers' fields. In Oas and Polangui, Albay, azolla growth was most abundant. In Camarines Sur, azolla use was most promising in Nabua, Baao, and Bombon.

Table 7. Azolla biomass production for 20 d without P at 8 sites in Albay Province, Philippines, 1986-87.

Strain no.	Biomass production[a] (kg/m²)									
	October 1986					February 1987			Average	STD
	Ligao (87)	Ligao (15)	Oas (50)	Polangui (45)	Polangui (10)	Oas (34)	Ligao (29)	Oas (12)		
5	1.7	1.6	0.5	0.6	0.5	1.2	1.5	1.7	1.2	0.5
3001	0.8	1.4	0.4	0.8	0.5	0.6	1.2	0.6	0.8	0.3
3010	1.3	0	0.7	0.9	0.4	1.0	1.1	0.9	0.8	0.4
4018	0.4	0.9	0	0.7	0.5	1.1	1.1	1.0	0.7	0.4
7001	1.5	1.1	0.6	0.7	0.8	0.7	1.0	1.1	0.9	0.3

[a]Numbers in parentheses represent Olsen P (ppm) for the various sites.

Soil and crop management

Management of organic manures

Soils, Agronomy, Soil Microbiology, Agricultural Economics, Entomology, and Multiple Cropping Departments

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DECOMPOSITION OF ^{14}C-LABELED RICE STRAW IN PALEAQUULTS IN THE PHILIPPINES AND NORTHEASTERN THAILAND

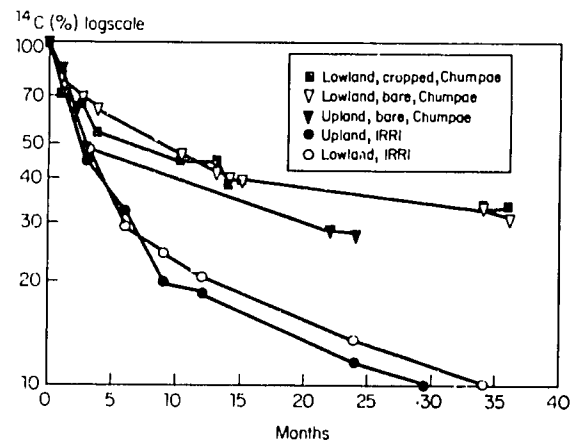
Soils Department

Field experiments with ^{14}C-labeled rice straw were conducted in randomized complete block designs (RCBD) with 4 replications on the IRRI farm (ongoing since Sep 1983) and at the Chumpae Rice Experiment Station, northeastern Thailand (Jul 1984-Jul 1987). Labeled straw (equivalent to 3 t/ha) was incorporated into the top 1.5 cm.

The Aeric Paleaquult at Chumpae has lower organic matter content, clay content, and cation exchange capacity (CEC) values than the IRRI soil (Table 1). The dry bulk density of soils at Chumpae is higher and hardly decreases after flooding and puddling. The lower bulk density of the Aeric Paleaquult at IRRI (set in as monoliths) decreases after flooding and puddling to 0.5 g/cm^3 in the top 15 cm.

The decomposition patterns of ^{14}C-labeled rice straw at both sites are shown in Figure 1. Decomposition is rapid during the first months. Thereafter decomposition at Chumpae slows, leading to half lives of more than 10 yr for the more resistant metabolites and residue. At IRRI we found half lives of 2 yr irrespective of water regime. A half life of 5 yr in the nonsubmerged treatment at Chumpae is estimated because of missing data 1 yr after incorporation.

The retarded decomposition at Chumpae is likely caused by the higher bulk density and lower CEC. The resulting low pH-buffer capacity at microspots of acid formation during decomposition limits bacterial activity. At IRRI, the high CEC and wide soil water ratio (low bulk density) of the puddled layer provide a better buffer system, resulting in faster decomposition. High biological activity of aerobic soil macrofauna (snails, tubificids) enhanced decomposition in the continuously submerged soil at IRRI, resulting in the same half life as in the nonsubmerged treatment.



1. Decomposition patterns of ^{14}C-labeled rice straw in Aeric Paleaquults at the Chumpae Rice Experiment Station, northeastern Thailand, and at IRRI, Philippines, 1987.

Table 1. Characteristics of soils used for decomposition studies of ^{14}C-labeled rice in the fields at the Chumpae Rice Experiment Station and IRRI, Philippines, 1987.

Soil type	Soil depth (cm)	pH (H_2O)	CEC[a] (meq/100 g)	Organic matter (%)	Clay (%)	Silt (%)	Sand (%)	Dry bulk density (g/cm^3)
			Chumpae					
Loamy, kaolinitic	0-10	5.2	7.05	0.94	21	33	46	1.44
Isohyperthermic	10-20	5.9	10.5	0.87	26	29	45	1.39
Aeric Paleaquult	20-30	6.5	11.9	0.74	32	26	42	1.33
	30-40	6.4	11.5	0.60	31	28	41	1.33
	40-50	6.2	12.9	0.54	35	28	37	1.40
			IRRI					
Fine, mixed	0-10	4.9	25.3	3.2	48	46	6	1.06
Isohyperthermic	10-20	5.5	22.3	1.5	48	43	9	1.15
Aeric Paleaquult	20-30	5.6	22.1	1.0	51	40	9	1.14
	30-40	5.7	20.8	1.0	51	40	9	1.11
	40-50	5.8	20.4	0.68	53	39	8	1.09

[a]Cation exchange capacity.

The measurements of remaining C in soil profiles at Chumpae after 3 yr (Fig. 2) reveal that straw-C was not translocated downward but upward. The traffic pan restricts translocations downward, and evaporation is higher than precipitation (ascending water regime) during the fallow dry season (DS).

The decomposition patterns confirm that, under similar climates, the soil pH and its buffer capacity under actual field conditions may be the leading determinant of decomposition rate.

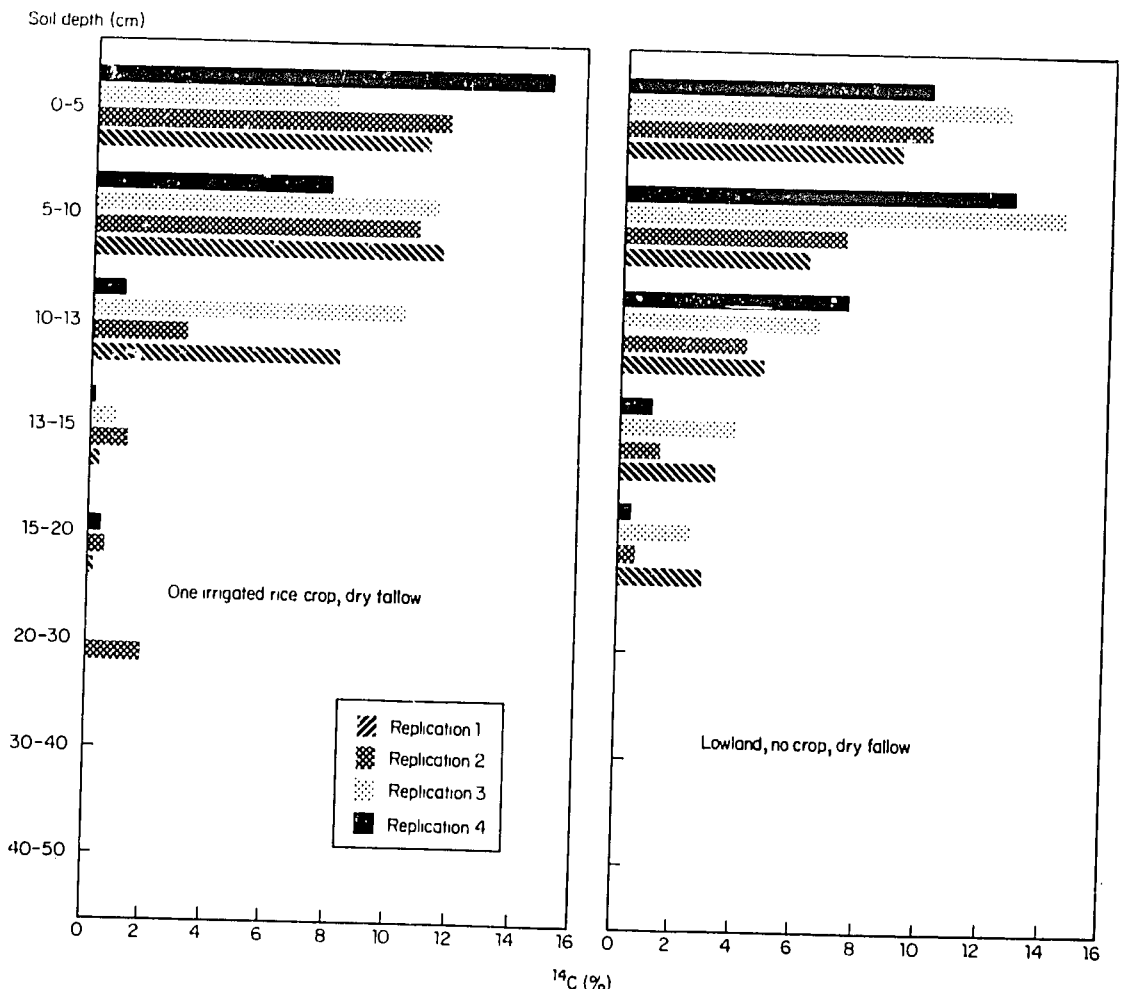
Since the soils at Chumpae have lower organic matter (OM) content despite lower decomposition rates, the annual biomass production and its recycling into the soil must be much less than at IRRI.

EFFECT OF MULCHING AND WEED CONTROL ON RICE GROWTH AND YIELD IN ACID UPLAND SOILS

Soils and Agronomy Departments

In an acid upland soil in Balabag, San Dionisio, Iloilo, Philippines, we evaluated the effect of rice straw mulch on the growth and yield of rice in a farmer's field during the 1986 and 1987 wet seasons (WS). Varieties Kutian and UPLRi-5 were used with two levels of mulch and two levels of weed control in a factorial (split-plot) RCBD replicated four times.

Rice straw mulch was applied on the soil surface in bundles between the rows after rice germinated. In 1 treatment, preemergence herbicide butachlor



2. ^{14}C remaining from labeled rice straw 3 yr after incorporation into a loamy, kaolinitic Aeric Paleaquult (1.4% OM, 21% clay, pH 5.2, CEC 7.05 meq/100 g) at the Chumpae Rice Experiment Station, northeastern Thailand, 1987.

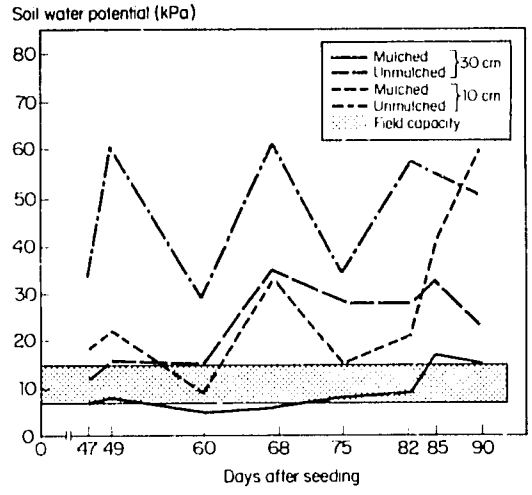
was applied 2-3 d after seeding (DAS); in the other, weeds were pulled by hand and left between rows.

Mulch significantly increased grain yields of both rices in both years (Table 2). The effect of mulch was greater on traditional rice Kutian than on UPLRi-5. This would be expected in 1987 because of delayed and lower rainfall -- the worst drought in 10 yr. In drought, Kutian's deep rooting is more pronounced in mulched plots.

Varietal performance was related to rainfall pattern and soil moisture. In 1986, with less moisture stress, UPLRi-5 had significantly higher yields than Kutian. In 1987, yields were similar.

Grain yields were similar for herbicide application and for hand weeding.

At 10- and 30-cm soil depths, unmulched plots had twice as much water stress as mulched plots. During the growth period, water tension at 10-cm depth averaged 45 kPa in unmulched plots and only 20 kPa in mulched plots (Fig. 3). At 30-cm depth, averages were 25 kPa and 10 kPa.



3. Soil water potential in mulched and unmulched upland areas, Balagbag, San Dionisio, Iloilo, Philippines, 1987.

NUTRIENT KINETICS AND UPTAKE BY RICE AS AFFECTED BY ADDITION OF RICE STRAW IN COMBINATION WITH GREEN MANURE AND INORGANIC NITROGEN FERTILIZER

Soils Department

Previous experiments with IR36 demonstrated that incorporation of rice straw immobilizes N throughout the growing period.

In the greenhouse, we studied the effect on nutrient kinetics and uptake of adding rice straw and green manure (GM) or inorganic N fertilizer.

Table 2. Grain yield of rice with different levels of mulch and weed control in acid upland soils. Balabag, San Dionisio, Iloilo, Philippines, 1986 and 1987 WS.

Treatment	Grain yield (t/ha)	
	1986	1987
Kutian, mulch, herbicide	1.26 b	1.67 a
Kutian, mulch, hand weeding	1.01 b	1.07 b
Kutian, no mulch, herbicide	0.74 c	0.50 c
Kutian, no mulch, hand weeding	0.99 c	0.49 c
UPLRi-5, mulch, herbicide	1.68 a	1.01 b
UPLRi-5, mulch, hand weeding	1.87 a	1.00 b
UPLRi-5, no mulch, herbicide	1.49 ab	0.50 c
UPLRi-5, no mulch, hand weeding	1.49 ab	0.44 c

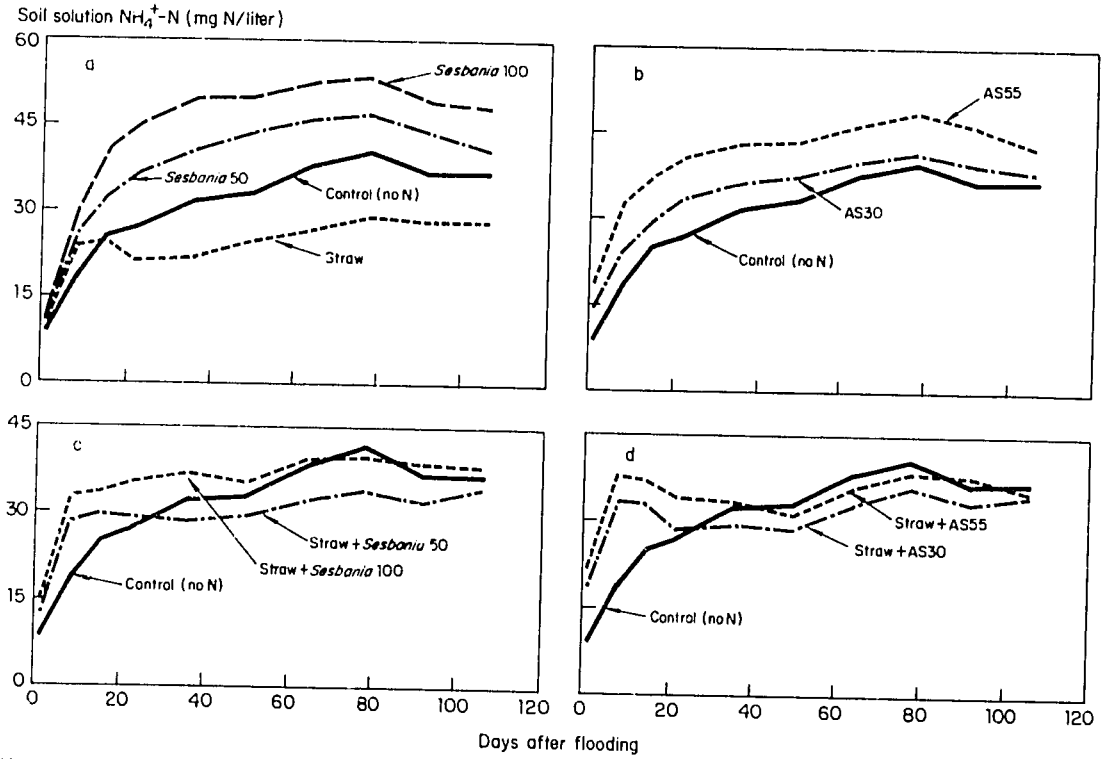
All treatments received 25 kg P/ha as triple superphosphate (TSP) and 25 kg K/ha as KCl. No rice was planted.

The soil was a loamy Aquic Ustifluvent from Concepcion, Pampanga, Philippines (pH 5.7, 0.5% organic C, 0.05% total N, CEC 48 mmol/kg, Olsen P 27 mg/kg, available Zn 4.5 mg/kg, 8% clay).

Soil solution NH_4^+-N with and without GM increased fairly rapidly up to 20 DAS and became almost constant at 50 DAS (Fig. 4). Straw depressed soil solution NH_4^+-N, while adding ammonium sulfate or sesbania enhanced it.

When straw was combined with either sesbania or N fertilizer, initially soil solution NH_4^+-N was higher than in the control. But from 30 DAS the concentrations were either the same as in the control or lower. The kinetics of exchangeable NH_4^+-N was similar to that of soil solution NH_4^+-N.

Ferrous and Mn^{2+} concentrations were higher for treatments receiving GM, while ammonium sulfate had no effect. Soil solution Zn^{2+} concentrations were lowered insignificantly by GM. Addition of GM increased soil solution K^+ considerably. Combining straw and sesbania resulted in the highest K^+ concentration, up to 93 mg/liter at 15 DAS (control, 48 mg/liter). GM initially decreased soil solution P but increased concentrations at 15 DAS. Thereafter, no significant difference was found between the treatments.



4. Kinetics of soil solution NH_4^+-N in a flooded soil as affected by incorporation of a) straw, and *Sesbania* alone, b) ammonium sulfate alone, c) straw + *Sesbania*, and d) straw and ammonium sulfate. Greenhouse experiment, IRRI, 1987.

A field experiment in Concepcion with combined treatments of straw and ammonium sulfate (45, 75, 105, and 135 kg N/ha) confirmed the results from the greenhouse experiment. Grain yields were lower with straw than without straw except when 135 kg N/ha was added. If N is the only yield-limiting factor, straw amendments are not recommended. But at sites with Fe, Mn, P, and K disorders, straw application is beneficial, especially when combined with GM or N fertilizer.

GROWTH OF RICE ON IRON-TOXIC SOIL AS AFFECTED BY STRAW INCORPORATION AND PRESUBMERGENCE

Soils Department

The effect of rice straw incorporation and soil submergence before transplanting on the growth and yield of rice (Table 3) was evaluated in inland Fe-toxic soils in San Dionisio, Iloilo, in 1986. Rice straw was chopped (3-5 cm) and incorporated at 5 t/ha in dry or presubmerged soils 1 d before transplanting (DBT). For presubmergence, soils were flooded for 2 wk. After straw was added, rice was transplanted, and all soils were kept flooded

Table 3. Effect of 2 water regimes and rice straw incorporation (5 t/ha) on rice grain yields in inland Fe-toxic soils. San Dionisio, Iloilo, Philippines, 1986.

Variety or line	Grain yield (t/ha)			
	No pre-submergence		Pre-submerged	
	No straw	With straw	No straw	With straw
Tolerant rices				
Palasithari	1.4	1.6	2.4	3.4
Matcandu	1.0	1.2	2.5	2.6
DV86	0.7	1.1	1.3	1.4
Moderately tolerant rices				
IR24632-145-2-2-3	0.9	1.1	1.0	1.2
IR29725-21-2-3-2	0.5	0.7	1.0	1.1
IR31802-48-2-2	0.8	1.0	1.1	1.3
Susceptible rices				
BR51-282-8	0.6	0.7	1.0	1.1
BR153-2B-37-1-3	0.7	0.8	1.3	1.8
P2057-F4-48-1B	0.9	0.9	1.2	1.6

throughout the growth period. Basal fertilizer was 20 kg N/ha as urea, 8.7 kg P/ha as TSP, and 16.6 kg K/ha as muriate of potash.

Both straw incorporation and presubmergence significantly increased rice yield. All varieties responded, but tolerant rices produced the highest yields in all treatments. Presubmergence was more effective than straw incorporation. Straw incorporation increased yield by 19% in dry soils and by 23% in presubmerged soils. Variations among varieties ranged between 4 and 52% in dry soil, and between 4 and 39% in presubmerged soils.

Presubmergence increased yield by 66% over dry soil treatment without rice straw and by 71% with rice straw incorporation. Varietal response ranged from 8 to 135%.

Presubmergence for 2 wk was 2-3 times more beneficial than rice straw incorporation. The highest benefits came when rice straw incorporation was combined with presubmergence.

Presubmergence and rice straw incorporation increased plant height slightly, but not the number of productive tillers. Differences in grain filling produced the differences in yield. All varieties planted in presubmerged soils with and without rice straw incorporation had more filled grains. In dry soil, rice straw incorporation produced more filled grains than no straw incorporation.

The benefits of presubmergence and rice straw incorporation came during the reproductive phase, perhaps because of the remobilization of immobilized N, the kinetics of Fe compounds, and the supply of other nutrients.

EFFECT OF CHICKEN MANURE APPLICATION ON RICE GROWTH AND YIELD

Soils Department

As a satellite experiment of the maximum yield trials on the IRRI farm, we have studied the effect of chicken manure application (2 t/ha) on soil properties and rice growth since 1985 DS. The experiment used a 4 × 2 split plot, with N and chicken manure combinations as main plots, and varieties as subplots, replicated 4 times. Rice varieties were IR2180-154 and IR29723-143.

After 2 yr, the combination of N and chicken manure maintained OM content, and both total and available N. Chicken manure increased available P (Olsen) and available N. Chicken manure increased IR29723-143 yields by more than 1 t/ha in DS (Table 4). Yields in wet season (WS) were generally lower but showed similar trends. In WS, plant nutrient contents of N, P, Fe, Cu, and Zn at 8 wk after transplanting were lower, but Mn contents were higher and ratios of Fe to Mn were inverse.

The lower Fe:Mn in WS may be related to less oxidation of the soils between DS and WS. Fe may

Table 4. Grain and straw yields at 2 sites as affected by N and chicken manure treatments. IRRI, 1987 DS and WS.

Treatment[a]	IR29723-143 yield (t/ha)			
	Dry season		Wet season	
	Grain	Straw	Grain	Straw
		Block M13		
Control	4.14 c	4.68 c	3.48 c	4.76 b
Chicken manure, 2 t/ha	6.20 b	5.32 c	4.40 b	5.41 b
118 kg N/ha as USG and PU	6.83 b	6.89 b	5.07 a	6.46 a
118 kg N/ha as USG and PU + 2 t/ha chicken manure	8.47 a	8.18 a	5.20 a	7.14 a
		Block 424		
Control	4.29 c	4.84 c	3.89 b	4.58 c
Chicken manure, 2 t/ha	4.96 c	5.62 c	4.79 ab	5.31 bc
118 kg N/ha as USG and PU	6.95 b	6.90 b	4.20 b	6.30 ab
118 kg N/ha as USG and PU + 2 t/ha chicken manure	7.96 a	8.13 a	5.18 a	7.37 a

[a]USG = urea supergranules, PU = prilled urea.

remain precipitated as $FeCO_3$, while $MnCO_3$ is changed to Mn oxides faster, resulting in higher availability upon reflooding. Plant nutrient contents of IR29723-143 (Table 5) in 1987 DS at the main maximum yield trials (grain yield 7.9 t/ha at 147 kg N/ha and 50 kg P/ha) reveal lower plant N, Ca, and Fe contents, inverse Fe:Mn, and higher Cu contents. In the chicken manure trials, we found in 1985-86 that inorganic P application (50 kg P/ha, split application as single superphosphate) decreased plant N, Ca, and Fe uptake, leading to nutrient imbalances.

AQUATIC GREEN MANURE LEGUME AND *RHIZOBIUM* GERMPLASM

Soil Microbiology Department

Fifty ecotypes or species of *Sesbania, Aeschynomene, Neptunia, Crotalaria, Pueraria, Calopogonium*, and *Macroptilium*, and 110 strains of *Azorhizobium, Rhizobium*, and *Bradyrhizobium* are maintained. Major legume genera, number of their ecotypes or species, and sources are as follows: *Aeschynomene*, 24 from USA, China, India, Madagascar, Senegal, and Brazil; *Sesbania*, 12 from Indonesia, China, India, and Madagascar; and others, 14 from China, India, Thailand, and Indonesia.

SESBANIA ROSTRATA: A GREEN MANURE FOR LOWLAND RICE

Soil Microbiology Department

A pot experiment evaluated the effects of *Rhizobium*-inoculated *Sesbania rostrata* as a GM crop on the survival of rhizobia, grain yield, and N accumulation in succeeding WS and DS rice crops (1986-87), plus total N balance. The following treatments and crop sequence were included: 1) flood fallow - rice -flood fallow - rice (F/R/F/R), 2) *Sesbania* (uninoculated) - rice - *Sesbania* (uninoculated) - rice (S-/R/S-/R), and 3) *Sesbania* (inoculated) - rice -*Sesbania* (inoculated) - rice (S+/R/S+/R). In inoculated treatments, *Sesbania* was inoculated with *Azorhizobium caulinodans* ORS571 (resistant to streptomycin and spectinomycin) in the soil, seed, and stem (spray) in the first crop and in the seed and stem (spray) in the second crop. *S. rostrata* was grown and incorporated at 45 d after emergence (DE) before WS rice and at 55 DE before DS rice.

Effect on survival of *Azorhizobium caulinodans*. *A. caulinodans* was counted by the plant infection (most probable number [MPN]) and antibiotic plate count methods for total and inoculated azorhizobia, respectively. Counts in soil were made at 1) 1 d after inoculation (initial), 2) 1 d after the first *Sesbania* incorporation, 3) 1 d after the first rice harvest, 4) 1 d after the second *Sesbania* incorporation, and 5) 1 d after the second rice harvest (Table 6). Counts associated with rice roots were made at maximum tillering and heading of both crops (Table 7).

The initial count of native rhizobia in soil was 2,500 MPN/g dry weight. In the F/R/F/R treatment, this level remained constant until the end of the first crop and then declined during the second crop to 20 MPN/g dry weight. *Sesbania* incorporation in both uninoculated (S-/R/S-/R) and inoculated (S+/R/S+/R) treatments increased the number in both crops, but declined to the initial level at the end of the second crop (Table 6). No

Table 5. Comparison of nutrient contents of plants at 8 wk after transplanting in a maximum yield trial and chicken manure experiments. IRRI farm, 1987 DS.

Site	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)
					Maximum yield trial				
N13	1.86	0.25	2.9	0.14	0.16	50	195	44	32
UB2	2.16	0.26	2.8	0.17	0.17	55	276	47	35
					Chicken manure				
M13	2.97	0.22	2.3	0.24	0.18	228	144	25	36
424	2.49	0.23	2.4	0.22	0.18	227	153	27	44

Table 6. Population of total (most probable number [MPN] method) and inoculated (antibiotic plate count method) azorhizobia of *Sesbania rostrata* in soil as affected by green manuring and rice cropping. IRRI, 1986 WS and 1987 DS.

Treatment	Log_{10} cells/g dry weight of soil									
	Initial		1 d after first *Sesbania* incorporation		1 d after first rice harvest		1 d after second *Sesbania* incorporation		1 d after second rice harvest	
	MPN	Plate count	MPN	Plate count	MPN	Plate count	MPN	Plate count	MPN	Plate count
Flood fallow - rice - flood fallow - rice	3.4	0.0	3.1	0.0	3.5	0.0	2.1	0.0	1.3	0
Sesbania (uninoculated) - rice - *Sesbania* (uninoculated) - rice	3.4	0.0	4.9	0.0	4.8	0.0	6.1	3.5	3.5	0
Sesbania (inoculated) - rice - *Sesbania* (inoculated) - rice	7.1	7.7	6.6	7.1	5.5	3.2	6.4	4.9	3.6	<2

Table 7. Population of total (most probable number [MPN] method) and inoculated (antibiotic plate count method) azorhizobia of *S. rostrata* associated with rice roots at maximum tillering and heading.[a] IRRI, 1986 WS and 1987 DS.

Treatment	Log_{10} cells/g dry weight of rice root			
	At maximum tillering		At heading	
	MPN	Plate count	MPN	Plate count
Flood fallow - rice - flood fallow - rice	2.8	0.0	3.7	0.0
Sesbania (uninoculated) - rice - *Sesbania* (uninoculated) - rice	4.9	0.0	[illegible].2	0.0
Sesbania (inoculated) - rice - *Sesbania* (inoculated) - rice	5.9	6.0	6.5	5.3

[a]Averages of WS and DS crops.

antibiotic-resistant strains were found in F/R/F/R or S-/R/S-/R. The counts of inoculated azorhizobia declined in both crops and throughout the experiment (Table 6), suggesting that the inoculated strain may not be more ecologically competitive than the native strains, even though it is more effective in nodulation and N_2 fixation. The higher populations of native and inoculated azorhizobia recorded after *Sesbania* incorporation may have been due to their release from degrading nodules.

Because the azorhizobia counts in rice roots at maximum tillering and heading in the first crop were not different from those in the second crop, the averages of both crops are shown in Table 7. Rice plants in F/R/F/R harbored significantly fewer azorhizobia than both *Sesbania* - rice treatments at both growth stages. Antibiotic-resistant strains were found only in the plants of S+/R/S+/R, where high numbers were maintained. The results suggest the stimulation of azorhizobia by rice roots.

Effect on succeeding crop yield and nitrogen balance. Incorporation of *S. rostrata* increased rice grain yield and N uptake two- to three-fold over the flood fallow treatment. N gains were positive and significantly different among F/R/F/R (106 mg N/pot), S-/R/S-/R (712 mg N/pot), and S+/R/S+/R (873 mg N/pot). Inoculation gave significantly more N gain (873 mg N/pot) than no inoculation (712 mg/pot). About 80% of the N gained was transferred to the succeeding rice crop, and about 20% remained in the soil. The soil N in F/R/F/R significantly declined (-140 mg N/pot), but significantly increased in both *Sesbania* - rice treatments (159 mg N/pot in S-/R/S-/R and 151 mg/pot in S+/R/S+/R). The amount of N_2 fixed was calculated by subtracting the N gain of

F/R/F/R from the N gain of *Sesbania* - rice treatments; S+/R/S+/R fixed significantly higher N (767 mg N/pot) than S-/R/S-/R (606 mg N/pot).

EVALUATION OF *AESCHYNOMENE AFRASPERA* AND *SESBANIA ROSTRATA* AS GREEN MANURE FOR LOWLAND RICE

Soil Microbiology Department

A collaborative project with the University of Giessen, Federal Republic of Germany, evaluated in 1987 WS on the IRRI farm (Maahas clay, 0.123% N, 15 ppm Olsen P, CEC 32 meq/100 g, pH 6.3) and in a farmer's field in Floridablanca, Pampanga (sandy loam, 0.063% N, 7.3 ppm Olsen P, CEC 8 meq/100 g, pH 5.6), 2 stem-nodulating legumes *Aeschynomene afraspera* and *S. rostrata* as GM for lowland rice. There were 4 replications in the following treatments: 1) control (no N, no GM), 2) urea at 60 kg N/ha (40 kg/ha at transplanting and 20 kg/ha at panicle initiation [PI]), 3) *A. afraspera* incorporated, and 4) *S. rostrata* incorporated. The GM species grew for 49 d until incorporation at 3 d before IR64 was transplanted.

S. rostrata produced significantly higher biomass and taller plants than did *A. afraspera*; however, nodulation, N_2 fixation (measured by acetylene-reducing activity), and N content (% N) were higher in *A. afraspera*. Both GM species increased rice grain yield significantly over the control (Table 8). *A. afraspera* seems superior to *S. rostrata*—the same rice yield increase was obtained with a lower biomass—and is easier to incorporate.

EVALUATION OF RATOONING AND STEM CUTTING OF *SESBANIA ROSTRATA* FOR VEGETATIVE PROPAGATION

Soil Microbiology Department

Experiments were conducted in a farmer's field in Floridablanca, Pampanga, in 1987 WS in collaboration with the University of Giessen. There were 4 replications in the following ratooning treatments: 1) seeding (40 kg seed/ha), 2) first ratooning, and 3) second ratooning. Plants were grown for 6 wk and ratooned by cutting 25-35 cm above the ground. Plant density, biomass production, and N content were measured in two crops each of seeded and first ratooned rice and in one crop of second ratooned rice. The experiments on stem cuttings had 5 treatments with 4 replications: 1) seeded (40 kg seed/ha), 2) fifty 15-cm-long stem cuttings/m^2, 3) fifty 30-cm-long stem cuttings/m^2, 4) one hundred 15-cm-long stem cuttings/m^2, and 5) one hundred 30-cm-long stem cuttings/m^2. Stem cuttings were taken from 6-wk-old plants and were pushed about 5 cm deep into the soil. Measurements were made after harvesting the plants (cutting at ground level) after 6 wk.

Ratooning and stem cutting produced signifi-

Table 8. *Aeschynomene afraspera* and *Sesbania rostrata* as biofertilizers for lowland rice.[a] IRRI and Floridablanca, Pampanga, Philippines, 1987 WS.

Treatment	Plant height (cm)	Nodules (no./plant)	ARA[b] (μmol C_2H_4/h per plant)	Dry matter production (t/ha)	N (%)	N yield (kg/ha)	Rice grain yield (t/ha)
			IRRI farm				
S. rostrata	197	75	11.7	8.4	1.88	157	6.5
A. afraspera	77	113	13.3	3.7	3.16	115	6.5
60 kg N/ha	–	–	–	–	–	60	6.3
No N	–	–	–	–	–	0	4.9
			Floridablanca				
S. rostrata	272	91	11.1	10.2	1.72	195	4.9
A. afraspera	155	216	17.9	7.7	2.61	201	5.2
60 kg N/ha	–	–	–	–	–	60	4.6
No N	–	–	–	–	–	0	3.5
LSD (0.05)	8	47	2.0	1.2	0.23	18	0.47

[a]Dash = not measured. [b]Acetylene-reducing activity.

cantly higher biomass and N accumulation than did seeded plants (Table 9, 10). The fewer plants in the ratooning and stem cutting treatments than in the seeded treatment were compensated for by more branches per plant. Short cuttings (15 cm) exhibited slower growth and fewer tillers, with a higher mortality rate than long cuttings (30 cm), 23% versus 7%. Vegetative propagation is advantageous because of lower seed and land preparation expenses.

EFFECT OF AZOLLA AND SESBANIA GREEN MANURE ON WETLAND RICE

Soil Microbiology Department

In 1985, a long-term experiment began to compare the effects on rice of two GM crops that can grow under flooded conditions—*Azolla microphylla* 4018 and *Sesbania rostrata*.

In the 4th trial, *Sesbania* was grown for 61 d until incorporation. Its N content was 1.7% and dry matter 3.2 t/ha (Table 11). In the 5th trial, it was grown until 53 d after sowing; its N content was 1.8% and dry matter 5.0 t/ha. Azolla was incorporated four times before transplanting. Its N content was 3.0-3.5%. The production and the manuring effect of azolla were better later in the year than were those of sesbania.

Natural abundances of N (δ ^{15}N values) in the rice grain of the 4th crop were 6.0 ± 2.9, 1.2 ± 1.4, 1.4 ± 0.3, and 2.2 ± 0.3 per thousand in the control, urea, azolla, and sesbania treatments, respectively. Delta ^{15}N in available soil N was about 5 ± 1. The contribution of biologically fixed N was, therefore, higher in rice grains in azolla-treated plots than in sesbania-treated plots. Because δ ^{15}N of sesbania was 0.2 ± 0.05, N in sesbania originated mostly from atmospheric N. Higher ^{15}N abundance in the rice grain after sesbania means, therefore, less availability to rice of sesbania N than of azolla N.

INSECT PESTS OF *SESBANIA*

Entomology Department

Seven species of insects and a mite were found damaging *Sesbania rostrata* from the vegetative to the postreproductive phases. Three species—*Eurema hecabe, Maruca testulalis,* and *Spodoptera litura*—were key pests (Table 12). *Sesbania* is an alternate host for grain legume crop pests *M. testulalis, S. litura,* and *Aphis craccivora.*

INTEGRATED NITROGEN MANAGEMENT IN LOWLAND RICE

Agronomy Department

We continued to evaluate supplementary N fertilizer sources in the 10th (DS) and 11th (WS) consecutive crops at IRRI and in a farmer's field in Victoria, Laguna (Table 13).

In DS, deep placement of urea supergranules (USG) gave significantly higher grain yields than did other treatments at IRRI. In Victoria, several other management practices gave grain yields similar to that of USG in WS.

At both sites in DS, azolla, fresh rice straw, and rice straw compost were superior to the control. Similar results for azolla and fresh rice straw were obtained in WS at both sites and for sesbania as GM in both seasons.

Table 9. Vegetative propagation of *S. rostrata* by ratooning.[a] Floridablanca, Pampanga, Philippines, 1987 WS.

Harvest date	Parameter	Seeded	First ratoon	Second ratoon
10 Jun	Plants (no./m^2)	66 a	40 b	
	Tillers (no./plant)	1 a	1.6 b	
	Dry weight biomass (t/ha)	2.90 a	7.95 b	
	N (%)	2.10 a	2.01 a	
	N (kg/ha)	60.9 a	159.0 b	
22 Jul	Plants (no./m^2)	65 a	42 b	33 bc
	Tillers (no./plants)	1 a	1.6 b	2.0 c
	Dry weight biomass (t/ha)	2.16 a	4.25 b	5.08 c
	N (%)	2.11 a	1.99 b	1.94 b
	N (kg/ha)	45.4 a	84.6 b	98 bc

[a]In a row, numbers followed by a common letter are not significantly different at the 5% level by the *t*-test.

Table 10. Vegetative propagation of *S. rostrata* by stem cuttings.[a] Floridablanca, Pampanga, Philippines, 1987 WS.

Parameter	Seeded	50 cuttings		100 cuttings	
		15-cm-long	30-cm-long	15-cm-long	30-cm-long
Cuttings (no./m²)	–	50	50	100	100
Plants established (no./m²)	126 a	38 c	46 c	78 b	93 b
Tillers (no./plant)	1.0 c	1.5 a	1.6 a	1.2 b	1.3 b
Dry weight (g/m²)	384 a	514 b	726 c	557 b	887 d
N (%)	2.14 a	2.06 a	2.08 a	2.01 a	1.99 a
N (g/m²)	8.2 d	10.6 c	15.1 b	11.2 c	17.5 a

[a]In a row, numbers followed by a common letter are not significantly different at the 5% level by the *t*-test.

Table 11. Azolla and sesbania green manure as biofertilizers for lowland rice. IRRI, 1986 WS-1987 WS.

Crop	Season and data	Variety	N input (kg/ha)			Rice grain yield (t/ha)			
			Urea	Azolla	Sesbania	No N	Urea	Azolla	Sesbania
4th	1986 WS-DS (Dec 1986-Apr 1987)	IR54	60	96	55	5.2	7.0	8.5	6.9
5th	1987 WS (Jul-Oct 1987)	IR64	69	70	90	4.5	5.6	6.2	5.8

Table 12. Insect pests of *Sesbania rostrata* in the Philippines, 1987.

Pest	Prevalence[a]	Stage attacked
Lepidoptera		
Noctuidae		
Spodoptera litura (F.)	+++	Vegetative
Pyralidae		
Maruca testulalis (Geyer)	+++	Flowering
Pieridae		
Eurema hecabe (L.)	+++	Vegetative
Tineidae		
Endrosis nr. *sarcitrella* L.	+	Late vegetative-flowering
Hymenoptera		
Eurytomidae		
Bruchophagus millipes Gahan	++	Postreproductive
Megachilidae		
Megachile sp.	+	Vegetative
Hemiptera		
Aphididae		
Aphis craccivora L. Koch	++	Late vegetative-flowering
Acari		
Tetranychidae		
Eotetranychus ? cendanai Rimandoi	++	Vegetative

[a]+++ = abundant, ++ = moderate, + = rare.

In DS, azolla performed better than rice straw, rice straw compost, and sesbania. Yields from azolla were comparable to those from prilled urea (PU) at both sites and to that from USG in the farmer's field.

Application of organic sources combined with PU or USG consistently gave higher yields than the control. These results suggest the importance of combining inorganic and organic N sources to sustain high yields.

INTEGRATED NUTRIENT MANAGEMENT

Agronomy Department

Lowland rice response to various green manure management practices. In 1987 WS, field experiments evaluated the effects of various GM management practices on the succeeding rice crop under irrigated and rainfed lowland conditions at IRRI and in farmers' fields in Tarlac and Pampanga, Central Luzon. *Sesbania rostrata* was the GM and IR64 the test variety. Under irrigated conditions, rice was transplanted and direct seeded in separate experiments. The rainfed experiment involved only transplanting.

Table 13. Effect of supplementary N fertilizer source on grain yield of IR64 in IRRI Block G_{11}, and in Victoria, Laguna, Philippines, 1987.

N source[a]	Grain yield[b] (t/ha)			
	Dry season (10th crop)		Wet season (11th crop)	
	IRRI	Victoria	IRRI	Victoria
No fertilizer N (control)	2.8 h	3.2 e	3.2 e	3.9 b
Single sources				
PU, BS (best split)	5.7 bcd	6.6 abc	4.4 abc	5.0 a
USG	6.7 a	7.2 a	4.8 a	5.4 a
Fresh azolla, incorporated into soil	5.4 de	6.9 abc	4.1 bcd	5.1 a
Fresh rice straw, incorporated into soil	4.4 g	5.4 d	3.8 cd	5.3 a
Rice straw compost, incorporated into soil	4.9 f	5.4 d	3.6 de	4.3 b
Fresh sesbania, incorporated into soil	4.8 fg	–	4.1 bcd	–
Combined sources[c]				
Fresh azolla + PU, BS	5.8 bcd	6.1 bcd	4.1 bcd	5.0 a
Fresh rice straw + PU, BS	5.2 ef	6.0 cd	4.6 ab	5.0 a
Rice straw compost + PU, BS	5.6 cde	6.5 abc	4.1 bcd	5.0 a
Fresh azolla + USG	6.1 b	7.0 a	4.3 abc	5.1 a
Fresh rice straw + USG	6.0 bc	6.4 abc	4.0 cd	5.2 a
Rice straw compost + USG	5.6 cde	6.9 abc	4.2 bcd	4.9 a

[a]All treatments applied at equal N rates: 116 kg N/ha in DS and 58 kg N/ha in WS. For BS application, 2/3 urea was broadcast and incorporated at planting and 1/3 topdressed at 5-7 d before panicle initiation (DBPI). [b]CV = 6% in DS and 9% in WS at IRRI and 9% in DS and 6% in WS in Victoria. [c]For combined applications, 58 kg N/ha in DS and 29 kg N/ha each of organic and inorganic sources in WS.

Irrigated sites. S. rostrata seed was broadcast at 50 kg/ha on puddled soil. *S. rostrata* GM was grown in situ for 45 DE before it was coarsely chopped and incorporated into the soil at 1-2 DBT or direct seeding of rice. Other GM management treatments—stem and leaf incorporation and root incorporation—were compared with the combined application of GM and PU, and with farmers' and researchers' split application of PU.

Table 14 shows characteristics of the soils. *S. rostrata* grown in mid-April in IRRI soil, low in P, had the lowest total dry matter and N yields, compared with that grown more than 1 mo later in Tarlac and Pampanga soils, with higher P (Table 15).

GM in situ incorporation, and stem and leaf incorporation in transplanted (TPR) and direct seeded (DSR) rice gave significantly higher yield

Table 14. Characteristics of soils at 3 sites in the Philippines, 1987 WS.

Soil property	Irrigated					Rainfed	
	Transplanted			Direct seeded		Transplanted	
	IRRI	Tarlac	Pampanga	IRRI	Tarlac	IRRI	Tarlac
pH	6.4	5.6	4.8	6.1	5.9	6.3	5.2
Organic C (%)	1.7	0.5	1.8	1.8	0.6	1.4	0.5
Total N (%)	0.16	0.05	0.17	0.19	0.05	0.14	0.06
CEC (meq/100 g)	41.0	6.6	6.8	39.1	6.5	37.2	30.0
Exchangeable K (meq/100 g)	0.9	0.10	0.13	0.9	0.09	0.9	0.06
Olsen P (mg/kg)	3.2	8.9	42	5.6	7.7	30.5	1.6
Soil texture	Clay	Sandy loam	Loamy sand	Clay	Sandy loam	Clay	Clay

Table 15. Total dry matter yield and N accumulation of *S. rostrata* at 45 d after emergence on irrigated and rainfed farms at 3 sites in the Philippines, 1987 WS.[a]

Site	Rice establishment	Total GM incorporated (kg DW/ha)			Accumulated N (kg/ha)		
		Whole plant	Stem and leaf	Root	Whole plant	Stem and leaf	Root
			Irrigated				
IRRI	Transplanted	1085	760	325	23	17	6
IRRI	Direct seeded	1430	930	500	30	22	8
Tarlac	Transplanted	4840	4085	755	129	118	11
Tarlac	Direct seeded	4030	3340	690	95	84	11
Pampanga	Transplanted	4145	2920	1225	93	76	17
			Rainfed				
IRRI	Transplanted	3895	3576	319	118	114	4
Tarlac	Transplanted	2965	2076	889	59	46	13

[a]GM = green manure, DW = dry weight.

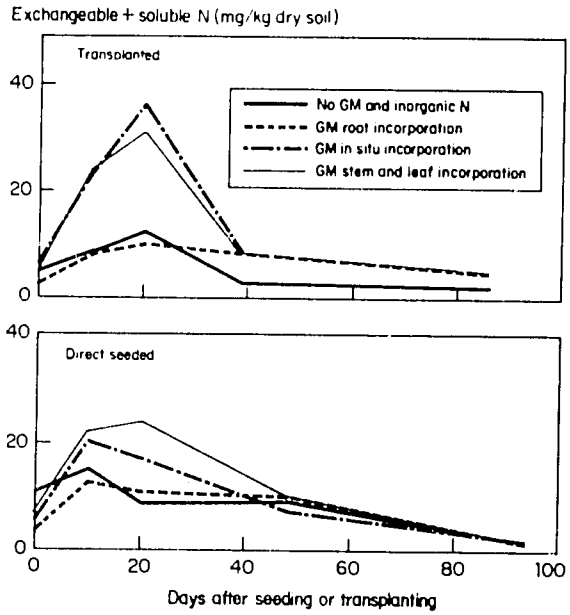
than the unfertilized control in Tarlac, but not at IRRI and in Pampanga (Table 16). Yield differences could be attributed to differing amounts of N as GM. Despite high N from GM incorporation, yield of TPR in Pampanga showed no response to GM because of severe crop lodging during the ripening phase. GM root incorporation did not increase rice yield at any site. At IRRI, where GM biomass and N yields were low, topdressing 30 kg N/ha as PU at 5-7 d before panicle initiation (DBPI) significantly increased yields of TPR and DSR. In Tarlac, only GM root incorporation needed inorganic N supplement at PI to produce high yields. At that site, GM alone—either incorporation of the entire *S. rostrata* plant or of its stems and leaves—can reduce or replace costly inorganic fertilizer while sustaining high rice yields.

In Tarlac, KCl-extractable + soluble N measurements showed higher NH_4^+N levels with GM in situ incorporation, and with stem and leaf incorporation than with root incorporation or the unfertilized control during the first 3 wk after rice transplanting or direct seeding (Fig. 5). The N-release patterns of both planting methods were similar. However, N levels in the transplanted trial at 20 d after transplanting were considerably higher

Table 16. Rice grain yield as influenced by *Sesbania rostrata* green manuring practices, and methods of inorganic N application on irrigated farms at 3 sites in the Philippines, 1987 WS.

Treatment	Grain yield (t/ha)				
	Transplanted			Direct seeded	
	IRRI	Tarlac	Pampanga	IRRI	Tarlac
No GM or fertilizer N	3.4 c	3.4 d	4.8 ab	3.9 d	3.3 d
GM in situ incorporation	3.8 bc	5.3 a	4.6 ab	4.1 cd	5.0 a
GM in situ incorporation + topdressed inorganic N[a]	4.3 ab	5.3 a	3.9 c	4.5 abc	4.7 ab
GM leaf-stem incorporation	3.8 bc	5.2 a	4.5 abc	4.3 bcd	4.8 ab
GM leaf-stem incorporation + topdressed inorganic N[a]	4.4 a	5.3 a	3.9 c	4.7 ab	4.2 c
GM root incorporation	3.5 c	3.7 d	4.2 bc	3.8 d	3.3 d
GM root incorporation + topdressed inorganic N[a]	3.8 bc	4.2 c	4.5 abc	4.7 ab	4.6 abc
Farmers' split PU, 60 kg N/ha[b]	4.3 ab	4.5 bc	5.1 a	4.7 ab	4.4 bc
Researchers' split PU, 60 kg N/ha[c]	4.6 a	4.9 ab	4.3 bc	4.8 ab	4.7 ab
Researchers' split PU, 90 kg N/ha[c]	4.8 a	4.9 ab	4.4 bc	5.0 a	4.9 ab

[a]30 kg N/ha as PU at 5-7 DBPI. [b]1/2 at 15 d after transplanting or after direct seeding + 1/2 1 wk after panicle initiation. [c]2/3 basal broadcast and incorporated + 1/3 at 5-7 DBPI.



5. Status of exchangeable and soluble NH_4^+-N in irrigated rice soil as affected by *Sesbania rostrata* green manuring practices in Tarlac, Philippines, 1987 WS. GM = green manure.

than in the direct seeded trial at 20 DAS because DSR used more N during that stage than did TPR (Table 17).

Rainfed sites. S. rostrata seeds (50 kg/ha) were row-seeded 40 cm apart using a carabao-drawn, IRRI-designed inverted-T seeder. GM was grown for 45 DE before it was coarsely chopped, following the same procedure and treatments used in the irrigated trials.

Trials at IRRI and in Tarlac showed significant responses to both inorganic N and GM applications, except when GM roots were incorporated alone (Table 18). At both sites, topdressing inorganic N at 5-7 DBPI to supplement GM in situ incorporation, and stem and leaf incorporation did not increase rice yield further. Yield trends at rainfed sites were similar to those observed at the irrigated sites in Tarlac.

EVALUATION OF *SESBANIA ROSTRATA* AS A GREEN MANURE FOR RAINFED WETLAND RICE ENVIRONMENTS

Multiple Cropping and Agricultural Economics Departments

GM crops may have the greatest potential in rice environments where they can be grown in periods when the usual commercial crops are not feasible. The single-crop rainfed wetland TPR environment may thus be particularly suited to GM before rice. We examined the feasibility of *S. rostrata* as a N source for rice in this environment, which covers more than 20 million ha in Asia.

Green manure-rice simulation model. The model consisted of three main submodels: 1) the simulation of biomass and N production from a prerice rainfed *Sesbania* crop, 2) estimation of complementary inorganic N application (as urea), and 3) a rice production model.

Sesbania submodel. The model calculates the daily water balance of a *S. rostrata* crop from daily rainfall and class A pan evaporation. Actual evapotranspiration (ET_a), potential crop evapotranspiration (ET_p), and their ratio were calculated on a daily basis.

Table 17. N uptake at 2 growth stages of transplanted and direct seeded IR64 as influenced by *Sesbania rostrata* green manuring practices, and methods of inorganic N application at irrigated sites in Tarlac, Philippines, 1987 WS.

Treatment	N uptake[a] (kg/ha)			
	Transplanted		Direct seeded	
	20 DT	PI	20 DAS	PI
No GM or fertilizer N	19 b	29 e	22 cd	34 d
GM in situ incorporation	25 ab	92 a	42 a	96 a
GM leaf-stem incorporation	28 a	72 bc	40 a	98 a
GM root incorporation	19 b	44 de	20 d	34 d
Researchers' split PU, 60 kg N/ha	27 a	58 cd	28 bcd	56 c
Researchers' split PU, 90 kg N/ha	28 a	78 ab	34 ab	73 b

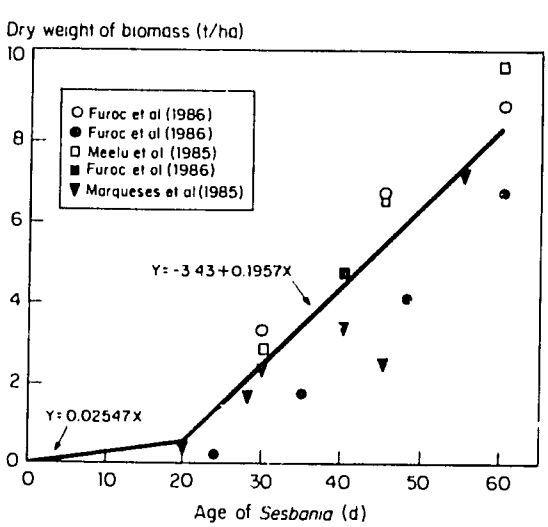
[a]DT =d after transplanting, DAS = d after seeding, PI = panicle initiation.

Table 18. Rice grain yield as influenced by *Sesbania rostrata* green manuring practices, and methods of inorganic N application at 2 rainfed sites in the Philippines, 1987 WS.

Treatment	Grain yield (t/ha)	
	IRRI	Tarlac
No GM or fertilizer N	2.8 b	3.4 c
GM in situ incorporation	4.5 a	4.4 a
GM in situ incorporation + topdressed inorganic N[a]	4.6 a	4.4 a
GM leaf-stem incorporation	4.7 a	4.2 ab
GM leaf-stem incorporation + topdressed inorganic N[a]	4.8 a	4.4 a
GM root incorporation	2.9 b	3.0 c
GM root incorporation + topdressed inorganic N[a]	3.2 b	3.9 b
Farmers' split PU, 60 kg N/ha[b]	4.0 a	4.6 a
Researchers' split PU, 60 kg N/ha[c]	4.3 a	4.3 ab
Researchers' split PU, 90 kg N/ha[c]	4.6 a	4.2 ab

[a]30 kg/ha as PU at 5-7 DBPI. [b]1/2 at 15 d after transplanting + 1/2 at 1 wk after panicle initiation. [c]2/3 basal broadcast and incorporated + 1/3 at 5-7 DBPI.

Potential *Sesbania* biomass accumulation was estimated using a growth function derived from *Sesbania* experiments conducted at IRRI (Fig. 6). Estimated biomass accumulation, in the absence of water deficit, was 5.3 t dry weight/ha in 45 d. The N content of this biomass was conservatively estimated at 2% or 106 kg/ha.



6. Biomass accumulation of *S. rostrata* as a function of plant age under nonstress conditions. IRRI, 1987.

The reduction rate technique was used to adjust *Sesbania* yields down in the presence of moisture stress. Actual daily biomass accumulation, AB_a, was derived as

$$AB_a = PB_p * ET_a / ET_p$$

where PB_p is potential biomass accumulation.

The output of the *Sesbania* submodel included *Sesbania* biomass at 45 d, equivalent organic N, and soil moisture balances, which are input into the submodels that follow.

Integrated nitrogen submodel. Input into the integrated N submodel included the quantity of *Sesbania* N, the rice crop response to total N (organic and inorganic) and its interaction with moisture stress, and expected urea and rice prices. The N-rice response function, derived by Huijsman for rainfed rice under farmer's management in central Philippines, was specified as

$$Y = 1838 + 39.05N - 0.172\,N^2 - 56.8S - 0.78SN$$

where Y is yield in kg/ha,

N is total N (*Sesbania* N + urea N) in kg/ha,

S is days of water stress during flowering or grain filling, and

SN is an interaction between N and S.

In their mineralized form, *Sesbania* N and urea N were assumed to be perfect substitutes, requiring a transformation of *Sesbania* N to urea N equivalents. The relationship, following research observations at IRRI, assumed equal uptake and use efficiency of urea N and *Sesbania* N up to 50 kg of *Sesbania* N/ha, and decreasing efficiency of *Sesbania* N relative to inorganic N thereafter.

The quantity of urea N applied to the crop depended on 1) the quantity of N supplied from *Sesbania*, 2) rice and urea prices, 3) the response relationship defined above, and 4) the farmer's expectation of moisture stress in the coming season. Expected stress, ES_i, was estimated as a weighted (decay) function of observed stress in the previous 3 yr. That is:

$$ES_i = 0.50\,AS_{i-1} + 0.32\,AS_{i-2} + 0.18\,AS_{i-3}$$

where AS_{i-j} is observed stress in previous years (j = 1, ...3).

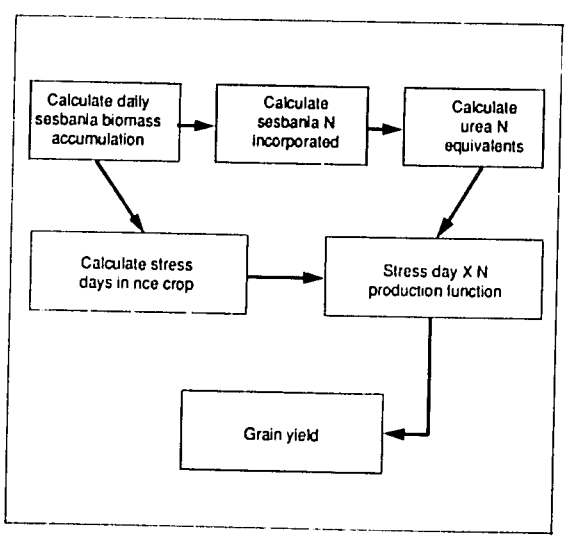
Outputs of the integrated N submodel included 1) total N applied to the rice crop (*Sesbania* N + urea N), and 2) an estimate of expected rice yields.

Rice submodel. A rice water balance model was used to calculate the number of stress days experienced by the rice crop during flowering and grain filling, which included the period from 55 to 10 d before harvest. Stress was defined as occurring on any day when ET_a/ET_p was less than 0.9.

Actual yield was then calculated using actual stress days and total N, which permitted estimation of the economic benefits of the conjunctive use of *Sesbania* N and urea N compared with urea N alone.

Model operation. A simple flow diagram of the *Sesbania*-rice model is shown in Figure 7. *Sesbania* is planted on the basis of cumulative rainfall after 1 Apr, using 50 mm and 100 mm rainfall accumulations as planting date criteria. GM biomass then accumulates until incorporated at 45 d. After a 10-d turnaround period, rice is transplanted if surface water is present. If not, transplanting occurs when surface water accumulates. The performance of a 110-d rice cultivar (IR36) with a field duration of 85 d was simulated.

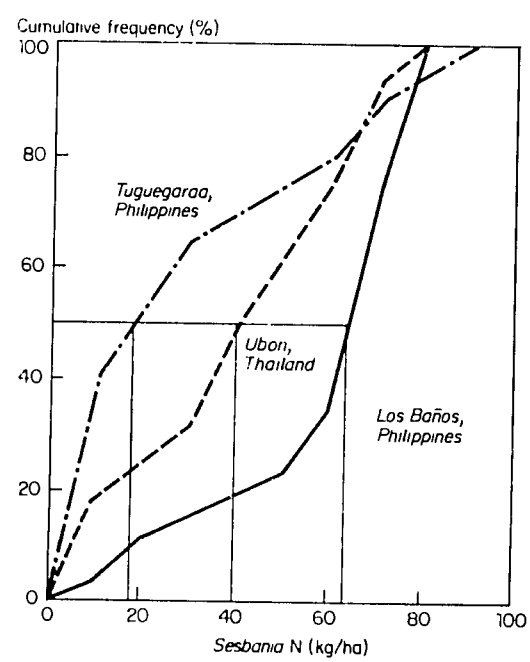
The simulation model was run for three locations with different WS onset: Tuguegarao in northern Philippines; Los Baños, Philippines; and Ubon in northeastern Thailand. The onset of WS is highly variable in Tuguegarao, but predictable in Los Baños. Ubon represents an intermediate situation.



7. Simple flow diagram of the *Sesbania*-transplanted rice cropping system in a simulation model. IRRI, 1987.

***Sesbania* nitrogen accumulation.** Long-term simulation using actual weather data compared *Sesbania* N accumulation at three locations (Fig. 8). In Tuguegarao, with poor distribution of transition period rainfall, drought reduced the N contribution of 45-d *Sesbania* to less than 18 kg N/ha in 50% of the years simulated. In Ubon, the water balance was unfavorable because of sandy surface soils with low water holding capacity. Less than 40 kg N/ha was accumulated in half the years. In Los Baños, with a more favorable onset of WS and with heavy soils with high water holding capacity, *Sesbania* N contributed more than 65 kg/ha in 50% of the years simulated, and more than 50 kg/ha in 75% of the years.

Waterlogging frequency. Waterlogging, which destroys conventional crops, largely determines the potential niches for GM. The frequency of shallow surface flooding during the prerice season was estimated for the three locations. Surface flooding periods exceeding 3 d during prerice crop growth occurred in 30-65% of the years. This suggests a high risk of producing waterlogging-sensitive crops during this period at each site. Thus, GM produce-



8. Cumulative frequency of simulated N yield from *S. rostrata* crops of 45-d duration planted with 100 mm rainfall accumulation from 1 Apr. IRRI, 1987.

tion, if feasible, would not compete with other crops.

Waterlogging does not seriously affect *Sesbania* growth after establishment, but it does seriously damage *Sesbania* during germination and emergence. Simulations determined that *Sesbania* crop loss due to flooding at emergence may be expected in 1 yr out of 5 at these sites. This would necessitate replanting, increasing GM production costs and risks.

Benefits of *Sesbania* nitrogen. Because Los Baños was the most dependable site, we used it to examine the potential benefits of the integrated management of *Sesbania* N and urea N. This required estimating the cost to grow and incorporate a *Sesbania* GM crop.

Table 19. Estimates of *Sesbania* production costs in Laguna, Philippines, first quarter of 1987.[a]

Item	Level per hectare	Cost ($) Per unit	Cost ($) Per ha
Land preparation (animal traction)			
Plowing (labor-animal d)	1	35	35
Harrowing[b] (labor-animal d)	2	35	35
Seed[c] (kg)	18	1	18
Labor for seeding (labor d)	0.6	1	1
Incorporation of *Sesbania*[d]			
Slicer (labor-animal d)	2	18	18
Harrow to incorporate (labor-animal d)	2	18	18
Opportunity cost of land[e]	–	–	–
Opportunity cost of capital[f]			4
Cost/hectare: Cash cost[g]			22
Full cost basis[h]			129

[a]*Sesbania* incorporated at 45 d after seeding. [b]One pass following plowing plus light harrowing to cover seed. [c]Assuming 15 kg/ha and that 1 yr in 5, the crop must be reseeded to cover stand loss from flooding in first 10 d of stand establishment. Labor for seeding also allows for 1/5 reseeding. [d]For about 40- to 45-day-old *Sesbania*: slice (2 passes at right angles) before plowing; plus 2 extra harrowings to incorporate. [e]Opportunity cost of land as an alternative use in this rainfed environment is assumed to be zero. However, in the simulation analysis, an opportunity cost of land will be implied for comparative purposes if the *Sesbania* crop results in late rice harvest and reduced yields. [f]Ten percent a month for 2 mo on seed costs only and assumes land preparation is household resource. [g]Assuming seed is purchased, but that all tillage costs are met with farm-owned resources. [h]Changing opportunity cost equal to market rates for farm-owned resources.

The costs of producing *Sesbania* in Laguna are listed in Table 19. The cost of establishment—1 plowing and 2 harrowings with a power tiller—may be about $70/ha. The second harrowing is light, to cover the broadcast seed. *Sesbania* seed is not sold in Laguna; hence seed cost was conservatively assumed at $1/kg, and rate at 15 kg/ha. The higher value in the table allows for reseeding 1 yr in 5. The cost of *Sesbania* incorporation (2 passes with a slicer plus an extra harrowing before rice transplanting) may reach another $36/ha. The cost of biomass incorporation depends on biomass produced; however, precise figures are not available on the relationship between biomass level and the power necessary for incorporation.

Total cost, including the opportunity cost of farm resources, is nearly $130/ha, or $1.30/kg of N produced by the *Sesbania* crop—assuming this biomass produces 100 kg N or 82 kg N/ha equivalent. This is 2.6 times the cost of N applied as urea. Tillage costs for land preparation and incorporation must be reduced to improve the competitiveness of this N source.

Short-term benefits. The simulation model run for Los Baños weather data generated estimates of the contribution of *Sesbania* to N, the quantity of inorganic N applied, the costs of organic and inorganic N, and expected and actual rice yields. The mean values and CVs are listed in Table 20 for *Sesbania* establishment with 50 or 100 mm of accumulated rainfall, and for 2 production costs: full costs or assuming a technology that reduced tillage costs by 50%.

Sesbania was estimated to contribute 51 kg N/ha from the early and 63 kg N/ha from the late planted GM crop. The relative year-to-year variation in N from *Sesbania* was larger for the early (CV = 48%) than for the late planted GM crop (CV = 32%). Optimal N rates for rice were similar (85-86 kg/ha) for both *Sesbania* seeding dates. Consequently, the quantity of N applied as urea was higher for the early planted *Sesbania* crop (34 kg/ha) than for the late planted crop (23 kg/ha). However, the relative variability of applied inorganic N was substantially higher for the late (CV = 98%) than for the early planted *Sesbania* crop (CV = 68%).

The cost of growing *Sesbania* was higher with the late planted crop because incorporation costs

Table 20. Expected N contribution from *Sesbania*, applied N as urea, N costs and rice yields, by planting date and cost of cultivation (50% or full) with informal credit. IRRI, 1987.

Item	Planting at 50 mm rainfall				Planting at 100 mm rainfall			
	50%		Full		50%		Full	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV
N supply (kg/ha)								
Sesbania	51	48	51	48	63	32	63	32
N as urea	34	68	34	68	23	98	23	98
Total N	85	14	85	14	86	13	86	13
N cost ($/ha)								
Sesbania	66	17	101	16	74	20	109	13
N as urea	16	68	16	68	11	98	11	98
Total	82	7	117	8	85	10	120	7
Urea only	41	14	41	14	42	13	42	13
Cost/unit of N ($/kg)								
Sesbania	1.29	–	1.98	–	1.17	–	1.73	–
Total N	0.96	–	1.38	–	0.99	–	1.39	–
Rice yield (t/ha)								
Expected	3.1	22	3.1	22	3.1	21	3.1	21
Actual	2.9	40	2.9	40	3.0	38	3.0	38
Increment	0.4	17	0.9	17	0.4	13	1.0	13

rose with greater biomass production. Nonetheless, the cost per unit of producing N from *Sesbania* was marginally lower for the late planted crop ($2.00/kg N versus $1.70/kg N). Total N costs per hectare were similar for the two planting dates, as were the costs per unit of total N applied.

Expected rice yields were similar for the early and late planted rice crops—that is, late season stress was not a problem, given transplanting dates and weather events. Actual yields were also similar at 2.9-3.0 t/ha.

Had all fertilizer been supplied as urea (assuming no other beneficial effects from *Sesbania*), the cost savings would exceed $40 at low tillage costs, and about $80/ha if the higher cost situation prevailed. These short-term savings from using urea as opposed to *Sesbania* may be directly converted to rice equivalents. If benefits from *Sesbania* are realized from the following rice crop, a yield increment of 0.4 t/ha (about 13%) would be necessary to equate the profitability of combined urea and *Sesbania* with that of urea alone in the short run, given low cultivation costs. This figure increases to 0.9-1.0 t/ha (a 31% increase) if the higher tillage costs are assumed.

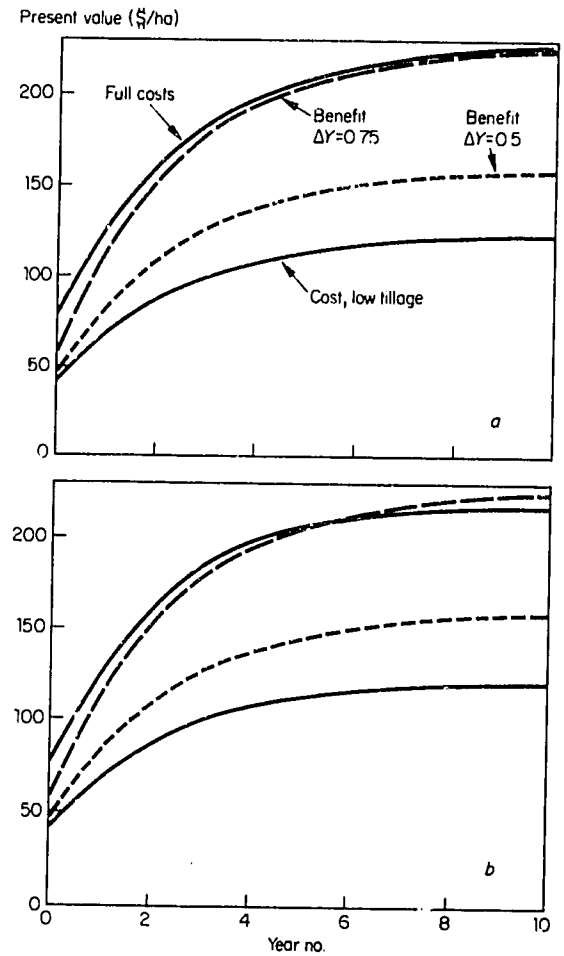
Long-term benefits. One benefit of incorporating GM is the longer-term impact of increasing and stabilizing rice yields. For example, experiments at IRRI have demonstrated yield gains more than 0.5 t/ha due to *Sesbania*, after differences in N rates are accounted for. Thus, longer-term yield impacts were examined.

Because individuals prefer to receive returns now rather than later, future benefits (and costs) of green manuring must be discounted to the present for comparison. In the following analysis, we make two assumptions: first, the farmer has a 10-yr or shorter planning horizon; and second, the farmer borrows money in the informal credit market at 50% interest for a 5-mo crop season.

Discounted cost and return streams for a 10-yr period of *Sesbania* production are shown in Figure 9. Two rice yields are presented: 0.5 t/ha and 0.75 t/ha yield gains from *Sesbania* incorporation beyond its contribution to total N. Similarly, 2 production costs are shown: 1) full cost, and 2) land preparation costs reduced by 50%. In Figure 9 (a), *Sesbania* is grown each year: in Figure 9 (b), the crop is planted every second year, after annual plantings in years 1-4.

Discounted benefits do not exceed discounted costs within 10 yr for yield increments of 0.75 t/ha at the higher input-cost scenario. However, with the lower cost, a 0.5 t/ha yield gain is profitable

from the first year. Alternatively, if the cost of *Sesbania* technology were reduced through planting each alternative year, the practice would be profitable after year 5, even at high tillage costs. Again, a yield gain of 0.5 t/ha would be immediately profitable if land preparation costs were reduced by 50% and *Sesbania* were grown each second year. Analysis of the long-term cost effectiveness demonstrates the importance of yield gains attributed to *Sesbania* (not realized from inorganic N alone) and the cost of producing the *Sesbania* crop.



9. Discounted benefit and costs from GM adoption, informal credit for *Sesbania* grown each crop season (a) and each second season (b). IRRI, 1987.

FARMER MANAGEMENT OF GREEN MANURE CROPS IN ASIA

Multiple Cropping and Agricultural Economics Departments

Because little comparative information is available on farm-level GM crops grown in rice-based systems in Asia, we did a survey of farmers' management of GM.

This study limits GM to mesophytic herbacious plants, involves only current farmer practices, and estimates productivity gains in rice yields from GM. The analysis rests on responses from China (3), India (4), Bangladesh (1), and the Philippines (1).

Species and environmental niches. Table 21 lists GM species grown by farmers in the rice-based systems diagrammed in Figure 10.

Chinese milk vetch *Astragalus sinica* L. is the most important GM crop in Asia, grown on 3.2 million ha of fully and partly irrigated riceland in southern and central China. This species as well as common vetch *Vicia sativa* L., and bird vetch *Vicia cracca* L. are grown as postrice crops in winter. Seeds are relay-broadcast into the second rice crop during grain filling. The vetch is incorporated before the first rice crop of the next year. This system is apparently unique to China among the countries surveyed.

In other areas except the Philippines, *Sesbania* species dominates. In the Philippines, indigo *Indigofera tinctoria* dominates.

Sesbania used as GM in Asia ranges from *S. aculeata* in South Asia to *S. speciosa* (southern India), *S. roxburghii* (Taiwan, China), and *S. cannabina* (China). These species are cultivated mainly as prerice GM during the premonsoon and early monsoon period from April to July. In China, *S. cannabina* is also transplanted into the first rice crop as an intercrop and is incorporated during land preparation for the second rice crop.

GM crops are rarely used in rainfed wetland rice-based systems. Exceptions are mixed cropping *S. aculeata* with dry seeded or wet seeded rainfed lowland rice in eastern India, and the establishment of *Indigofera* in the Philippines in the wet-dry transition period. No respondents reported GM as important components of upland rice-based systems.

Table 21. Green manure crops presently and previously grown by farmers in selected Asian countries.[a] IRRI, 1987.

Green manure presently grown	Previously grown
	China
1. Milk vetch *Astragalus sinicus* L.	1. Slender groundnut *Glycine gracilis* Skvor.
2. Bird vetch *Vicia cracca* L.	2. Joint vetch *Aeschynomene indica*
3. Common vetch *Vicia sativa* L.	3. Water peanut *Alternanthera philoveroides* (Mart.) Grisels.
4. Sesbania *Sesbania cannabina* Poir	
5. Broad bean *Vicia faba*	
6. Radish *Raphanus sativus* L.	
7. Azolla *Azolla filiculoides* Lamk. and *Azolla imbricata* (Roxb) Nakai	
	Taiwan, China
1. Sesbania, sesbeans *Sesbania roxburghii* Merr.	1. *Carthamus tinctorius* L.
2. Sunn hemp *Crotalaria juncea* L.	2. *Mucuna capitata*
3. Rape *Brassica campestris* L.	3. Velvet bean
4. Berseem clover *Trifolium* sp.	4. *Tephrosia*
5. Soybean *Glycine max* [L.] Merr.	
	India (southern)
1. Dhaincha *Sesbania aculeata*	
2. Sesbania *Sesbania speciosa*	
3. Wild indigo *Tephrosia purpurea*	
4. Pillipesara *Phaseolus triloba*	
5. Sunn hemp *Crotalaria juncea*	
6. Aviri *Indigofera tinctoria*	
	India (eastern)
1. Dhaincha *Sesbania aculeata*	
2. Sunn hemp *Crotalaria juncea*	
3. Clusterbean *Cyamopsis tetragonoloba*	
4. Cowpea *Vigna unguiculata*	
5. Horsegram *Dolichos biflorus*	
6. Senji *Melilotus parcisflorus*	
	India (Chhotanagpur Plateau)
1. Dhaincha *Sesbania aculeata*	
2. Sunn hemp *Crotalaria juncea*	
3. Berseem *Trifolium alexandrinum*	
	India (northern)
1. Dhaincha *Sesbania aculeata*	
2. Sunn hemp *Crotalaria juncea*	
3. Berseem *Trifolium alexandrinum*	
	Bangladesh (northwest)
1. Dhaincha *Sesbania* spp.	1. Mungbean *Vigna radiata* (L.) Wilczek
2. Sunn hemp *Crotalaria juncea*	2. Cowpea *Vigna unguiculata* (L.) Walp.
3. Black gram	
	Philippines
1. Indigo *Indigofera tinctoria*	
2. Azolla	

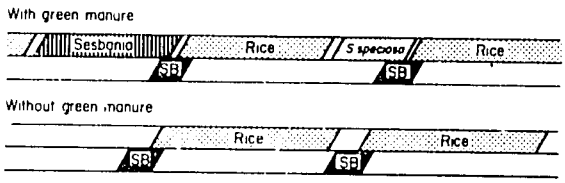
[a]From Regional Survey on Farm-level Management System for Green Manure Crops.

Asian farmers produce GM crops predominantly on irrigated ricelands, but alternative crops compete directly with GM for this land. For example, expanding land use in winter for wheat, barley, or rape is reducing the area planted to GM in China. As a Chinese respondent indicated, "green manure crops and agricultural crops compete for space and time, a competition between land use and land upkeep."

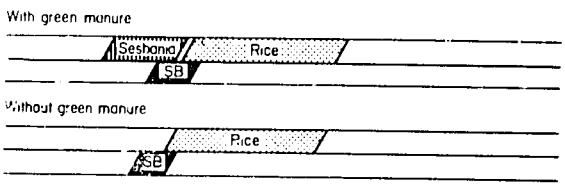
Green manure management. *Land preparation.* Tillage and seeding require major labor and cash in GM production. Land preparation varied from one to three plowings and harrowings for prerice *Sesbania* in India, to as many as six plowings with a traditional plow in Bangladesh (Table 22). In Taiwan, China, a single tractor plowing prepares riceland for *S. roxburghii.*

In these cases, land preparation costs are wholly

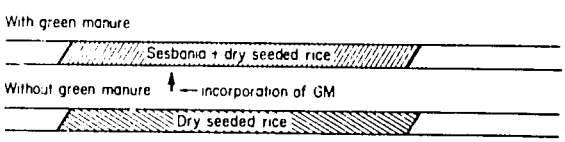
Country India (southern)
Rice environment irrigated
Green manure *Sesbania speciosa*
Estimated area 5000 ha
Crop sequences



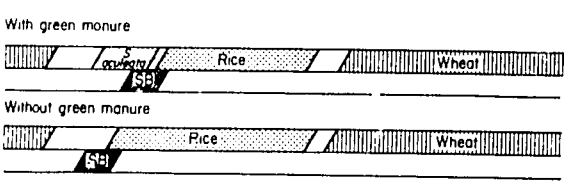
Country India (eastern)
Rice environment irrigated
Green manure *Sesbania aculeata* dhaincha
Crop sequences



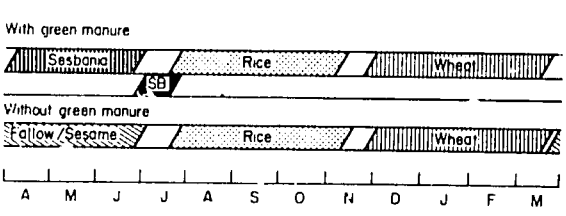
Country India (eastern)
Rice environment rainfed lowland
Green manure: *Sesbania aculeata* dhaincha
Crop sequences



Country India (northern)
Rice environment irrigated
Green manure *Sesbania aculeata* dhaincha
Estimated area < 1% rice area
Crop sequences



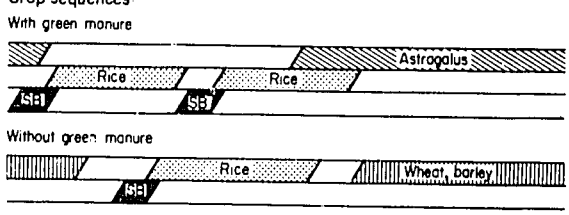
Country Bangladesh
Rice environment irrigated
Green manure *Sesbania aculeata* dhaincha
Estimated area 1500 ha (Thakurgaon)
Crop sequences



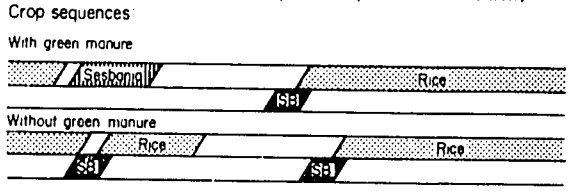
Country Philippines
Rice environment partially irrigated
Green manure: *Indigofera tinctoria*
Crop sequences

Rice environment rainfed
Green manure: *Indigofera tinctoria*
Crop sequences

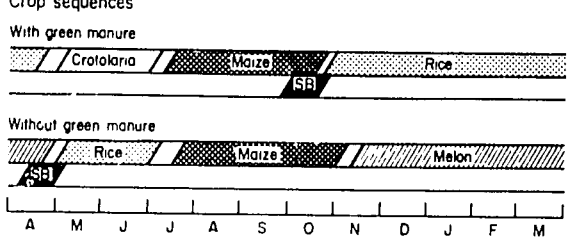
Country China
Rice environment fully and partially irrigated wetland
Green manure *Astragalus sinica* L. Chinese milk vetch
Estimated area 3.17 million ha (Hunan, Jiangxi, Zhejiang, Hubei Provinces)
Crop sequences



Country China (Taiwan)
Rice environment irrigated wetland riceland
Green manure: *Sesbania roxburghii* M.
Estimated area 3737 ha (central, southern, and eastern Taiwan)
Crop sequences



Country China (Taiwan)
Rice environment irrigated wetland riceland
Green manure: *Crotalaria juncea* L. sunn hemp
Estimated area 1725 ha (central, southern, and eastern Taiwan)
Crop sequences



10. Rice environments and crop sequences including green manures in several Asian countries. Source: Regional Survey on Farm-level Management Systems for Green Manure Crops.

attributed to the cost of the GM crop. In the Philippines, the land preparation cost of *Indigofera* is shared with the postrice intercrop; in eastern India, the cost of *S. aculeata* is shared with the

Table 22. Management of green manure (GM) crops in some Asian countries.[a] IRRI, 1987.

Item	Chinese milk vetch (China)	*S. roxburghii* (Taiwan, China)	*S. speciosa* (India, southern)	*S. aculeata* (Chhotanagpur, India)	*S. aculeata* (India, northern)	*S. speciosa* and *S. aculeata* (India, eastern)	*Sesbania* spp. (Bangladesh)	*Indigofera* (Philippines)
Land preparation for GM								
No (N) or conventional (C) tillage	N	C	C	C	C	C	C	C
Plowings (no.)	0	1	1	2	*d*	3	6	1
Harrowings (no.)	0	1	0	1	3	3	3	1
Tillage equipment used	0	Tractor	Desi plow	Desi plow, plank	Desi plow or tractor disc harrow	Desi plow and ladder	Desi plow	Harrow
Seeding								
GM seeding rate (kg/ha)	45-60	25-30	15-30	10	40	50	15	5
Method of seeding	Broadcast	Broadcast	Broadcast	Broadcast	Broadcast	Broadcast	Broadcast	Broadcast or drill in furrows
Method of incorporation[b]	P	C/P	S/P	S/P	S/P	S/P	C/P	K/P S/P
Plowing equipment used[c]	T/AP	T	AP/T	AP	AP	AP	AP/T	AP/T
Plowings/harrowing (no.)	1	*d*	2	2	1.2	3-4	6/2	1/2-3
Average age of GM at incorporation (d)	180+	50-70	45-65	30-55	40-50	40-55	50-65	173.4
Incorporation difficult for farmers?	No	*d*	Yes	No	Yes	Yes	Yes	No

[a]Source: Regional Survey on Farm-level Management Systems for Green Manure. [b]P = plowed in directly, C/P = cut by machine, then plowed, S/P = slashed by hand, then plowed, K/P = knocked flat, then plowed. [c]T = 4-wheel tractor, HT = hand tractor, AP = animal power. [d]No comment made by respondent.

Table 23. Yield effects and inorganic fertilizer substitution by green manure (GM) cultivation.[a] IRRI, 1987.

Item	Chinese milk vetch (China)	*S. roxburghii* (Taiwan, China)	*S. speciosa* (India, southern)	*S. aculeata* (Chhotanagpur, India)	*S. aculeata* and *S. speciosa* (India, eastern)	*S. aculeata* (India, northern)	*Sesbania* spp. (Bangladesh)	*Indigofera tinctoria* (Philippines)
Approximate rate of inorganic N applied to rice (kg N/ha)								
Without GM	180	1st: 120-150 2d : 100-130	100	80-100	60	100-120	80	88
With GM	120	1st: 120-150 2d : 30- 39	60	40- 50	30	60-80	60	38
Approximate yield level farmers obtain (t/ha)								
Without GM	5.3	1st: 7.0 2d : 5.0		4.0	3.0	6.0-7.0	3.0-5.0	4.5

With GM	6.0	1st: 7.5 2d : 5.3	10-15% inc.	5.0-6.0	2.8	6.0-7.0	4.0-6.0	4.6
Frequency of GM cultivation	1 yr in 3[b]	1 yr in 2 or 2 yr in 3	Every year[c]	Skip some years	Every year	Skip some years	Skip some years	Every year
Reduction in weed growth and weeding costs observed with GM?	d	No difference	Slight	Yes	No difference	Yes[e]	Yes, large	Yes, large
GM cultivation delays establishment of rice crop?	No	No	No	No	By 1 wk	No	No	No
Optimum time to transplant after GM incorporation (d)	10-15	d	7-10	d	d	7	10-15	4-7
Early rice growth depression due to GM observed?	Yes[f]	No	Sometimes	No	Yes	No	Yes	No
Potential for expanded use of GM	d	Large	Large	Modest	Large	Modest	Large	Moderate
Area planted to GM is	Decreasing	Increasing	Decreasing	Increasing	Stable	Decreasing	Increasing	Decreasing

[a]Source: Regional Survey on Farm-level Management Systems for Green Manure Crops. [b]This is the case in most ricelands. In poor soil, GM is cultivated continuously. [c]Continuously cultivated except in years when drought prevents sowing. [d]No comment made by the respondent. [e]One weeding is saved. [f]Farmers incorporate some N fertilizer to avoid this problem.

companion dry seeded rice crop. Only in China, where *Astragalus* is relayed into the standing rice crop, were there no land preparation costs for GM.

Seeding. Seed quantities vary by species and locality (Table 22). *Sesbania* seeding rates ranged from 10 to 50 kg/ha in India. When *Sesbania* was intercropped with rainfed rice, farmers used 15-20 kg/ha. Seeding rates for vetches in China were higher (45-75 kg/ha). Except in the Philippines, GM crops were broadcast seeded, whether monocropped, mix-cropped, or relay-cropped. As an intercrop with DS upland crops, *Indigofera* in the Philippines is drilled in rows.

Farmers both saved GM seed and purchased it, although seed availability was a common problem. In China, northern India, and Bangladesh, most farmers purchased GM seed from the market or private dealers. In southern and eastern India, most farmers grew their own seed, either by leaving random *S. aculeata* plants to mature in ricefields or by planting them along the bunds.

Pests and diseases. Insect pests and diseases were reported in China and in southern and eastern India. Damaging insects included pod borers, leaf rollers, and mealybugs in India, and cabbage loopers in Taiwan, all on *Sesbania.* In China, *Aphis fabae* was reported as a serious insect pest, and *Sclerotinia trifolium* Erik was an important disease on *A. sinicus.*

Green manure incorporation. Thorough incorporation of the GM biomass is difficult for most Asian farmers. Incorporation strategies appear in Table 22. Most farmers slash GM by hand, and then plow under the biomass. In some areas (Taiwan and Bangladesh), the GM is cut by machine and then plowed under. In other cases (Taiwan and the Philippines), it is plowed in directly.

Frequent slashing confirms farmers' inability to incorporate GM directly with their tillage equipment. Slashing often takes labor when it is most needed in land preparation and transplanting of rice. Thus, lack of labor is a constraint.

Benefits of green manuring. Farmers substantially reduce inorganic N fertilizer rates when they cultivate GM (Table 23). But GM does not entirely substitute for inorganic N. Further, estimates of grain yields are consistently higher with GM than when higher rates of N alone are applied. Esti-

mated yield increases attributed to GM were about 15% in China and southern India, and about 25% in eastern India and Bangladesh.

GM crops are seldom grown every year on the same field. Chinese farmers generally grow GM once every 3 yr, with grain the second year and fallow the third winter.

Although GM production can delay the rice crop beyond normal transplanting time, this was not reported as a significant problem (Table 23). The optimum time to transplant after GM incorporation was reported to be between 7 and 15 d in all areas where a gap occurs between the 2 crops. Early rice growth may be depressed in some areas after GM incorporation, but not enough to depress rice yields.

Respondents foresaw modest to large potential for increasing GM use. In China, the Philippines, and southern and northern India, respondents estimated decreasing GM use; but in Taiwan, the Chhotanagpur Plateau of India, and Bangladesh, respondents reported increasing GM use.

Soil and crop management

Management of other nutrients

Agronomy Department

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LONG-TERM FERTILITY TRIALS

Long-term fertility trials continued at the IRRI farm, at three Bureau of Plant Industry (BPI) experiment stations, and in farmers' fields.

IRRI. The 46th dry season (DS) and 47th wet season (WS) consecutive crops were grown in 1987, using the test cultivars used in 1986 (see Annual report for 1986). IR8 was free from virus diseases.

In DS, N alone significantly increased grain yield irrespective of cultivar (Table 1). IR64 yields in N-fertilized plots were similar to those with NP, NK, and NPK. However, in IR8 and IR29723-143-3-2-1, NP and NPK were better than N and NK, indicating a probable sensitivity to P deficiency (13 ppm by Bray II method) in plots not fertilized with P for 23 crop years. Furthermore, maturity was delayed 1 wk without P.

NPK-fertilized plots using inorganic N gave the highest yields, but not significantly more than with N partially from rice straw compost.

In WS, yield responses to various NPK combinations were similar to those in DS. Maturity was delayed in plots without P application.

Bureau of Plant Industry. At the Maligaya station in DS, IR64 yields did not vary from the control with N alone (Table 2). But in IR8 and IR29723-143-3-2-1, N increased yield about 1.3 t/ha over the control. Yields did not differ between N only and NK. Although NPK gave the highest yields, NP was comparable.

In WS, yield responses to treatments were similar for all test rices.

Irrespective of season, Maligaya seems to need N and P. Soil analyses of N and P in 1986 showed these nutrients below critical levels (0.09% N and 17 ppm P by Bray II method) even with continuous application.

In Bicol, tungro damaged IR8 in DS, resulting in low and similar yields among fertilizer treatments (Table 3). Early-maturing IR64 was hurt by a 2-wk water stress during midseason. IR29723-143-3-2-1, however, fully recovered. These rices yielded similarly, with NP giving yields comparable to those with NPK

IR8 in WS was infected by virus, although less severely than in DS. In WS, IR29723-143-3-2-1 yields were similar to and IR64 yields were better than those in DS. N alone increased yield by 0.9 t/ha. NP improved yields from 0.6 t/ha in IR64 to 1.1 t/ha in IR29723-143-3-2-1. NPK did not produce yields significantly better than did NP.

Table 1. Effect of NPK on grain yield in the 46th (DS) and 47th (WS) consecutive crops in the long-term fertility trial. IRRI, 1987.

Fertilizer (kg/ha)			Grain yield[a] (t/ha)			Mean
N[b]	P	K	IR8	IR64	IR29723-143-3-2-1	
			Dry season			
0	0	0	3.6 c	3.2 b	3.4 d	3.4
140	0	0	6.7 ab	6.1 a	6.2 c	6.3
0	13	0	4.2 c	3.2 b	3.8 d	3.7
0	0	25	4.0 c	2.9 b	3.7 d	3.5
140	13	0	7.3 a	6.5 a	7.2 a	7.0
140	0	25	6.1 b	6.3 a	6.4 bc	6.3
140	13	25	7.3 a	6.4 a	7.3 a	7.0
140[c]	13	25	6.8 ab	6.0 a	7.0 ab	6.6
			Wet season			
0	0	0	2.7 c	2.7 b	2.8 c	2.7
60	0	0	4.1 b	3.6 a	4.2 b	4.0
0	13	0	2.5 c	2.4 b	3.1 c	2.7
0	0	25	2.8 c	2.5 b	3.0 c	2.8
60	13	0	4.7 ab	4.1 a	4.8 ab	4.5
60	0	25	4.6 ab	3.6 a	4.5 ab	4.2
60	13	25	5.1 a	4.1 a	5.0 a	4.7
60[c]	13	25	4.5 ab	3.9 a	4.4 ab	4.3

[a]Within a season, in a column, values followed by a common letter are not significantly different at the 5% level by DMRT. CV = 9% for DS and 12% for WS. [b]Includes topdressing at 5-7 d before panicle initiation of 40 kg N/ha in DS and 20 kg N/ha in WS. [c]24 kg N/ha from rice straw compost.

Table 2. Effect of NPK on grain yield in the long-term fertility trial. Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines, 1987.

Fertilizer (kg/ha)			Grain yield[a] (t/ha)			Mean
N[b]	P	K	IR8	IR64	IR29723-143-3-2-1	
			Dry season			
0	0	0	2.5 e	1.4 b	3.4 d	2.4
140	0	0	4.2 cd	1.7 b	4.8 c	3.7
140	26	0	5.1 bc	6.0 a	5.8 b	5.6
140	0	50	4.1 d	1.9 b	3.9 d	3.3
140	26	50	5.4 ab	6.6 a	6.1 ab	6.0
140	26	50+25	6.0 a	6.4 a	6.7 a	6.4
			Wet season			
0	0	0	3.0 b	2.5 c	2.6 b	2.7
70	0	0	3.4 ab	3.3 b	2.9 b	3.2
70	26	0	4.1 a	4.3 a	3.9 a	4.1
70	0	50	3.5 ab	3.2 b	3.0 b	3.2
70	26	50	3.7 ab	4.8 a	4.2 a	4.3
70	26	50+25	4.1 a	5.0 a	3.8 a	4.3

[a]Within a season, in a column, values followed by a common letter are not significantly different at the 5% level by DMRT. CV = 11% for DS and 11% for WS. [b]Includes topdressing at 5-7 d before panicle initiation of 40 kg N/ha in DS and 30 kg N/ha in WS.

Table 3. Effect of NPK on grain yield in the long-term fertility trial. Bicol Experiment Station, Pili, Camarines Sur, Philippines, 1987.

Fertilizer (kg/ha)			Grain yield[a] (t/ha)			Mean
N[b]	P	K	IR8[c]	IR64	IR29723-143-3-2-1	
			Dry season			
0	0	0	2.1	3.0 b	2.5 b	2.5
140	0	0	2.0	3.0 b	3.4 b	2.8
140	26	0	1.9	3.8 ab	6.4 a	4.0
140	0	50	1.9	3.0 b	2.6 b	2.5
140	26	50	2.1	3.8 ab	6.6 a	4.2
140	26	50+25	2.9	4.4 a	6.3 a	4.5
			Wet season			
0	0	0	3.3 cd	3.6 d	4.0 c	3.6
70	0	0	4.5 ab	4.5 cd	4.9 b	4.6
70	26	0	3.7 bc	5.1 abc	6.0 a	4.9
70	0	50	2.6 d	4.6 bc	5.0 b	4.1
70	26	50	3.5 cd	5.6 a	6.1 a	5.1
70	26	50+25	5.3 a	5.5 ab	6.4 a	5.7

[a]Within a season, in a column, values followed by a common letter are not significantly different at the 5% level by DMRT. CV = 22% for DS and 12% for WS. [b]Includes topdressing at 5-7 d before panicle initiation of 40 kg N/ha in DS and 30 kg N/ha in WS. [c]IR8 damaged by virus in DS; no statistics computed.

The drought in the Visayas in DS caused total crop failure. In WS, yields were high, comparable to those in DS at other long-term fertility sites, and similar to those in 1986.

Farmers' fields. The 20th (DS) and 21st (WS) crops in Tanay, Rizal (Vertic Tropaquept), and the 22d (DS) crop in Luisiana, Laguna (Aquic Troporthent) were grown in farmers' fields (Table 4, 5). IR64 and IR29723-143-3-2-1 were used.

The NPK-treated plots yielded the highest in WS in Tanay and in DS in Luisiana. In most croppings, yields increased with increase in N. Yields further increased with either P or K, or both, combined with N.

Response to N was observed in both soils with

Table 4. Effect of NPK on yield of IR64 and IR29723-143-3-2-1 in the 20th (DS) and 21st (WS) consecutive crops. Long-term fertility trial, Tanay, Riza., Philippines, 1987.

Fertilizer treatment[a]	Yield[b] (t/ha)			
	Dry season		Wet season	
	IR64	IR29723-143-3-2-1	IR64	IR29723-143-3-2-1
Control	3.3 d	3.5 d	3.7 b	3.4 d
N	4.7 c	4.8 b	4.1 ab	4.1 bc
P	3.7 d	3.6 d	2.8 c	4.8 b
K	3.5 d	3.7 d	4.2 ab	3.6 cd
NP	5.3 b	4.7 b	4.0 ab	5.0 a
PK	3.7 d	4.0 c	3.5 b	5.0 a
NK	4.7 c	5.7 a	4.3 ab	4.2 bc
NPK	6.0 a	5.8 a	4.7 a	5.6 a

[a]120 kg N/ha for DS and 60 kg N/ha for WS, 17.5 kg P/ha and 33 kg K/ha in both seasons. [b]CV = 8% for DS and 11% for WS.

Table 5. Effect of NPK on yield of IR64 and IR29723-143-3-2-1. 22d cropping, long-term fertility trial, Luisiana, Laguna, Philippines.

Fertilizer treatment[a]	Yield[b] (t/ha)	
	IR64	IR29723-143-3-2-1
Control	2.3 c	2.9 c
N	4.7 b	4.1 b
P	3.1 c	3.3 c
K	2.6 c	2.9 c
NP	5.4 a	4.8 b
PK	2.7 c	2.7 c
NK	4.3 b	4.2 b
NPK	5.6 a	5.5 a

[a]120 kg N/ha, 17.5 kg P/ha, and 33 kg K/ha. [b]CV = 14%.

Table 6. Properties of soils used in P-sources trials. Pili, Camarines Sur, and Lucban, Quezon, 1987 WS.

Soil property	Pili, Camarines Sur	Lucban, Quezon
pH (1:1)	5.1	4.7
Organic C (%)	2.3	1.8
Total N (%)	0.20	0.20
Exchangeable bases (meq/100 g)		
Na	0.14	0.37
K	0.08	1.15
Mg	1.63	2.84
Ca	10.1	6.07
CEC (meq/100 g)	17	26
Available P (ppm Bray II)	11	11
Available Zn (ppm)	2.0	1.0
Particle size (%)		
Sand	42	55
Silt	44	36
Clay	14	9
Texture	Loam	Sandy loam

single or combined applications. However, P and K responses were better in combined applications in both acidic (pH 4.7) Luisiana soil and calcareous (pH 7.5) Tanay soil.

Continuing the same application rates of N, P, and K in continuous croppings may not be able to sustain yields.

PHOSPHORUS SOURCES FOR RICE ON ACID SOILS

Trials were started in 1987 WS to determine the effect of different P sources and application rates on rice yields in farmers' fields in Pili, Camarines Sur, and Lucban, Quezon. Table 6 shows the soil properties.

P application produced a yield response only in Lucban (Table 7). The highest P response (1.7 t/ha) was obtained with partially acidulated phosphate rock (PAPR) applied at 30 kg P/ha. With all P sources, except for triple superphosphate (TSP), P increased yields only at the highest rate. With TSP, P response was recorded at 20 and 30 kg P/ha. PAPR at 30 kg P/ha proved superior to North Carolina rock phosphate. At 20 kg P/ha, PAPR and North Carolina rock phosphate were less effective than TSP. Less reactive phosphate (guano) was effective only at 60 kg P/ha, similar to TSP at 30 kg P/ha.

Table 7. Grain yield of IR64 as affected by P source and application rate. Lucban, Quezon, Philippines, 1987 WS.

Treatment (kg P/ha)	Grain yield (t/ha)
Unfertilized control	2.9 d
No fertilizer P	3.0 d
Triple superphosphate	
10	3.1 d
20	3.9 bc
30	4.2 ab
North Carolina rock phosphate	
10	3.4 cd
20	3.2 d
30	4.0 b
Partially acidulated phosphate rock	
10	3.2 d
20	3.2 d
30	4.7 a
Less reactive phosphate (guano)	
20	3.4 cd
40	3.4 cd
60	4.2 ab
CV (%)	9

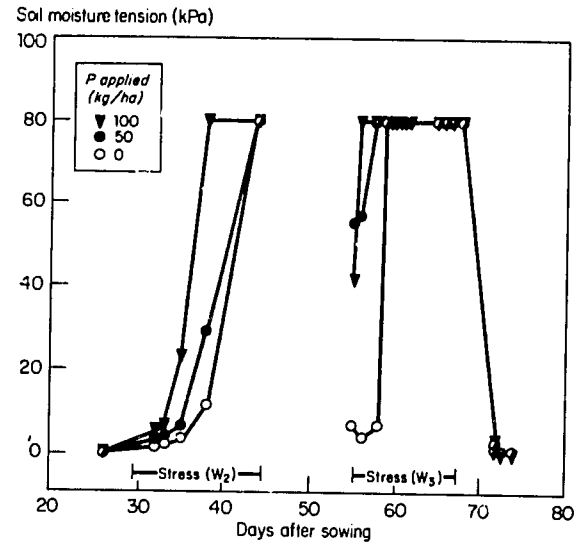
PHOSPHORUS NUTRITION OF RICE FOR SUSTAINABLE RICE FARMING

The effect of P source on rice in acid and acid sulfate soils was studied in four countries. See Cooperative Country Projects.

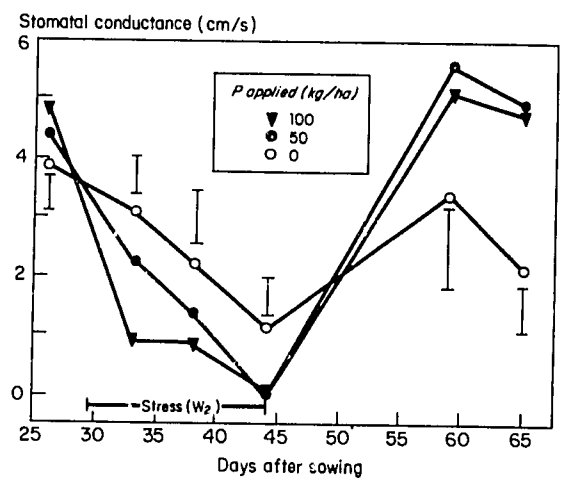
STOMATAL AND GROWTH RESPONSES TO WATER DEFICIT AND PHOSPHORUS FERTILIZATION IN UPLAND RICE

Phosphorus increases the root growth and yields of upland rice in acid soils, but little is known about P effects under moisture deficit. To assess this, a greenhouse experiment was conducted during 1987 WS. Plants were grown in 110-liter barrels containing soil from IRRI's acid-upland testing site in Mahipon, Cavinti, Laguna. Main plots were 3 P fertilization levels: 0, 50, and 100 kg P/ha. Subplots were 3 irrigation treatments: continuously saturated (W1), unirrigated from 29 to 44 d after sowing (DAS) (W2), and unirrigated from 55 to 67 DAS (W3). Soil moisture tension (SMT) at 30 cm soil depth reached the breakdown limit of 80 kPa during both stress periods (Fig. 1). Increase in P fertilization level resulted in faster rise in SMT.

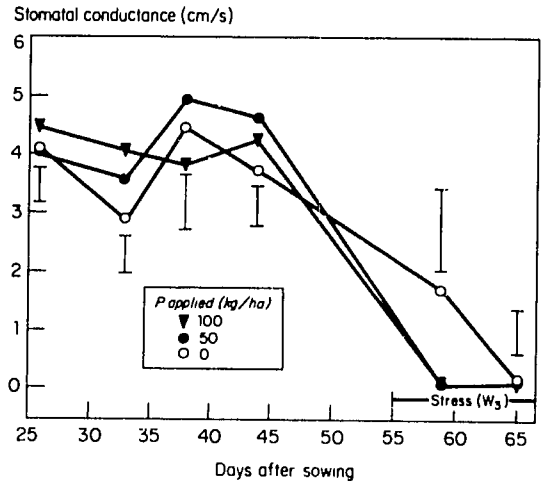
P application reduced stomatal conductance and leaf water potential faster during both stress periods and led to a faster recovery of stomatal conductance upon reirrigation after the first stress (Fig. 2, 3, 4, 5). Stress developed much faster during the second period, presumably because the plants were larger and used water faster. Although P fertilization may speed recovery from drought, it may also lead to drought susceptibility if it enhances canopy growth and water use. To simulate field conditions, this experiment used large barrels; however, field-grown plants might respond differently to P fertilization under water deficit.



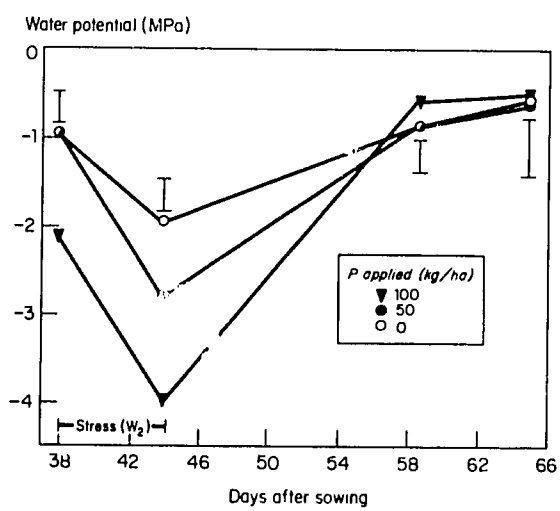
1. Soil moisture tension for 3 P fertilizer levels at 30-cm depth. IRRI greenhouse, 1987.



2. Effect of applied P and water deficit on stomatal conductance of IR64. IRRI greenhouse, 1987.



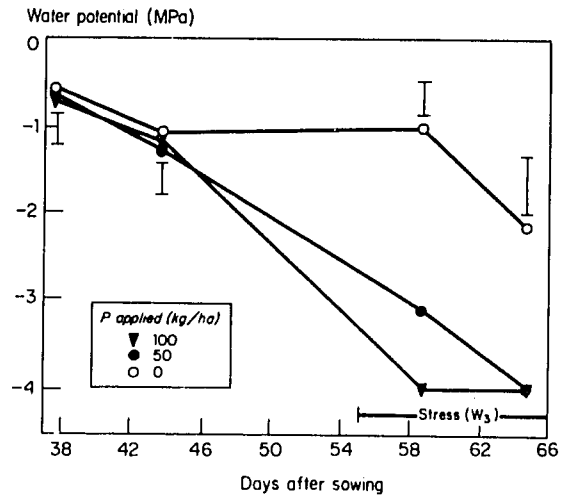
3. Effect of applied P and water deficit on stomatal conductance of IR64. IRRI greenhouse, 1987.



4. Effect of applied P and water deficit on water potential of IR64. IRRI greenhouse, 1987.

FERTILIZER RESPONSE OF DEEPWATER RICE

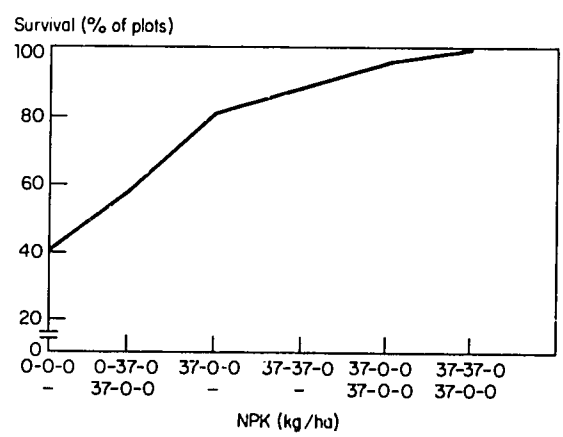
Split-plot experiments with fertilizer treatments as main plots and deepwater rice (DWR) entries as subplots were conducted on acid sulfate soil in Prachinburi, Thailand. Fertilizer was basal incorporated, or broadcast before the onset of the flood for second applications. There were 30 entries in 1984, 21 in 1985, and 24 in 1986. Each entry was sown in a 3-row, 3-m-long plot, with 25 cm between rows, at 3 g dry seed/m of row. Entry yields were regressed against treatment mean yields to estimate fertilizer response.



5. Effect of applied P and water deficit on water potential of IR64. IRRI greenhouse, 1987.

In 1986, floodwater came 40 d after emergence (DE), with a rapid rise in early September that completely submerged most plants at 60 DAS. Many plots, particularly the nonfertilized, did not survive. Only 40% of the check plots (zero fertilizer) did. Survival was successively higher with increasing application of N and P (Fig. 6).

Data for 3 yr (Table 8) indicated that SPR'76 com3-5-2 was most responsive to fertilizer—it gave very high yield with high fertilizer, but low to zero yield with little or no fertilizer under early severe flooding. In both the fertilizer response experiment and the farmers' fields, it had a regression slope



6. Effect of fertilizer on survival of plots of deepwater rice (24 entries × 3 replications) after early flooding, Prachinburi, Thailand, 1986 WS. Top row = basal incorporation, bottom row = preflood broadcasting.

Table 8. Mean yields of entries across 6 fertilizer treatments (main plots), 1984-86 WS. Prachinburi, Thailand.

Entry	Grain yield over treatments (g/m^2)			
	1984	1985	1986	Av
SPR'76com3-5-2	273	204	51	176
HTAFR77058-45-3	241	155	122	173
HTAFR79256-3	250	136	52	146
BKNFR76045-35-1-2-1	236	164	71	157
BKNFR76042-18-1-1	174	149	90	138
SPR7411-7-2-3-2	206	131	142	160
RD19	185	173	86	148
LMN111	230	–	158	194
Mean	224	159	96.5	161.5

greater than 1.2 and a mean yield higher than the overall average. LMN111 had regression slopes of 0.5-0.6 in both. It yielded less than the mean in farmers' fields, but higher than average in the response experiments, mainly because it performed well at low fertilizer level in 1986

Correlations for the regression analyses of responsive genotypes have been high, indicating that data from small plots can indicate their performance.

RESIDUAL EFFECTS OF ROCK PHOSPHATE IN A DEEPWATER RICEFIELD

A long-term experiment begun in 1984 in Prachinburi, Thailand, is assessing the response of DWR to annual dressings of rock phosphate (1.8% available P, 16% total P) or TSP (45% P) in comparison with residual effects of single initial applications. The soils are Sulfic Tropaquepts, low in natural fertility, with pH 4.0 (1:1 water). Available P was 4 ppm from Bray II at the start of the experiment, and total P was 265 ppm. Treatments, soil and crop P, and mean grain yield for 1985-86 are listed in Table 9.

For each year there was a highly significant curvilinear correlation between P uptake by plants at 6 wk after emergence and soil Bray II-P: $R^2 = 0.76$ for 1984, 0.85 for 1985, and 0.88 for 1986. From 1986, the highest yields were from the residual effects of the initial application of rock phosphate equivalent to 140 kg available P/ha (Treatment 7), and were about 0.5 t/ha more than the other phosphate treatments (Table 9). Predic-

Table 9. Comparison of predicted levels of available P after 3 yr of crop growth and measured available P in the soil after harvest in 1986, with estimates of fixed and released available P for each treatment. Prachinburi, Thailand.

Treatment	Available-P application			Added to soil[b] (ppm)	Calculated available P (ppm)	Crop uptake[c] (g/m^2)	Predicted final[d] (ppm)	Measured at harvest (ppm)	Estimated fixed[e] (ppm)	Estimate released[e] (ppm)	Mean grain yield (1985-86) (t/ha)
	Rate (kg P/ha)	Source[a]	Time								
1	–	–	–	–	4	7.2	–3.2	6.2[f]	–	9.4	1.28
2	8.7	TSP	Annual	15	19	11.3	7.7	6.9	0.8	–	2.17
3	8.7	RP	Annual	15	19	12.1	6.9	13.7	–	6.8	2.18
4	35.0	TSP	Initial	19	23	9.8	13.2	8.6	4.6	–	2.02
5	35.0	RP	Initial	19	23	14.4	8.6	20.7	–	12.1	2.27
6	140.0	TSP	Initial	77	81	12.5	68.5	8.4	60.2	–	2.21
7	140.0	RP	Initial	77	81	15.7	65.3	97.8	–	32.5	2.81

[a]TSP = triple superphosphate, RP = rock phosphate. [b][(Applied available P in $g/m^2 \times 10^6$) × 3 yr of application]/[Wt of soil (g) in 1 m^2 × 15 cm depth (g)]. [c]% P × dry wt. [d]Calculated available P less crop uptake. [e]Measured available soil P less predicted final available P. Assumed that negative differences indicate fixed P, and positive differences indicate released P. [f]Evidence that sample was contaminated.

tion of available P after three crop seasons showed that the measured available P values for TSP plots were lower than the predicted values, whereas in the rock phosphate plots all measures were higher than predicted. It appears that rock phosphate in this acid sulfate soil has released P from the total fraction to produce more available P, whereas available P from TSP was fixed, and the higher the TSP the greater the fixation. On acid sulfate soils, DWR responds to phosphate application, and residual effects may be important in determining phosphate fertilizer application.

LONG-TERM SULFUR FERTILITY TRIAL

The experiment continued at the IRRI farm during 1987 DS and WS (10th and 11th crops) on the effects of continuous application of high-analysis fertilizers (urea, TSP, and KCl) on rice grown in a clay soil.

In DS, N combined with other nutrients significantly increased yields over the control (Table 10). As in previous years, N remained limiting. Zn fertilizer applied alone or with P, K, or both gave no response. The yield from NPK + straw + Zn was comparable to those of NPK + azolla + Zn and NP + Zn.

Table 10. Yield of 15 treatments in the long-term S fertility trial with irrigated rice.[a] IRRI, 1987 DS and WS.

Treatment[b]	Yield (t/ha)	
	DS	WS
Control	3.8 c	2.5 b-e
Zn alone	3.1 c	2.2 de
N + Zn	6.4 a	3.2 a
P + Zn	3.3 c	2.2 de
K + Zn	3.4 c	2.5 b-e
NP + Zn	6.0 ab	2.9 abc
NK + Zn	6.4 a	2.9 abc
PK + Zn	3.2 c	2.1 e
NPK + Zn	6.4 a	2.9 abc
NPK only	6.6 a	2.8 a-d
NPK + S	6.4 a	3.2 a
NPK + Zn + S	6.6 a	2.7 a-e
NPK + azolla + Zn	6.0 ab	2.4 cde
NPK + straw + Zn	5.6 b	2.7 a-e
S. rostrata incorporated into the soil at 1 DBT		2.9 abc

[a]IR64 was used in DS and IR66 in WS. [b]Zn as root dip in 4% ZnO solution. S as urea S at 40 kg S/ha.

In WS, yields were low because of heavy rains during the reproductive phase and rat damage during ripening.

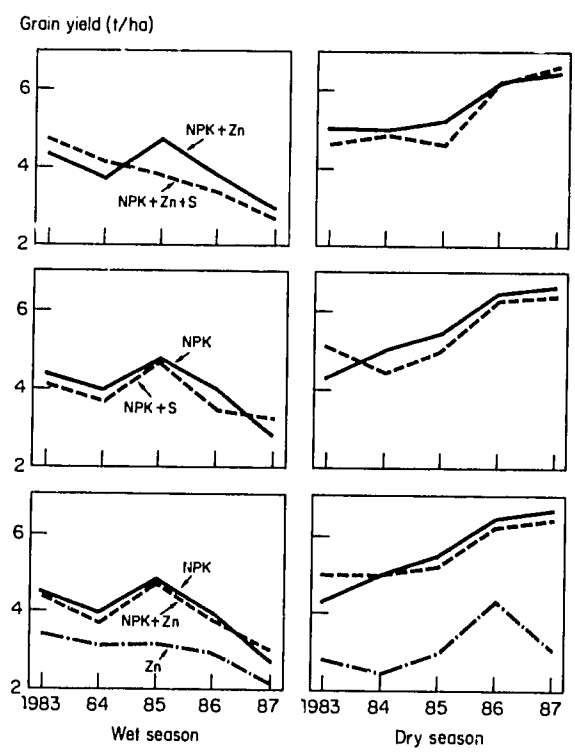
Despite the high-analysis fertilizers containing almost no S, S deficiency is not yet apparent. Yield responses from NPK alone were comparable to those from NPK + Zn and significantly higher than those from Zn alone in all trials (Fig. 7).

Over the 5-yr period, yields have increased during DS but declined during WS (Fig. 7). To explain this, we plan additional research.

RESPONSE OF TWO LOWLAND RICES TO TIME OF SULFUR APPLICATION

Trials in Batangas, Philippines, during 1987 DS and WS determined the response of IR64, an early-maturing variety, and IR28222-9-2-2-2-2, a medium-maturing line, to three different times of S application, using elemental and urea S.

In DS, IR64 yielded significantly more than the control when S was applied at transplanting than



7. Grain yield trends over 5 yr of 5 treatments in Block 421-A, IRRI farm. Long-term sulfur fertility trial in irrigated rice, 1983-87.

when applied 15 or 30 d after transplanting (DT). IR28222-9-2-2-2-2 yielded higher when S was applied at transplanting or at 15 DT than at 30 DT. Yields were similar between elemental and urea S.

In WS, residual S in the soil gave no significant effect.

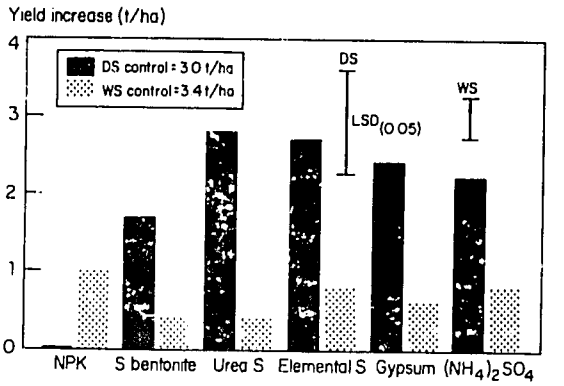
Results support S application at transplanting for early-maturing rices and from transplanting up to 15 DT for medium-maturing rices.

RESIDUAL EFFECTS OF APPLIED SULFUR ON LOWLAND RICE

The residual effects of five S fertilizers—$(NH_4)_2SO_4$, elemental S, S bentonite, gypsum, and urea S—were determined during 1987 DS and WS in a farmer's field in Batangas, Philippines (Fluvaquentic Tropaquept). IR64 was the test variety.

In DS, yield increases of all sources of S over the control were significantly higher than that of NPK alone (Fig. 8). Moreover, yield increases of elemental S and S bentonite were higher than those obtained from the previous cropping season (1986 WS), but yield increases of $(NH_4)_2SO_4$, urea S, and gypsum decreased.

In WS, no S source gave a significant increase in yield over NPK alone, indicating that residual S from the fertilizer had been depleted.



8. Average yield increases of IR64 over control due to residual effects of applied S for 2 successive cropping seasons. Batangas, Philippines, 1987.

Significant differences in S uptake were observed between sources of S, except S bentonite, and NPK alone and the control in the first crop. However, S uptake was the same in all treatments in the second and third crops which depended only on the residual S.

Total dry matter yields (TDMY) with all S sources except S bentonite were significantly higher than those with NPK alone and the control in the first crop fertilized with S, as well as those in the second crop with residual S only. No significant difference in TDMY was observed with any treatment in the third crop.

Soil and crop management

Rice crop cultural practices

Agronomy, Plant Physiology, and Agricultural Economics Departments

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EFFECTS OF PLANTING TECHNIQUE AND NITROGEN MANAGEMENT ON CANOPY PHOTOSYNTHESIS IN LOWLAND RICE

Agronomy Department

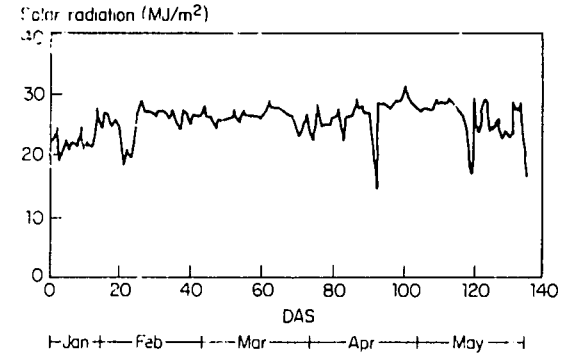
In a cooperative study with the University of Hamburg, Federal Republic of Germany, canopy photosynthesis and respiration measurements were used to determine crop growth rate (CGR) in lowland rice grown under several cultural practices. In the 1987 dry season (DS), responses in canopy gas exchange and standard agronomic parameters to various N application split ratios and techniques were monitored from seeding to maturity in transplanted (TPR) and direct seeded (DSR) IR64 at the Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija. Solar radiation for this period is shown in Figure 1.

Transplanted IR64 suffered a 2- to 3-wk delay in development, vegetative growth, and tillering because of transplanting shock. Modified N application timing and method could not eliminate the transplanting shock but affected vegetative CGR markedly (Fig. 2). N deep placement (USG and band placement) and 1/3-2/3 split application reduced initial CGR but led to more vigorous growth at panicle initiation (PI) than did researchers' split.

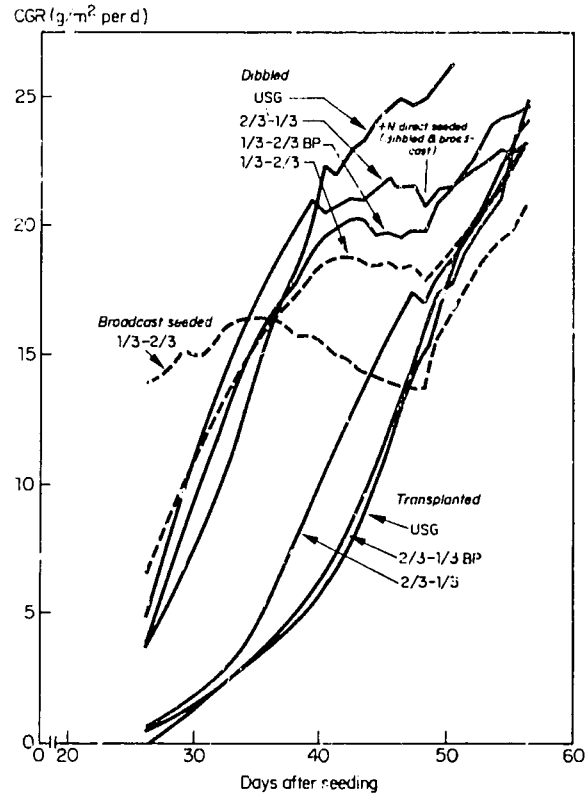
High initial CGR in broadcast seeded rice (BSR) was followed by slower growth at 40-55 d after seeding due to exhaustion of applied N (Fig. 2). This temporary N deficiency interrupted tillering, which resumed after N topdressing (Fig. 3). Biphasic tillering kinetics occurred only in direct seeded IR64. This led to aborted tillers, particularly in row seeded and broadcast rice, where plant competition was high.

When fertilizer was broadcast and incorporated into the soil, the generally superior vegetative growth in direct seeded IR64 resulted in N dilution in shoot tissues, followed by temporary N deficiency (Fig. 4). This adverse effect was overcome when N fertilizer was injected into the soil. The yield potential of DSR was therefore best realized through a 1/3-2/3 split band placement of N fertilizer at 87 kg N/ha, which gave a crop productivity of 72 kg/ha per d and an average grain yield of 8.5 t/ha.

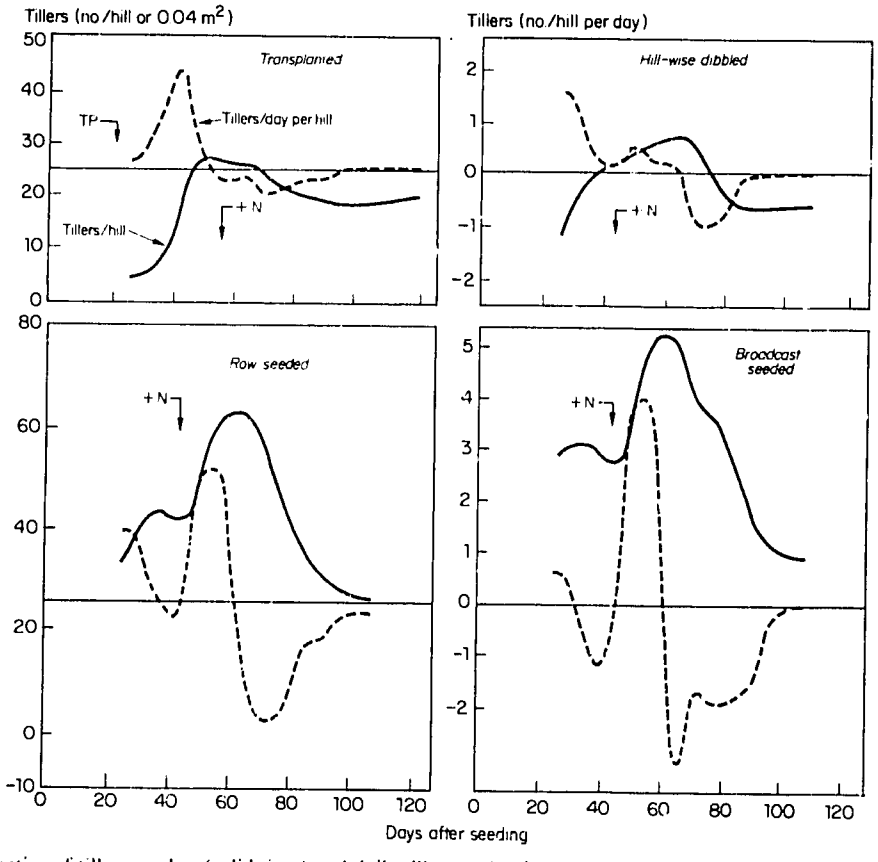
These results suggest that canopy photosynthesis and resulting yields depend largely on N concentration in leaf tissue (Fig. 5). The dynamic interaction of leaf area formation, N dilution in tissue, and canopy photosynthesis is manageable through cultural practices.



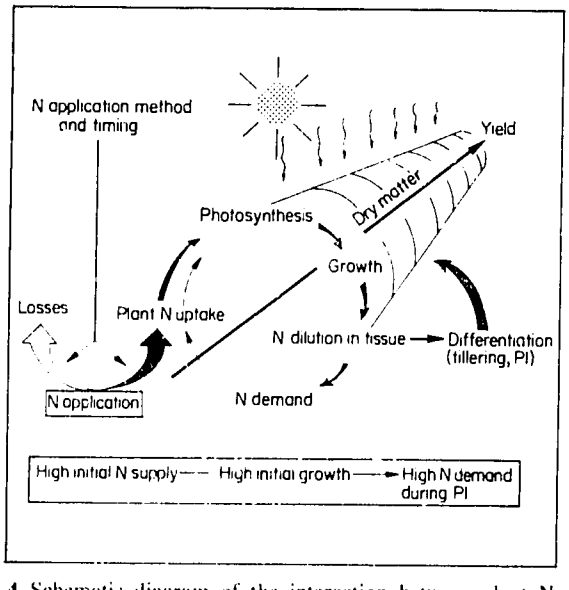
1. Solar radiation in Muñoz, Nueva Ecija, Philippines, 1987 DS. DAS = days after seeding.



2. Vegetative phase crop growth rates (CGR) as computed from canopy gas exchange and radiation in IR64 with various planting techniques and fertilizer splits (90 kg/ha), Muñoz, Nueva Ecija, Philippines, 1987 DS. BP = band placement, USG = urea supergranules.



3. Kinetics of tiller number (solid lines) and daily tiller production (broken lines) in IR64, using 4 planting methods in Muñoz, Nueva Ecija, Philippines, 1987 DS. TP = transplanting.



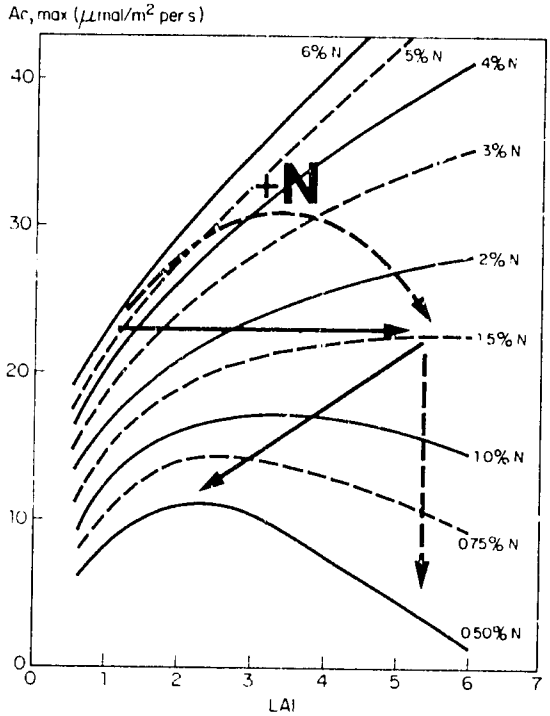
4. Schematic diagram of the interaction between plant N uptake, N utilization, and growth leading to N dilution in tissues, IRRI, 1987. PI = panicle initiation.

EFFECT OF CULTURAL CONDITIONS ON THE PATTERN OF NITROGEN UPTAKE

Plant Physiology Department

This experiment examined the effects of cultural practices and soil fertility on the N absorption pattern of varieties with different growth durations. IR64 and IR36892-163-1-2-2-1 were planted in 1986 wet season (WS) at IRRI under 4 N levels (0, 60, 120 kg N/ha, and 60 kg N/ha as slow-release fertilizer) applied basally, 3 plant densities (20 × 10, 20 × 20, and 20 × 30 cm), and 2 soils varying in fertility (Table 1).

Little difference was observed in patterns of N absorption between short- and medium-duration varieties grown under varying cultural practices and soil fertility (Fig. 6). The amount of N in plants increased exponentially ($y = ab^x$) during early growth stages and linearly ($y=a + bx$) during middle and late growth stages. Similar trends were



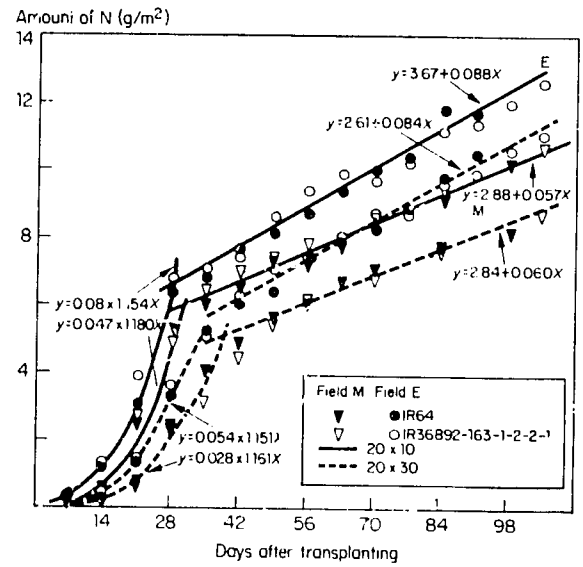
5. Response of maximum canopy photosynthesis (Ac) to leaf area index (LAI) at various levels of leaf N content in IR64, Muñoz, Nueva Ecija, Philippines, 1987 DS. Arrows left to right: leaf area buildup until 2-3 wk before flowering. Arrows pointing left and down: late reproductive and ripening phases. Maintenance of high LAI reduces production.

Table 1. Chemical characteristics of soils at 2 IRRI sites, 1987.

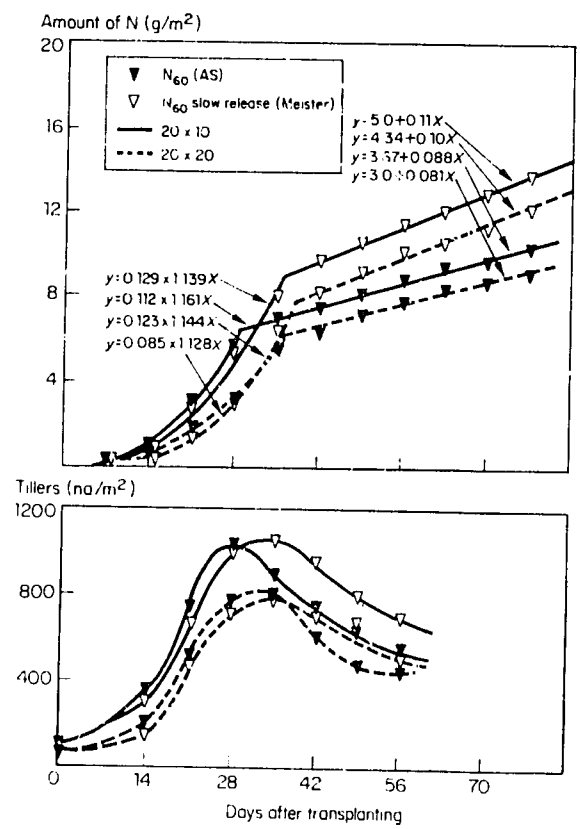
Property	Field E33	Field M11
pH (H_2O)	7.1	6.4
pH (KCl)	6.3	5.4
Organic C (%)	1.36	1.23
Total N (%)	0.136	0.129
C:N	10.0	9.5
CEC (meq/100 g soil)	36.3	33.3
Ammonification[a] (mg/100 g)		
Dry soil	11.76	10.72
Fresh soil	6.70	4.55

[a]Incubation at 30 °C for 4 wk.

obtained at both high and low basal N rates and plant densities during middle and late growth stages, except parameter 'a' representing the initial N absorbed. The crossing point of the two equations coincided with maximum tillering, which varied with plant density and kind of fertilizer (Fig. 7).



6. N absorption pattern of rice plants grown under different soil fertility, IRRI, 1986 WS.



7. N absorption pattern and pattern of tillering of rice plants grown under different kinds of N fertilizer, IRRI, 1987 WS. AS = ammonium sulfate.

During the exponential phase, the rapidly decomposable soil organic N and basal N were largely absorbed by plants to produce new tillers, and the limiting factor for N absorption was the N absorption ability of the plant. During the linear phase, the slowly decomposable organic N was largely absorbed by plants, and the limiting factor for N absorption was the mineralization rate of soil organic N.

Narrow spacing shortened the exponential phase. On the other hand, use of slow-release fertilizer lengthened the exponential phase and increased parameter 'b', reflected in the high N absorption rate during the linear phase (Fig. 7). During the linear phase, the N absorption rate based on parameter 'b' was also affected by the soil chemical characteristics (soil fertility) but not by plant density and amount of basal N.

The absorption pattern of the rice plant was also affected by the level of NH_4^+-N in the plow layer, which decreased exponentially after transplanting and became constant at a very low level after maximum tillering.

Table 2. Highest yield in transplanted (TPR) and broadcast seeded (BSR) flooded rice in the continuous cropping experiment, IRRI, 1968-87.

Year	Highest yield (t/ha)					
	Dry season		Wet season[a]		Wet season[b]	
	TPR	BSR	TPR	BSR	TPR	BSR
1968	8.0	7.4	6.4	6.3	5.8	6.0
1969	8.0	8.1	7.8	7.9	7.1	5.7
1970	9.9	9.4	7.8	7.5	3.8	3.7
1971	9.9	10.1	6.5	6.8	3.5	3.5
1972	8.7	9.9	4.9	4.9	5.0	4.8
1973	8.4	7.9	5.0	5.0	3.2	2.9
1974	7.1	7.0	4.3	4.3	4.1	3.8
1975	7.1	7.1	4.8	5.3	3.9	3.8
1976	7.1	7.5	4.3	4.6	3.7	3.7
1977	7.6	6.9	6.3	6.4	4.6	4.7
1978	6.8	6.1	5.2	4.6	4.5	4.6
1979	6.5	6.2	5.9	4.9	4.4	4.3
1980	6.6	6.7	4.8	4.6	4.3	4.0
1981	7.5	7.8	5.0	4.9	3.5	3.5
1982	6.4	6.0	4.6	4.5	4.6	4.1
1983	7.1	6.4	3.6	3.6	3.9	4.5
1984	6.7	5.7	4.9	4.9	3.9	4.0
1985	6.1	6.5	4.4	4.4	–	–
1986	7.0	6.8	4.0	4.0	4.2	3.6
1987	6.4	6.4	4.1	4.1	–	–
	7.5	7.3	5.2	5.2	4.3	4.2

[a]May-October planting. [b]October-January planting.

CONTINUOUS CROPPING

Agronomy Department

From 1962 to 1967, crop stand establishment methods with three crops per year were evaluated at four N levels in Block B_{5-8} of the IRRI farm. In 1968, this experiment was redesigned to compare the yield of TPR with that of flooded BSR at four N rates; this design has continued.

Yields of BSR and TPR have been similar in DS and WS (Table 2). During 20 yr of continuous cropping at 3 crops/yr, the highest yields from plots supplied with N fertilizer have averaged 7.4 t/ha in DS, 5.2 t/ha in the WS crop grown in May-October, and 4.2 t/ha in the October-January planting. Yields declined after 5 yr. Yields have been higher in DS than in WS. Similarly, the May-October WS planting has yielded higher than that in October-January.

In plots not receiving N fertilizer since 1968, total yield was 16.0 t/ha per yr for the first 5 yr and declined to only 10-11 t/ha per yr from the 6th year to the present.

CULTURAL PRACTICES AND THEIR EFFECTS ON LODGING AND YIELD OF IRRIGATED RICE

Agronomy Department

Experiments evaluated the effects of plant spacing, crop establishment method, and N application rate on lodging and yield of two rices at IRRI in 1987 DS.

The bending resistance of tall cultivar IR21820-154-3-2-2-3 was higher than that of the short-statured IR32429-47-3-2-2 when both were direct seeded or transplanted at 20- × 20-cm spacing, irrespective of N level. At 20- × 10-cm spacing, the bending resistance value of both cultivars was 2.3 kg at 100 kg N/ha. In IR21620-154-3-2-2-3, it increased to 2.6 kg at 125 kg N/ha, then to 3.1 kg at 150 kg N/ha.

The elasticity index of IR32429-47-3-2-2 was higher than that of IR21820-154-3-2-2-3, irrespective of plant spacing, crop establishment, or N level.

Yields of IR21820-154-3-2-2-3 at 20- × 20-cm and 20- × 10-cm spacing were similar and significantly higher than those obtained in BSR, irrespective of N level. Lodging increased with N rate, subsequently reducing yield.

Yields of short-statured IR32429-47-3-2-2 spaced 20 × 20 cm decreased with increasing N rate because of the proliferation of more unproductive tillers with increasing N rate when plants are widely spaced. With 20- × 10-cm spacing, yields increased with increasing N rate. In BSR, the optimum yield (6.2 t/ha) was obtained with 125 kg N/ha.

EFFECT OF WATER MANAGEMENT ON LODGING AND YIELD OF IRRIGATED RICE

Agronomy Department

The effect of withdrawing irrigation at different growth stages on lodging and yield of rice was evaluated. In DS, lodging-resistant IR32429-47-3-2-2, moderately resistant IR64, and moderately susceptible IR21820-154-3-2-2-3 were used.

Even if it had the lowest bending resistance value (Table 3), IR32429-47-3-2-2 did not lodge because it is short. IR64 also did not lodge. Severe lodging was noted with IR21820-154-3-2-2-3 under continuous flooding.

Elasticity values were lowest at 0.69 for IR21820-154-3-2-2-3 and at 0.70 for IR64 under continuous flooding, indicating highly probable lodging (Table 3).

Grain yields did not significantly differ among water management treatments, irrespective of rice variety. Tungro reduced IR64 yields. IR21820-154-3-2-2-3 yielded 5.3 t/ha when continuously flooded, 1.3 t/ha lower than that obtained by draining at 10 d after transplanting (DT) to PI and at booting to heading. Lodging in the continuously irrigated treatment resulted in spikelet germination and subsequently low yields.

In WS, IR64 was replaced by IR66, and IR29723-143-3-2-1 was included. Grain yields did not differ according to water management treatment. Before bending resistance and elasticity index data were taken, the crop lodged because of a typhoon. Yields were extremely low because of shattering, except in IR66, which lodged before it was battered.

EFFECT OF SEEDLING PREPARATION ON TRANSPLANTING SHOCK RECOVERY AND YIELD OF IRRIGATED RICE

Agronomy Department

In 1987 DS, we studied ease of recovery from transplanting shock, and yield in an irrigated field of seedlings raised from an ordinary seedbed and in trays. At 5-10 DT, seedlings raised in trays were more vigorous than those from the ordinary seedbed. At 15-20 DT, plant vigor was similar for both seedling preparations.

Yields did not significantly differ between the seedling preparation methods irrespective of N level. In most cases, seedlings raised from the ordinary seedbed outyielded seedlings raised in trays by 0.1-0.8 t/ha. The highest yield was obtained with IR32307-107-3-2-2-1 (5.8 t/ha),

Table 3. Effect of water management on bending resistance and elasticity index of 3 rices. IRRI, 1987 DS.

Water management[a]	Bending resistance (kg to 30°)			Elasticity index		
	IR64	IR21820-154-3-2-2-3	IR32429-47-3-2-2	IR64	IR21820-154-3-2-2-3	IR32429-47-3-2-2
Continuously flooded	3.1	2.9	2.6	0.70	0.69	0.85
Drained at 20 DT to PI	3.0	3.0	2.5	0.81	0.57	0.82
Drained for 10 d at booting	2.7	3.3	2.6	0.73	0.73	0.86
Drained at 10 DT to PI and at booting to heading	2.8	3.3	2.3	0.73	0.70	0.88

[a]DT = days after transplanting, PI = panicle initiation.

while IR64, hurt by tungro (RTV), gave the lowest (3.1 t/ha). Intermediate yields were obtained with IR29723-143-3-2-1 and IR21820-154-3-2-2-3.

EFFECT OF PLANT GROWTH REGULATORS ON LODGING IN IRRIGATED RICE

Agronomy Department

Research at IRRI in 1987 WS evaluated the effect of plant growth regulators Hoe 78784, CCC, and PP-333 on minimizing lodging in rice. Four rices were used: Khao Dawk Mali 105, Basmati 307, IR21820-154-3-2-2-3, and IR42. IR42 was later excluded because of heavy RTV infection. Plant growth regulators were sprayed on leaves in appropriate dosages at early booting.

The entire crop lodged because of a typhoon during the milk to dough stages; hence, no reliable grain yield data were obtained. However, culm samples were taken to determine how plant growth regulator application affected internode length.

Hoe 78784 significantly reduced second and third internode lengths in Basmati 307 and IR21820-154-3-2-2-3, and the third to fifth internodes in Khao Dawk Mali 105. PP-333 significantly shortened the third to fifth internodes in Khao Dawk Mali 105. CCC produced no differential effects. Generally, panicle length was not affected by plant growth regulator application.

WATER DEFICIT AND NITROGEN FERTILIZATION EFFECTS ON SIMULATED UPLAND RICE YIELD ACROSS A PLANTING DENSITY GRADIENT

Agronomy Department

Upland rice farmers generally cannot manipulate water inputs, but by properly managing crop nutrients and planting density (PD) they may be able to reduce drought damage. In 1987 DS, a study determined the effects of N fertilization and PD relationships on yield. Low tillering Kinandang Patong and high tillering UPLRi-5 were direct seeded in a fan design to generate PDs from 2 to 238 plants/m^2. Three N fertilization treatments (0, 50, and 100 kg/ha) were applied in equal split applications (basal and at tillering) across 2 water regimes (stressed and fully irrigated). Water was applied by a whole-plot overhead sprinkler. To impose drought stress, irrigation was stopped for 15 d, from 24 Mar to 6 Apr.

Leaf water potentials of fully irrigated plants were not related to PD (Fig. 8). On the other hand, predawn and midday leaf water potentials of stressed plants were inversely related to PD. For stressed Kinandang Patong, N fertilization exacerbated leaf water potential reduction at high PD.

With higher PD, less light penetrated the rice canopy in both irrigated and stressed plots. At moderate PD (32.9 plants/m^2), N fertilization significantly reduced light transmission. At lower PD, N fertilization did not affect light transmission, suggesting that N nutrition did not limit canopy development at low PD, even when no N fertilizer was added.

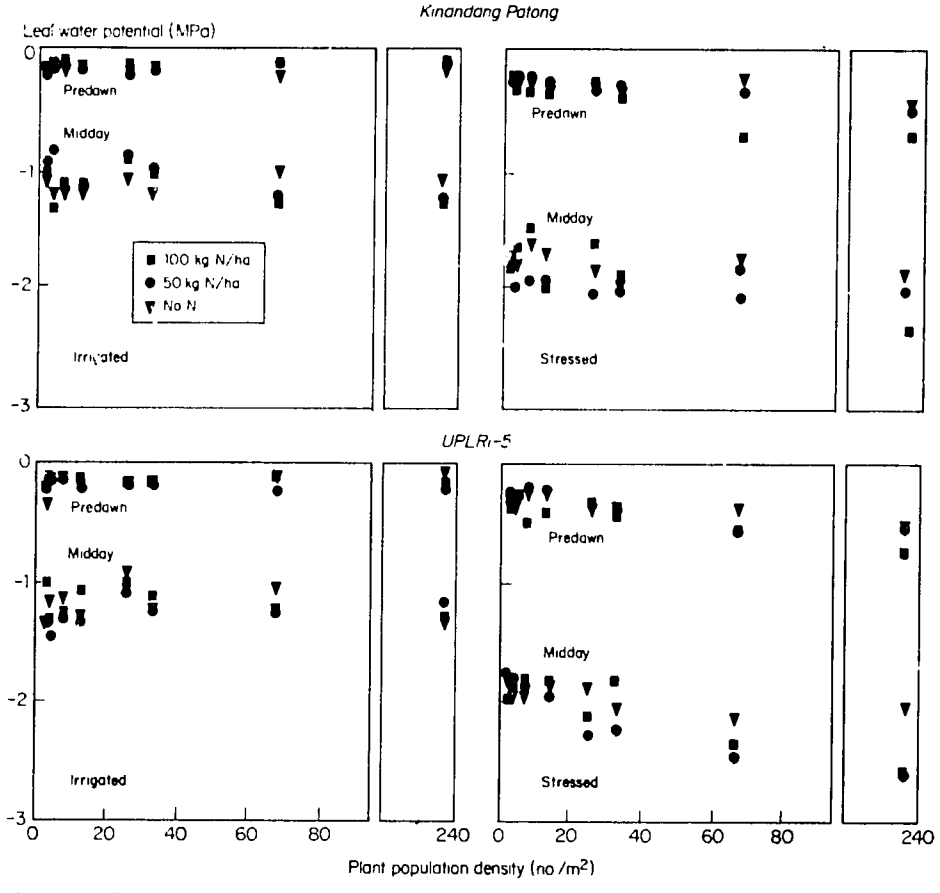
Shoot dry matter and leaf area index (LAI) were not significantly affected by cultivar; therefore data for Kinandang Patong and UPLRi-5 were combined. The relationships between shoot dry matter or LAI and PD differed significantly between stressed and fully irrigated treatments and between N fertilization treatments (Fig. 9, 10). These results suggest that N application above 50 kg/ha has no benefit under drought.

Grain yields were highly variable, probably a result of nematodes and other pests evident late in the season. Three overall trends were observed: 1) grain yields were significantly greater in fully irrigated than in stressed plots, 2) yields were directly related to N fertilization level, and 3) yields were greater in UPLRi-5 than in Kinandang Patong. Under stress, the optimum PD of UPLRi-5 increased with N fertilization level. At 0 N, the optimum PD was 8-15 plants/m^2, whereas at 100 kg N/ha the optimum PD was 30-80 plants/m^2. For other varieties and irrigation treatments, relationships between grain yield and PD appeared asymptotic, showing no clear optima.

FACTORS AFFECTING UPLAND RICE YIELDS

Agronomy Department

Effects of fertilizer, weed control, and their interactions on the grain yields of farmers' and modern varieties in WS were determined on three farms in Santo Tomas, Batangas; four in Cuenca, Batangas; and three in General Trias, Cavite. A second



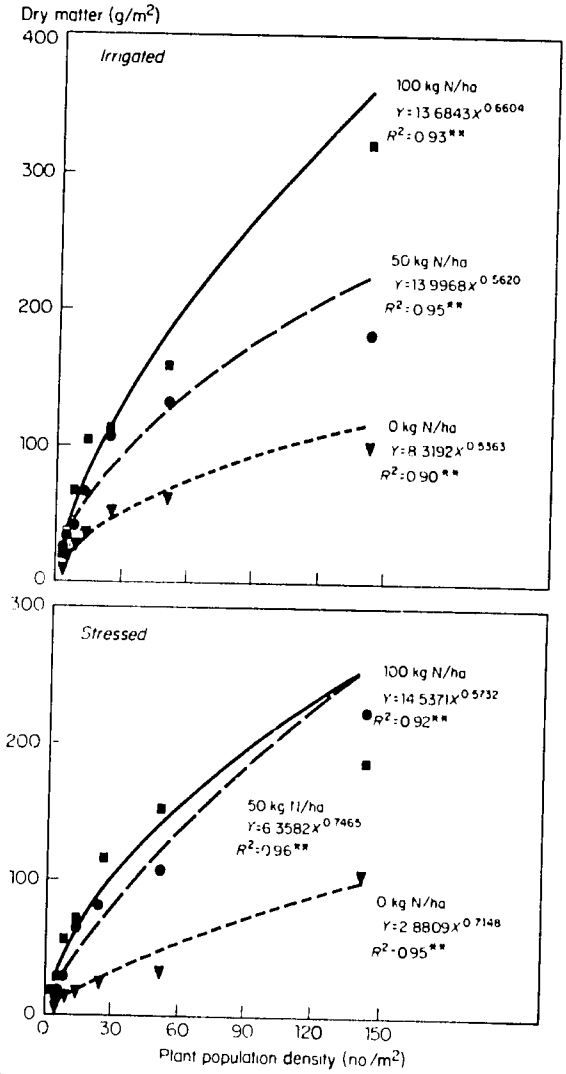
8. Predawn and midday leaf water potentials on the last day of stress for 2 rice cultivars, in response to irrigation and N fertilization across a plant population density gradient. IRRI, 1987.

experiment evaluated five integrated input packages of fertilizer, weed control, and insect control using farmers' and modern varieties. A third experiment evaluated the performance of six rice cultivars under three weed control levels.

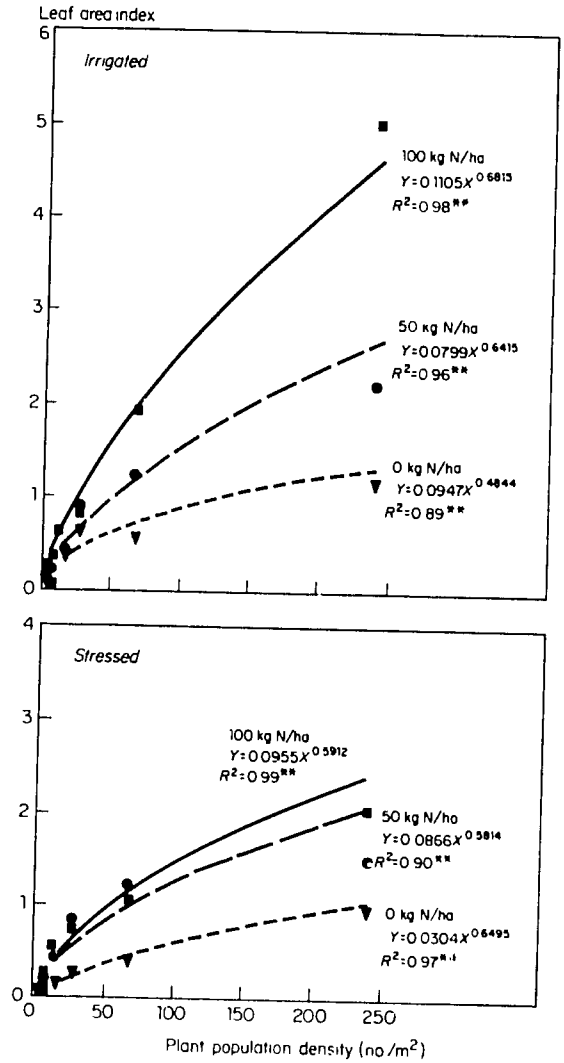
Table 4 lists the soil properties of the sites.

Table 4. Chemical properties of 4 Cuenca, 3 Santo Tomas, and 3 General Trias soils. Batangas and Cavite, Philippines, 1987 WS.

Property	Range			Mean		
	Santo Tomas	Cuenca	General Trias	Santo Tomas	Cuenca	General Trias
pH	5.2 - 5.5	5.1 - 5.6	5.2	5.3	5.4	5.2
Organic C (%)	0.6 - 0.8	0.6 - 0.7	0.7 - 0.8	0.7	0.7	0.8
Total N (%)	0.08- 0.09	0.08- 0.09	0.09- 0.10	0.09	0.08	0.10
Exchangeable K (meq/100 g)	0.83- 0.90	0.98- 1.46	0.45- 1.83	0.86	1.14	1.30
Mg	4.56- 5.00	4.69- 7.32	5.92- 8.77	4.83	5.66	7.04
Ca	10.9 -11.7	12.0 -19.2	14.9 -17.3	11.2	14.6	16.2
Al	0.08- 0.40	0.06- 0.27	0.06- 0.11	0.22	0.14	0.08
CEC (meq/100 g)	21.8 -22.3	22.3 -31.0	27.4 -29.9	22.0	25.0	28.9
Olsen P (mg/kg)	30-40	13-25	8-53	34	19	28
Active Fe (%)	3.23- 3.41	2.38- 2.54	2.46- 2.66	3.31	2.47	2.53
Mn (%)	0.14- 0.15	0.13- 0.16	0.23	0.15	0.15	0.23



9. Shoot dry matter yield of rices in response to irrigation and N fertilization across a plant population density gradient. IRRI, 1987.



10. Leaf area index of rice in response to irrigation and N fertilization across a plant population density gradient. IRRI, 1987.

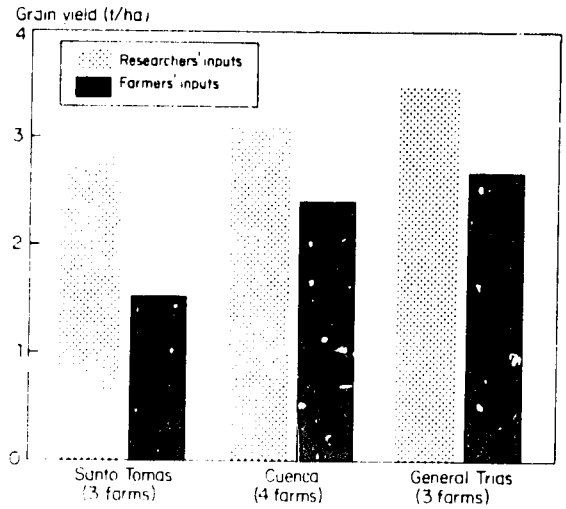
Rainfall distribution in Santo Tomas was fairly even, resulting in low soil moisture tension (SMT). Low rainfall during the vegetative phase raised SMT to 51 kPa in Cuenca and to 56 kPa in General Trias.

Santo Tomas farmers' fertilizer N rates averaged 52 kg/ha. No farmer applied P or K. Weed control was done three times with animal-drawn farm implements and once by hand. Two of three farmers planted the traditional upland variety Kinandang Patong.

In Cuenca, farmers' fertilizer rates averaged 60 kg N/ha. Mechanical weed control was done five times and hand weeding twice. All farmers planted Kinandang Patong.

General Trias farmers' fertilizer rates averaged 49 kg N/ha. Mechanical weed control was done twice and hand weeding once. Two of three farmers planted C-171.

Yield with farmers' inputs was lowest in Santo Tomas and highest in General Trias (Fig. 11). Rice variety accounted for 79% of the 1.1 t/ha yield gap in Santo Tomas (Fig. 12). In Cuenca, variety accounted for 94% of the yield gap on the 4 farms; weed control did not contribute to the yield gap, because farmers' weed control consisted of five



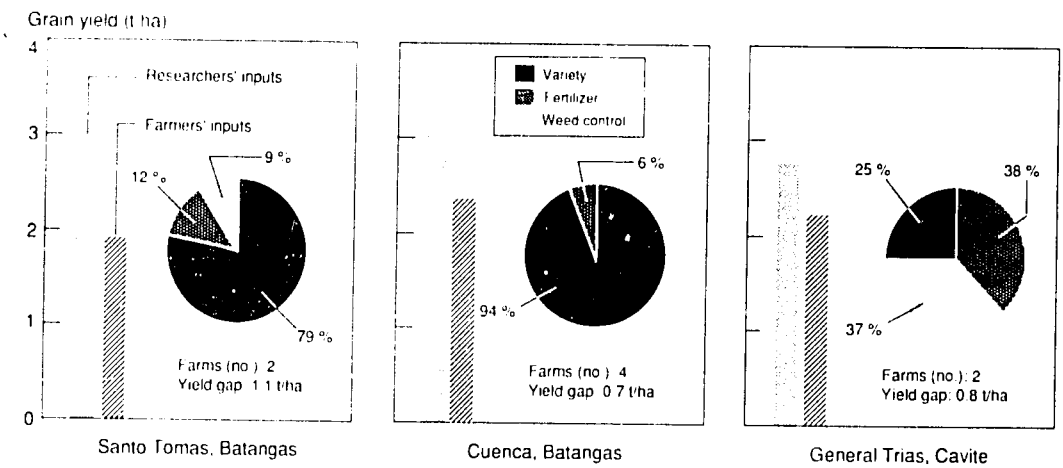
11. Average upland rice yields with farmers' and researchers' inputs in 2 Philippine provinces, 1987 WS.

mechanical and two hand weedings. In General Trias, fertilizer, rice variety, and weed control accounted substantially for the yield gap of 0.8 t/ha.

Performance of integrated input packages. Package levels (M1-M5) used in another experiment on the same farms appear in Table 5. No farmer applied insecticides.

In Santo Tomas and Cuenca, treatments M1 and M5 produced higher and comparable yields than M2-M4. In General Trias, M5 yielded 1.3 t/ha higher than M1. M2-M4 produced lower yields (averaging < 1 t/ha) because of ineffective weed control methods. M5 averaged 3.4 t/ha over the 3 sites and M1, 2.1 t/ha.

Performance of rice cultivars. In a separate experiment, all rice cultivars in Santo Tomas



12. Average yields with farmers' and researchers' inputs and relative contributions of fertilizer, weed control, and variety to the yield gap in upland rice in 2 Philippine provinces, 1987 WS.

Table 5. Farmers' inputs and 4 input management package levels. Batangas and Cavite, Philippines, 1987 WS.

Location	Sites (no.)	Package level	Fertilizer N (kg/ha)	Weed control[a] (no.)			Insect control[b] (no.)
				C.	M	HW	
Cuenca	4	M1	60	0	5	2	0.3
Santo Tomas	3	M1	52	0	3	1	0
General Trias	3	M1	49	0	2	1	0
All sites	10	M2	20	0	1	0	0
All sites	10	M3	40	1	0	0	0
All sites	10	M4	60	1	1	0	0
All sites	10	M5	80	1	2	1	2

[a]C = chemical, M = mechanical, HW = hand weeding. [b]All foliar. No granular insecticide was applied.

Table 6. Yield of rice cultivars grown under 3 weed control levels in upland farmers' fields. Batangas and Cavite, Philippines, 1987 WS.

Cultivar	Yield (t/ha)							
	Santo Tomas			Cuenca[a]		General Trias		
	No weed control	Farmers' weed control[b]	Researchers' weed control[c]	Farmers' weed control[d]	Researchers' weed control	No weed control	Farmers' weed control[e]	Researchers' weed control
IR43	0.0 a	2.6 a	2.4 a	2.4 a	3.2 a	0.0 b	3.0 ab	4.2 a
UPLRi-5	0.3 a	2.1 ab	2.8 a	2.9 a	3.0 a	1.5 a	3.7 a	4.1 ab
IR12979-24-1	0.1 a	2.0 bc	2.2 ab	2.4 b	2.3 b	0.4 ab	3.9 a	3.2 bc
Farmers'[f]	0.1 a	1.6 bc	1.7 bc	2.0 c	1.6 c	0.6 ab	2.2 bc	1.8 d
IR9782-111-1	0.0 a	1.3 c	1.5 c	2.1 bc	1.8 bc	0.0 b	2.3 b	3.0 c
IR36	0.0 a	0.6 d	0.6 d	1.9 c	1.4 c	0.0 b	1.2 c	1.9 d

[a]Without weed control, no cultivar produced any yield. [b]Two mechanical weedings, 1 hand weeding. [c]Butachlor spray, 2 mechanical weedings, and 1 hand weeding. [d]Four mechanical weedings, 2 hand weedings. [e]One mechanical weeding, 1 hand weeding. [f]Kinandang Patong for Santo Tomas, Tinambiloc for Cuenca, and Kinandang Patong for General Trias.

produced low yields without weed control (Table 6). With farmers' and researchers' weed control, IR43, UPLRi-5, and IR12979-24-1 were the high yielders. In Cuenca, yields of IR43 and UPLRi-5 were significantly higher than those of other cultivars under farmers' and researchers' weed control. Without weed control, no cultivar gave any yield. In General Trias, UPLRi-5 produced 1.5 t/ha without weed control. With farmers' and researchers' weed control, IR43, UPLRi-5, and IR12979-24-1 were the high yielders.

DEEPWATER RICE FOR HERBAGE

Plant Physiology Department

A collaborative experiment with the Rice Research Institute, Thailand, and the Dairy Training and Research Institute, University of the Philippines at Los Baños, examined the effect of leaf cutting on the growth, development, and yield of DWR and the crude protein content, in vitro true dry matter digestibility, and chemical composition of its herbage. See the section on Cooperative Country Projects.

Soil and crop management

Tillage and management of soil physical conditions

Soils, Agricultural Engineering, and Agronomy Departments

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MANAGEMENT OF WETLAND SOILS FOR RICE

Soils and Agricultural Engineering Departments

Wetland management to lessen water percolation. Wetland preparation for rice usually comprises puddling by plows, harrows, or rotary implements. Such preparation can lessen soil porosity (especially of wider, elongated pores) and hence water-percolation rate. The tillage implement can lessen porosity by directly deforming soil, and the subsequent water flow through water-transmitting pores can close the pores by filling them with dispersed clay particles. In animal-powered operations, hoof pressure—typically 0.3 MPa—can change porosity.

The effects of this pressure on soil hydraulic conductivity and its interaction with soil-water content were measured in laboratory studies using 1.0- to 2.0-mm-diameter aggregates of nonpuddled silty clay loam soil. About 130 g of aggregates were loosely packed 3.5 cm high in each of 18 metal cylinders 7 cm high and 7 cm in diameter. Aggregates were wetted with deionized water to achieve moistures, in 6 cylinders per moisture, of 0.94, 1.00, and 1.06 × plastic limit (PL). For each moisture, 3 replications were compressed at 0.35 MPa and 3 at 0.10 MPa, and the resulting compressions (decrease in soil height) and saturated hydraulic conductivities were measured.

Compressions at 0.10 and 0.35 MPa lessened soil height by 48 and 54% (each averaged over 3 moistures), respectively; soil was compressed more at 1.06 than at 0.94 or 1.00 × PL, particularly for 0.1 MPa pressure. Hydraulic conductivity (Table 1) was lessened much more by 0.35 MPa than by 0.10 MPa compression, and more when compressed wetter than when drier than PL. The ratios of conductivities for the two compressions show the interaction of applied pressure and water content. For 0.35 MPa, compression at PL or wetter lessened conductivity sufficiently for water-efficient riceland management. For 0.10 MPa, compression at any tested moisture did not lessen conductivity sufficiently.

Thus, unless water tables are shallow enough to limit water flow, wetland preparations that do not exert sufficient ground pressure may not lessen percolation. Conversely, on some soils, compression alone without soil inversion (as by a duckfoot cultivator) may be sufficient to lessen percolation.

Table 1. Saturated hydraulic conductivity of columns[a] of silty clay loam aggregates compressed at 0.10 and 0.35 MPa at each of 3 moisture contents. IRRI, 1987.

Moisture[b] at compression	Saturated hydraulic conductivity[c] For 0.10 MPa compression (mm/d)	Saturated hydraulic conductivity[c] For 0.35 MPa compression (mm/d)	Ratio for 0.10/0.35 MPa
0.94 X PL	2200	6.5	330
1.00 X PL	320	2.5	130
1.06 X PL	6	0.3	20

[a]Aggregates (diameter 1.0-2.0 mm) compressed within cylinders 7 cm high X 7 cm diameter. [b]PL = plastic limit moisture (=0.35 g/g). [c]Too high to measure for uncompressed aggregates.

Soil tests for choosing wetland preparation method. To predict the suitability of rice soils for wetland preparations, we (with colleagues from the Commonwealth Scientific and Industrial Research Organization Division of Soils, South Australia) have established tentative guidelines (Table 2) for selecting the most efficient method of lessening water percolation. The low-cost tests relate to soil aggregates' stability against slaking and dispersion in water. Many IRRI soils and Guimba turod soil belong to Class 3, and their conductivity should be lessened by compaction at 0.3 MPa at field capacity (or PL) followed by flooding with salt-free water.

Field trials tested this hypothesis in previously puddled and previously nonpuddled silty clay loam soils using duckfoot cultivators pulled by hand tractors or 4-wheel tractors, but using salt-containing irrigation water. In previously puddled soil at its PL (0.37 g/g) and using irrigation water, duckfoot cultivation lessened percolation to 5 mm/d, as compared with 2 mm/d from animal-powered plowing and harrowing. In previously nonpuddled soil of conductivity 420 mm/d, duckfoot cultivation at about 1.15 × PL but only 0.03 MPa pressure and using irrigation water lessened percolation to 60 mm/d, compared with 12 mm/d by plowing and harrowing. But with rainwater rather than irrigation water, plowing and harrowing lessened percolation to 7mm/d.

Predicting percolation from pore size. In our field trials of implements and power sources for wetland preparation, we observe water percolation,

Table 2. Soil classes delimited by tests of soil-aggregate stability, and the corresponding tillage recommended to lessen water percolation rate to 1 mm/d.

Class	Property	Recommended tillage
1	Completely dispersive (e.g., sodic)	Zero tillage, then flooding
2	Partially dispersive	0.1 MPa compaction, then flooding
3	At plastic limit, dispersive in rainwater	0.3 MPa compaction at field capacity, flood immediately with salt-free water
4	Nonsodic, contains carbonate or gypsum	Work at plastic limit, with 0.3 MPa animal hoof pressure
5	Dispersive when very wet	Work at saturation, with 0.3 MPa animal hoof pressure
6	Acid; flocculates	None available
7	Gravel subsoil	None available

Table 3. Predicted[a] and measured water-percolation rates in silty clay loam soil due to various wetland preparation methods. IRRI, 1987 WS.

Value by	Relative hydraulic conductivity[b] for land preparation by			
	P+H[c]	SRT[d]	FRT[e]	NT[f]
Prediction	1.0	1.5	4.7[g]	1.9
Measurement	1.0[h]	1.4	1.8	1.8

[a]Predictions were made, using the Kozeny-Carman equation, from porosities measured by thin-section micromorphometry. Measurements (geometric means of 2 replications) were made using double-ring infiltrometers and corrected to a standard water table depth of 30 cm. [b]Normalized in relation to values for plow and harrow. [c]Plow and harrow. [d]Skid-supported rototiller. [e]Floating rototiller. [f]Nontilled. [g]No explanation for high value. [h]Actual: 8 mm/d.

soil structural properties, and rice and weed growth. We include measurements (from colleagues at the Istituto per la Chimica del Terreno, Pisa, Italy) of the porosity contributed in each 5-cm layer in 0-30 cm depth by pores of different widths and shapes, including elongated pores that facilitate water transmission. These measurements are made on thin sections of soil prepared from each soil layer in plots subjected to various wetland preparations.

These porosity values may be used to estimate approximate values of absolute soil hydraulic conductivity, and to predict more precise values for relative conductivities of zones of similar soil subjected to various structural manipulations. The predictions are made through the long-established Kozeny-Carman equation, and data for the 6 successive depth layers in 0-30 cm are combined through a simple electrical resistance analogue model. For the absolute conductivity, the measured porosities and assumptions predicted a value of 50 mm/d, close to the measured field values of 10mm/d. Relative values (Table 3) are normalized to an assumed value of 1.0 for the plow and harrow treatment. Apart from an inexplicably high value in the prediction for the floating rototiller (a value deriving from improbably high values of porosity in 0-10 cm), the normalized predictions and observations agree strongly.

CULTIVATION OF PUDDLED SOIL FOR DRY SEASON MAIZE AND LEGUMES

Soils, Agricultural Engineering, and Agronomy Departments

For dry season (DS) mungbean grown on previously puddled soil and using soil water remaining after irrigated rice harvest, experiments in 1985 and 1986 showed yield benefits from deep strip tillage, and yield penalties where seed-zone soil remained chemically reduced after long submergence during rice growth. The experiments quantified the effects on legume growth of the drying compact layer in puddled soil and the effects of soil drying and rice stubble on seedling emergence for mungbean planted by hand and by mechanical seeder.

Research in 1987 at IRRI and in farmers' fields measured percentage emergence of mungbean, soybean, and maize for various tillage methods and seeding techniques and timings (including relay seeding before rice harvest). Supporting studies measured the effects and interactions of soil water, temperature, and strength on germination and emergence for mungbean, soybean, and maize and for tropical sesame varieties. Field studies sought to determine the draft force needed for deep strip tillage, and the critical soil depth below which tillage is counterproductive. They also investigated the interactive effects on mungbean yield of deep tillage and soil redox status, the benefits to production of shallow water table, and the usefulness of

tests of soil aggregates' stability for predicting soil suitability for various methods of postrice tillage.

Seeding techniques, cultivars, redox status, and plant emergence (*Soils and Agricultural Engineering*). For mungbean seeded into previously puddled Vertic Tropaquept clay loam soils, we (with colleagues from the Institute of Plant Breeding, University of the Philippines at Los Baños, and from the University of Minnesota, USA) measured direct and interactive effects of seeding technique and delay, soil-redox status, and mungbean cultivar.

Before mungbean, contrasts of chemically reduced and reoxidized soil were created on each of two fields: rice was grown on submerged soil on half of each field (in randomized plots), with the other half uncropped and not submerged (though previously puddled). To equalize moistures at mungbean seeding, all plots (whether after rice = AR or after fallow = AF) were reflooded immediately after rice harvest; but flooding was brief to avoid changing redox conditions. On one field (Field F13), at 3 d after draining (DAD) reflooding water, 3 mungbean cultivars (CES 2G-4 (Pag-asa 3), IPB M79-9-82, and IPB M79-13-60 (Pag-asa 5)) were each planted into nontilled soil by an inverted-T mechanized seeder and planted by hand into manually opened furrows with 6 replications each of AR and AF plots. The two IPB varieties emerged significantly better than did CES 2G-4 (Table 4). Mechanized seeding produced higher emergence than did manual seeding. For mechanized seeding (but not for manual), emergence was higher AF than AR—in AF plots the seeder might have planted at more uniform depth and covered seeds with soil aggregates better.

Table 4. Emergence[a] of 3 mungbean cultivars from previously puddled silty clay loam rice soil, related to method of seeding and preceding cropping.[b] IRRI, 1987 DS.

Cultivar	Emergence (%) for seeding					
	By hand		By seeder[c]		SED	Mean
	AR	AF	AR	AF		
CES 2G-4	29	30	53	75	10	47
IPB M79-9-82	40	40	55	90	11	56
IPB M79-13-60	48	52	73	83	13	64
SED	8	8	12	16		3
Mean	40	41	60	83	4	

[a]At 14 DAS, mean of 12 × 1.6 m rows. [b]AR = after rice, AF = after fallow. [c]Inverted-T seeder.

Overall, emergence was far less than the 93% recorded with nontilled soil in 1986. Low emergence, especially on the manually seeded plots, may have been because recently imported topsoil was insufficiently friable for seeds to contact soil and imbibe water. Neither soil dryness nor soil strength is likely to have caused low emergence. Although soil moisture at 5 cm depth varied more than expected within the field (from 0.24 to 0.53 cm^3 cm^{-3}), emergence rate did not correlate with this moisture, which even at 0.24 cm^3 cm^{-3} was moist enough for mungbean emergence (Annual report for 1985). Furthermore, soil strength in 0-5 cm, as measured by cone penetrometer, and soil temperature (23 °C at 0800 h and 29 °C at 1400) showed no effect of previous cropping or seeding method.

In the second field (Field F11), we measured the effects of deliberate seeding delay and its interactions with seed-zone tillage and preceding cropping on emergence percentage for manually seeded CES 1d-21 mungbean. Seeding delay, measured from draining the reflooding water, extended by 1 to 15 d on nontilled (T0) plots and by 3 to 18 d on plots that had a combination (T6) of deep strip tillage followed by (fb) surface tillage. Correspondingly, soil moisture θ in 0-5 cm (average of 6 replications per treatment) ranged between 0.29 and 0.55 cm^3 cm^{-3}, and for combined data over all treatments correlated significantly with emergence percentage E:

$$E = (7.7 \pm 9.8) + (161 \pm 30)\,\theta \qquad (r = 0.78^{**})$$

Within this correlation the following relations were apparent. Emergence percentage was approximately constant, at 90% ± 5, for seedings at 1-5 DAD for both AF and AR and for T0 and T6. For T6, however, emergence from seeding at 5 DAD was about 7% more than for 3 DAD—the 2 d of additional drying helped create a better structured seed zone. For delays beyond 5 DAD, emergence declined progressively to about 70% for T0 at 15 DAD, and to about 40% for T6 at 18 DAD. Emergence in T6 plots declined more because tilled soil dried more rapidly. With longer

delays, emergence was consistently higher AF than AR, as with mechanized seeding at 3 DAD in the first field.

In a third field (Field F14) (in collaboration with the University of Reading, England), we measured changes in soil-water potential and content, and consequent effects on the emergence of manually seeded and machine-seeded IPB 79-17-79 mungbean. The previously puddled and reflooded rice soil was allowed to drain and dry (without further tillage) under DS high irradiance conditions. Manual seedings were done at 3, 5, 7, 10, and 14 DAD, and machine seedings at 3, 5, and 7 DAD using a prototype seeder developed for relay-seeding of legumes and maize into moist rice soil just before rice harvest. Every 2 d after the various seedings, soil-water potential was determined for each 1-cm layer in 0-15 cm depth by measuring the water absorbed by calibrated filter papers contacting the sampled soil.

Potential at 5-cm depth was -0.01 MPa at 3 and 5 DAD, and -0.05 MPa at 7 DAD. Emergence rates for manual seedings at 3, 5, and 7 DAD were 90% ± 2. For the prototype seeder, emergence rates were 80, 75, and 30, respectively. At 10 and 14 DAD, with potentials of -0.8 and -1.2 MPa, manual seedings gave emergence of 10 and 1%.

Laboratory studies at Reading University, in which mungbean seeds made contact through semipermeable membranes with solutions of polyethylene glycol at various water potentials, indicated that the limiting potential for germination was -2.2 MPa.

In Field F14, a colleague from the Agency for Agricultural Research and Development, Indonesia, evaluated the prototype relay seeder and manual broadcast seeding for CES 1d-21 mungbean and UPL SJ-2 soybean, each seeded at 3 DAD into soil with Eh of 300 mV and moisture of 0.45 cm^3 cm^3 at 5-cm depth. Emergence percentages were 65% ± 5 for mechanized-relay and 26% ± 5 for broadcast seeding for mungbean, and 34% ± 3 and 0% for soybean. Broadcast soybean seeds were unable to imbibe sufficient water for germination.

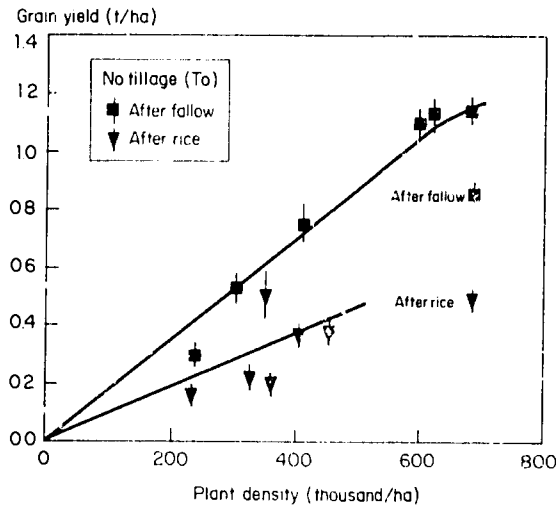
In Philippine fields in Santa Rosa and Victoria, in seed zones of 50-55% clay, mungbean was dibbled at 20 DAD into soil kept fairly moist (0.5 cm^3 cm^3) by rain and shallow groundwater. Emergence exceeded 75% in tilled and nontilled seed zones.

In wetter (0.55 cm^3/cm^3) clay soil on a Guimba farm (with very high evaporative demand), mungbean was seeded by hand and dry seeder at 3 DAD into a field with water table at 0.9 m depth, and at 9 DAD into a field with water at 0.1 m.

The prototype relay seeder gave mungbean emergence of 90% ± 10, but emergence from dibbled seeding on those same days was only 48% ± 2 in the deeper water-table regime and 62 ± 2 in the shallower regime. The mechanical seeder may promote emergence because its coulter disc disrupts the seed-zone soils, while dibbling presses the aggregated soil over the seeds. Mungbean emergence from soil rototilled after rice harvest (rototilled very wet because of groundwater upwelling) was only 14% ± 4 because rototillage in this wet state created a cloddy, sticky seed zone. In the Guimba experiment, emergence rate for relay-planted maize was 58% ± 4 with deeper groundwater and 68% ± 5 with shallower groundwater; corresponding rates for soybean were only 13% ± 4 and 36% ± 4, consistent with findings in IRRI Field F14. These lower rates for maize and soybean resulted in part from fungal attacks on the seeds in wet soil. Maize and soybean emergences from soil unintentionally wetted after rice harvest were about 10%—comparable to mungbean emergence.

Seed size, seed soaking, mulch, plant emergence, and crop production (*Soils*). Figure 1 illustrates the importance of crop establishment (seedling emergence) in determining crop production. Mungbean grain yield (from three cultivars and two seeding methods) is related to plant density under AF and AR conditions. Soaking seeds in water before seeding will increase and hasten seedling emergence, as will sowing the largest seeds (top 25%). Field trials in a silty clay seed zone showed that a 2-h seed soaking increased emergence by 10% for sowing at 4 DAD into wet soil, and by 30% for sowing into drier soil at 7 DAD. In growth-chamber studies at 25 °C, emergence from beds of 1-3 mm soil crumbs at -0.04 and -0.6 MPa potential increased about 15% for small seeds (2.8-3.4 mm diameter) but not for large seeds (>4 mm).

Because 1) the soil in both field and growth-chamber experiments was wetter than -2.2 MPa (the limit for germination), 2) the benefit of soaking



1. Grain yield of dry season (DS) rainfed mungbean in relation to plant population density and preceding land use on nontilled previously puddled Vertic Tropaquept clay loam soil IRRI Field F13, 1987. Average of 3 cultivars and 2 sowing methods.

was greater for smaller seeds, and 3) emergence in the field trial was higher for manual than for mechanized seeding, we conclude that soaking compensated for inadequate seed-soil contact.

Seed soaking and seed-soil contact also affected *time* for emergence: small seeds soaked for 2 h emerged in 2.1 d ± 0.2 compared with 2.5 d ± 0.2 for nonsoaked seeds; large seeds required 2.8 d ± 0.2, irrespective of soaking. Both large and small seeds emerged more quickly (at both 25 and 30 °C) from soil aggregates of 1.9 mm mean diameter than from those of 1.0 mm; emerging shoots may have found easier pathways between larger than between smaller aggregates.

Plants from larger seeds grew more vigorously. In the growth-chamber study, plant height at 7 d after seeding (DAS) was 32% ± 9 higher from large seeds than from small (17.0 ± 0.2 compared with 13.0 ± 0.2 cm). In the field, plants (measured at 39 and 45 DAS) were 34% ± 3 taller from large than from small seeds for seeding at 4 DAD, and 18% ± 2 taller for seeding at 7 DAD. Total dry matter at 35 DAS showed similar effects: a 70% ± 10 advantage for large seeds for 4 DAD, and 40% ± 20 for 7 DAD. The greater effects for 4 DAD may be because larger seeds had bigger energy reserves to overcome higher soil strength for that seeding, whereas soil was wetter after 7 DAD because of rain on that day. Plants were 9% ± 3 taller, and had 22% ± 20 more dry matter from manual than from mechanized seeding: better seed-soil contact stimulated slightly faster emergence, leading to better growth.

Rice-straw mulch (by conserving soil moisture and maintaining lower seed-zone strength) can also improve emergence and early growth of postrice mungbean. In a field trial, mungbean was seeded at 30-cm row spacing into a nontilled silty clay seed zone at 2 and 5 DAD on plots with and without 8 t rice-straw mulch/ha. (Rice-straw yield is typically 4 t/ha; the 8 t/ha was achieved by chopping 4 t straw/ha into 15-cm lengths and placing the chopped straw across the seed lines only, leaving the intervening 15-cm strips uncovered.)

The mulch lessened seed zone drying during 2-5 DAD by 0.02 unit of volumetric moisture (a 30% ± 20 effect) and kept temperature 2.5 °C lower. Consequently, emergence was higher from mulched than from nonmulched soil by 9% ± 11 (97 versus 88%) for seeding at 2 DAD and by 17% ± 11 (84 versus 67%) for seeding at 5 DAD. Plant height (average of 14, 21, and 28 DAS) similarly showed responses to mulch: 9% ± 3 and 13% ± 4 for seedings at 2 and 5 DAD, respectively.

Aggregate size, soil-water potential, temperature, strength and friability, and seedling emergence and rooting (*Soils*). Soil temperature and water potential, the strength of seed-zone soil, and the sizes of seed-zone aggregates relative to seeds affect germination and emergence in temperate soils. Corresponding effects and interactions for nonrice crops growing in tropical rice soils have been studied in basic research with collaborators from China, Indonesia, and Sri Lanka and from the Universities of Reading (England) and Minnesota (USA).

Mungbean germination showed interactive effects of water potential (set by polyethylene glycol-solutions) and temperature: germination percentage at 0.0 MPa potential was more than 50% for all temperatures between 15 and 40 °C; but at -0.9 MPa there was no germination at 15 °C, and only 35% germination at 20 °C; at -2.2 MPa, germination exceeded 50% only at 40 °C.

For the *speed* of germination, expressed as t_{g50} (days) for 50% of seeds to germinate, data for temperature T in 15 to 40 °C and for potential ψ in

0.0 to −1.7 MPa can be expressed as:

$$t_{g50} = (15.5 - 24.2\psi)\ (T - 10.1) \qquad (r^2 = 0.86)$$

This t_{g50} can in turn be used to describe, by correlation, the final percentage emergence F:

$$F = 112 - 38\ (T_{g50}) + 9.5\ (t_{g50})^2 - 0.90\ (t_{g50})^3$$

For root radicles, the thermal time-rate RE of elongation, that is elongation rate ÷ temperature (in mm/d.K), is related to ψ through the expression:

$$RE = 0.80 \exp(1.29\psi) \qquad (r^2 = 0.998)$$

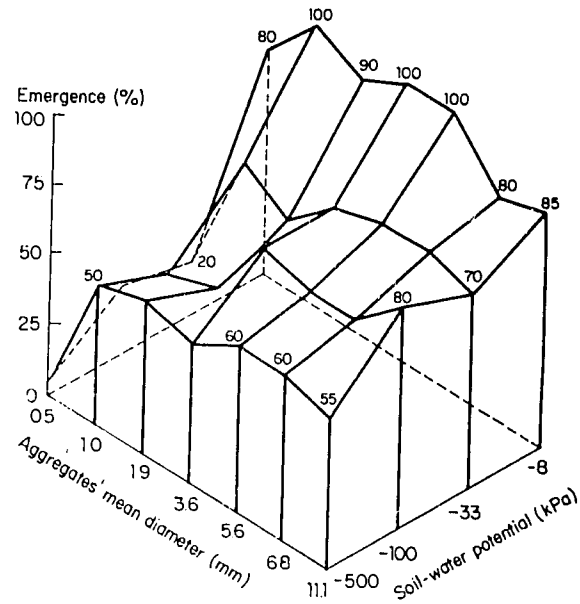
Interactions of soil aggregate size, soil temperature, and water potential on mungbean emergence were studied in a growth chamber. Seeds were placed between the end faces of two cylindrical cores of soil of chosen aggregate mean diameter and each brought to a desired potential.

Figure 2 shows for 25 °C that emergence exceeded 50% except for aggregates of mean diameter <1.0 mm in soil drier than −33 kPa potential. Correspondingly, emergence time lengthened with smaller aggregates in drier conditions. Emergence percentage was hardly affected by temperature, but speed of emergence was 2-3 times faster at 35 than at 20 °C. Measurements using a cone micropenetrometer fabricated in Minnesota showed that soil strength above the seed decreased emergence.

The ability to create soil aggregates of a desired size range depends on soil friability—the inherent capability of soil aggregates to fragment into smaller units. Friability values for IRRI silty clay loam (probably the first ever measured for rice soil) were approximately 0 ("not friable") at 7 DAD, but were much larger (approximately 0.3, "very friable") at 10 and 15 DAD, when the soil had dried beyond its liquid-limit moisture.

For a single size range of aggregates (1.0-2.8 mm diameter, in plastic trays), the effects of soil temperature and potential on emergence of sesame (Sri Lanka collaboration) and tropical wheat (China collaboration) were measured.

For sesame (cultivar Gingelly MI-3), emergence exceeded 50% from soil as dry as −1.0 MPa when temperature exceeded 25 °C; but at 20 °C, soil had to be wetter than −50 kPa for 50% emergence. At potentials between −10 and −300 kPa, emergence



2. Percentage emergence for CES Id-21 mungbean at 25 °C in a growth chamber as affected by size of soil aggregates and by soil-water potential. Aggregates' mean diameter was varied by mixing appropriate proportions of sieved aggregates of specific sizes.

rates at 25, 30, and 35 °C were, respectively, 80, 90, and 95% (all ± 5%); for −10 to −50 kPa at 20 °C, emergence was 75% ± 5. Times for 50% of final emergence to occur, for potentials between −10 and −100 kPa, were 110, 65, 45, and 35 h (each ± 5 h), respectively, for 20, 25, 30, and 35 °C.

For wheat (cultivar IPB UPLW-1) at 20, 25, and 30 °C, there were upper and lower limiting water potentials beyond which emergence was zero; between these limits, emergence was maximal (95% ± 5) at optimal temperatures. At 20, 25, and 30 °C, the respective upper (wet) limit, optimal potential, and lower (dry) limit were −5, −100, and −2000; −10, −200, and −2000 kPa; and −30, −300, and −3000 kPa. At and above 35 °C, germination and emergence were zero. Time to 50% of final emergence was 70 h ± 10 at both 25 and 30 °C, but was significantly longer (90 h ± 5) at 20 °C.

These studies indicate that farmers should 1) select large mungbean seeds for sowing, or 2) soak seeds (all sizes) for 2-3 h before seeding; 3) wet seed zone soil to field capacity when sowing mungbean, sesame, or tropical wheat into soil cooler than 25 °C; 4) use rice-straw mulch, concentrating it on

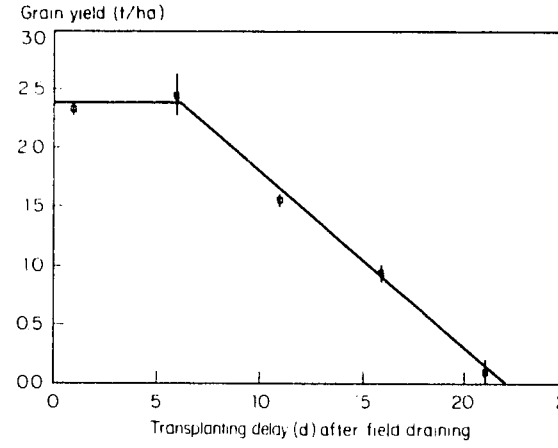
the seed row; and 5) create seed zones (soil structures) of low strength with few aggregates less than 1.0 mm.

Limitation of legume growth by the compact layer in puddled rice soil (*Soils*). Into a Vertic Tropaquept clay loam soil that was puddled and then drained, 7-d-old CES Id-21 mungbean seedlings were placed at 1, 6, 11, 16, and 21 DAD. The seedlings were growing in moist soil in 5-cm-diameter × 10-cm-high nonrigid plastic tubes. The tubes were placed in 10-cm-deep holes with 5 cm diameter made by auger. The tubes had openings in the bases to allow roots to emerge and encounter the drying, strengthening soil at 10-cm depth and below. Shoot and root growth, soil moisture and strength, and depth to water table were measured every 2 wk. Grain and fodder yields were taken from 7.9-m^2 harvest areas.

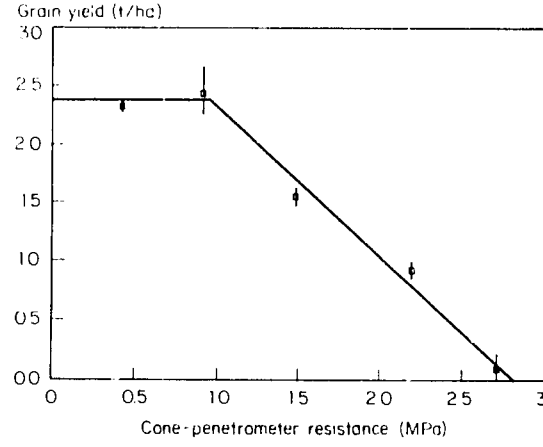
Crop growth and yield and soil strength were consistently free of any influence of a water table below 1.0 m, but were affected by planting delay. Plant height at maturity for plantings at 6 and 11 DAD was 52 cm ± 2; for 1 DAD, it was 39 cm ± 1, indicating an adverse effect of the initially reduced soil; and for 16 and 21 DAD, it was 43 cm ± 2 and 23 cm ± 1, respectively, showing the effects of increasing soil strength. Root mass per plant was significantly affected only for 21-DAD plantings less than half the value in other plantings. Grain yields were 2.4 t/ha ± 0.1 for 1 and 6 DAD, but declined steadily thereafter to only 0.1 t/ha ± 0.1 for 21 DAD (Fig. 3). Fodder yield declined similarly.

Increased soil strength produced this yield decline (Fig. 4). Yield was essentially zero when cone-penetrometer strength (resistance at 10-cm depth) exceeded 2.5 MPa at planting, and therefore over the season. In this particular soil in DS, mungbean should therefore be seeded during 0-6 DAD to avoid yield loss due to soil strength. On a similar soil in 1985 (Annual report for 1986), DS rains extended this optimal planting period to 0-14 DAD.

As an alternative to sowing soon after draining, deep tillage can be used to lessen the strength of the compact layer, preferably not over the whole field, but along parallel strips at 30-50 cm spacing, where mungbean or other nonrice crops will be seeded.



3. Effect of drying of the compact layer in previously puddled rice soil on the grain yield of DS CES Id-21 mungbean, IRRI Field F13, 1987. Drying was effected by delay in transplanting of rooted mungbean seedlings pregrown for 7 d in moist loose soil in perforated containers 10 cm high. Containers were placed into 10-cm-deep holes augered at successive days after field draining in Vertic Tropaquept clay loam.



4. Effect of rice-soil strength (cone-penetrometer resistance) on grain yield of DS CES Id-21 mungbean, IRRI Field F13, 1987. Strength measured at 10-cm depth at the time of transplanting rooted mungbean seedlings into augered holes in a progressively drying field of previously puddled Vertic Tropaquept clay loam. Seedlings were pregrown for 7 d in moist loose soil in perforated-bottom containers 10 cm high. Progression in field-soil strength was achieved by successive delays of seedling transplanting after field draining.

Effects on rainfed mungbean of deep tillage, planting delay, and preceding submergence of puddled soil (*Soils and Agricultural Engineering*). The 1987 DS experiment in Field F11 with CES Id-21 mungbean as the test crop measured the

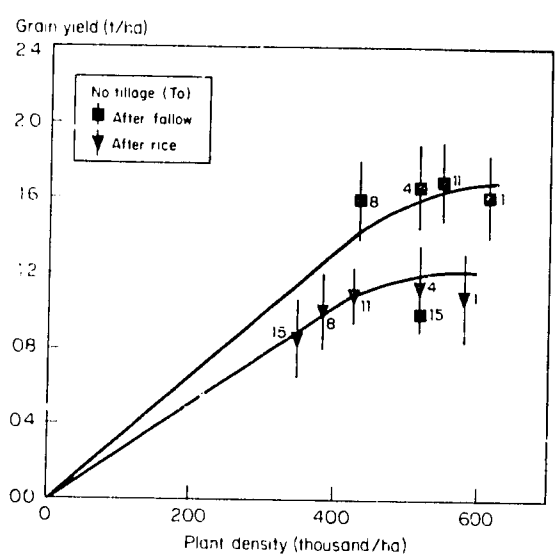
effects of no tillage (T0) and of deep-winged-tine strip tillage to 35-cm depth (b shallow plowing and harrowing (T6). The experiment used 5 seeding delays appropriate to each tillage, and compared AR with AF. Seedings for T0 were at 1, 4, 8, 11, and 15 DAD; for T6, they were at 3, 5, 9, 12, and 18 DAD; with delays of less than 3 d for T6, tractor wheels would have damaged the soil. The procedure for creating a contrast of AR and AF treatments of similar wetness at 1 DAD was described in the Annual report for 1986. Each treatment combination of preceding submergence, tillage, and delay was replicated 6 times; seeding was manual, at 35 cm between rows and 4 cm between plants, with first seeding (1 DAD) on 3 Feb. All seeds received both fungicide and inoculant, but no plots were fertilized. Insects and weeds were controlled by appropriate sprays, and weeds by hand weeding at 23 DAS. There was no irrigation after seeding, and the season's rainfall totaled only 10 mm. The crops thus relied on soil-profile moisture remaining after the brief re-flooding that simulated end-of-rice-season conditions. The water table was maintained below 1.4 m by drains.

Plant populations averaged 550,000 ha for seedings between 1 and 5 DAD, and 250,000 ha for those at 18 DAD, and were consistently lower AR than AF. Growth difference between AR and AF plots showed at 22 DAS, when AR plants (average of all delays and both tillages) were 12.0 cm ± 0.7 high and AF plants 15.2 cm ± 0.7; at 50 DAS, corresponding values were 34.4 ± 1.1 and 42.7 ± 1.3. Plants AR on T6 plots were 25% higher than those on T0 (average of 5 delays and 4 measuring occasions), but AF plants were equally tall for either tillage. Earliest AR seedings (1 or 4 DAD) produced plants slightly shorter (particularly for T6) than seeding at 8 or 11 DAD, but late AR and AF seedings (15 or 18 DAD) produced plants appreciably (20%) shorter, particularly from 30 DAS onward and for AF and for tilled conditions.

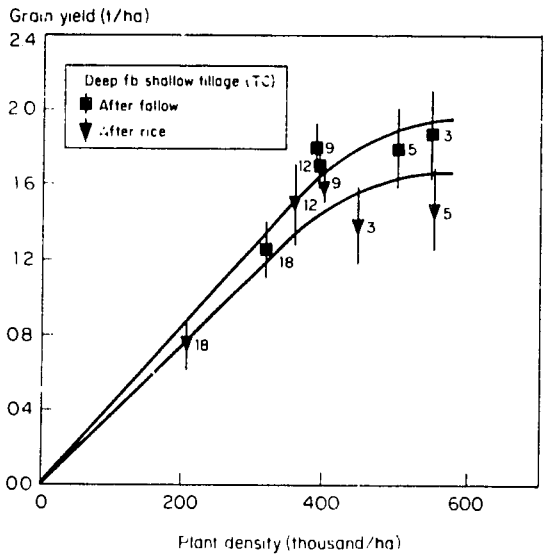
Differences in grain yield were similar to those for plant height. Figures 5 (for T0) and 6 (for T6) present yields in relation to plant population density, distinguishing between AF and AR. Additionally, for all 4 combinations of T0/T6 with AF/AR, yield increased in proportion to plant population up to about 500,000 plants/ha; thereafter, yield reached a plateau (Fig. 5, 6). Similar behavior was observed in AF in the experiment in Field F13 (Fig. 1). For both T0 and T6, yield from a particular population was less AR than AF. The fractional amount by which AR yield was less than AF (in the linear portions of the curves) was 23% ± 8 for T0, but only 11% ± 8 for T6.

Assuming that the soil's chemically reduced condition decreased yields, this finding would be expected, because tillage would promote reoxidation. The fractional decreases in Figures 1 and 5 (both T0) are 48% ± 8 and 23% ±8; the differences may have been due to the larger range of planting delays and redox conditions in Figure 5.

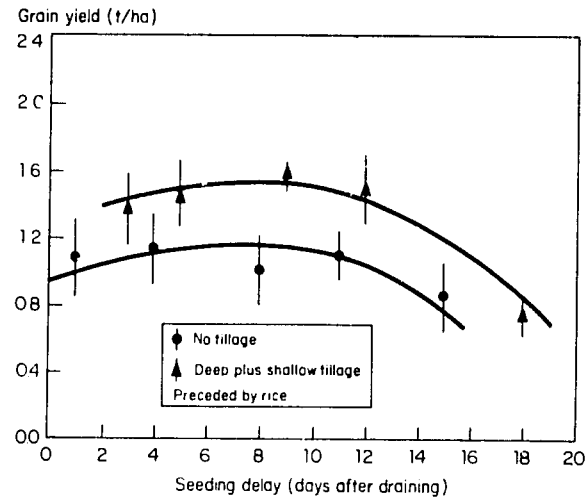
Seeding delays (DAD) are indicated in Figures 5 and 6 by the numbers within the symbols. For AR curves, data for the shortest delays (1-4) lie below their respective curves, supporting the hypothesis that growth and yield were affected by low redox status. For AF, when soil dried more quickly, data for longer delays (15, 18) also fall below the lines, as would be expected if rooting and yield were inhibited by high soil strength.



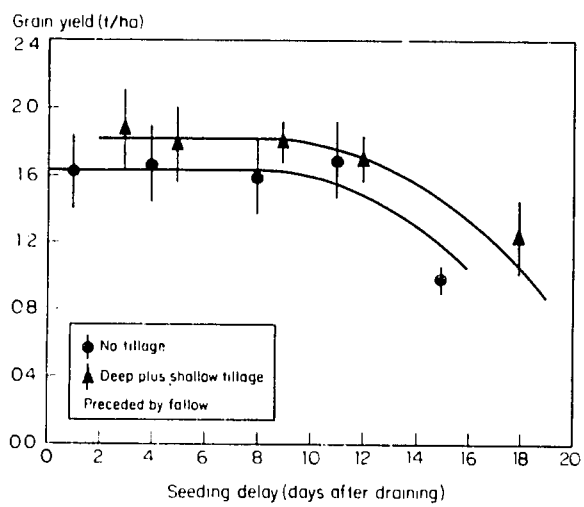
5. Grain yield of DS rainfed CES Id-21 mungbean in relation to plant population density, preceding land use, and delay in seeding on nontilled previously puddled Vertic Tropaquept silty clay over clay loam, IRRI Field F11, 1987. Numbers beside the symbols indicate days of delay in seeding after field draining.



6. Grain yield of DS rainfed CES 1d-21 mungbean in relation to plant population density, preceding land use, and delay in seeding on previously puddled Vertic Tropaquept silty clay over clay loam that after rice harvest was deep-tilled, then plowed and harrowed, IRRI Field F11, 1987. Numbers beside the symbols indicate days of delay in seeding after field draining. fb = followed by.



7. Grain yield of DS rainfed CES 1d-21 mungbean in relation to seeding delay after field draining and for no tillage and deep plus shallow tillage preceded by rice on Vertic Tropaquept silty clay over clay loam, IRRI Field F11, 1987.



8. Grain yield of DS rainfed CES 1d-21 mungbean in relation to seeding delay after field draining and for no tillage and deep plus shallow tillage preceded by fallow on Vertic Tropaquept silty clay over clay loam, IRRI Field F11, 1987.

Interactions of seeding delay and redox status are reflected in Figures 7 (for AR) and 8 (for AF), where yield is graphed against DAD for T0 and T6. Both figures demonstrate a consistent 0.2-0.3 t/ha benefit of tillage. Both show that yield declined rapidly with delays beyond 9 DAD, partly because of lesser emergence and poorer rooting each a product of increased soil strength. For delays <9 d, AR and AF plots behaved differently. For AF (Fig. 8), yield was constant, indicating that sufficient plants emerged and effectively used the available solar irradiance. For AR (Fig. 7), yield was lower in seedings made earlier into soil that was more reduced. Thus, for AR there was an optimal seeding time of 6-10 DAD, but even then, yield loss due to preceding submergence was 0.3-0.5 t/ha.

Total dry matter yield (TDMY) and fresh fodder yield (FFY) at harvest showed effects of tillage, seeding delay, and preceding submergence that were similar to those for grain yield. Maximum values (for seeding at about 8 DAD) for TDMY were 3.0 and 2.7 t/ha for T6 and T0 AF, and 2.4 and 1.9 t/ha AR. For FFY, the values were 6.2 and 5.3 t/ha AF, and 4.7 and 3.3 t/ha AR, for T6 and T0 respectively.

Draft force and critical depth in deep tillage (*Soils and Agricultural Engineering*). If small-scale rice farmers are to use deep-tine strip tillage, the force required to pull the tines must be achievable using farmers' power sources. The tillage must

loosen the soil deep enough to promote DS crop root growth. Generally, the deeper the tillage, the more extensive the loosening, but deeper tillage requires greater draft force. As tillage depth increases, specific resistance increases sharply at and beyond a *critical depth*. Tillage should *not* therefore penetrate deeper than this critical value; otherwise, soil will compact rather than loosen, wasting time and effort. Critical depth depends on the soil, its wetness, and the tine geometry.

In collaboration with the Rural Development Administration, Korea, draft force, area of soil loosening, and critical depth were measured in 1987 DS for various designs and combinations of tines in previously puddled silty clay loam at IRRI (for tillage to benefit DS crops) and in sandy loam and silty clay loam in Korea (where deep tillage is primarily for rice).

At wetness close to PL, draft forces for a single narrow tine working to 20, 35, and 50 cm depth were, respectively, 3-4, 7-8, and 19-20 kN in silty clay loams, and about 1 kN less in sandy loam. The forces were no greater when the single narrow tine was pulled together with two shallow leading tines to loosen a wider soil area. For a winged tine working at 35 cm at a range of moistures (tillage at increasing DAD) from the liquid limit to 1.2 × PL, draft correspondingly increased from 4 to 5 kN the latter consistent with measurements reported (together with tine illustrations) in the Annual report for 1985.

In these experiments, tines were pulled by 22 or 35 kW tractors. However, deep-tine tillage to 35 cm can be achieved using small (6 kW) gasoline engines exerting their draft through a winch and cable system (Annual report for 1984). For animal-powered tillage, the draft required even at a relatively shallow 20 cm is beyond a carabao's capacity. Work rate for deep-tine tillage to 20, 35, and 50 cm at 40-cm row spacing in the Korean silty clay loam was, respectively, 0.10, 0.07, and 0.04 ha/h; work rate for moldboard plowing to 25 cm using the same tractor was 0.20 ha/h.

The cross-sectional area (perpendicular to the line of tillage) of loosened soil was measured by two methods. The first involved excavating a 50-cm-deep trench across the line of tillage and tracing the perimeter of the loosened zone onto transparent rigid plastic sheets pressed against the trench wall. The second required measuring vertical profiles of soil strength to 50-cm depth using a cone penetrometer at 10-cm spacing along transects perpendicular to the tillage line, and then delineating in the data array the zone within which soil strength was less by at least 0.5 MPa than in untilled soil at corresponding depths.

The 2 methods gave consistent results for loosening by a single tine, but the penetrometer estimate was lower by 17% ± 8. Results were more divergent for combinations of tines, for reasons that need investigating. The area of loosened soil, by simplest mechanical theory, should equal d^2: the square of the depth of tillage. For the Korean wingless tine, loosened area approximated d^2 for the silty clay loam, but was less than (though proportional to) d^2 for the sandy loam. In IRRI silty clay loam, however, the d^2-relation did not describe soil loosening either for a winged or a wingless tine; loosening was larger than predicted in 0-25 cm depth, and less than predicted below 25 cm. These patterns of loosening possibly indicate that fracturing was influenced by layering in the soil structure. This layering was more developed at IRRI than at the Korean site.

Specific resistance to tillage was about 20 kN/m^2 for the winged or wingless tines working at <30-cm depth in the silty clay loams, and approximately 30 kN/m^2 for the sandy loam where force produced less loosening because of the shorter range of soil structure. For tillage deeper than 30 cm, and for all soils and tines, specific resistance increased sharply, identifying critical depth as 34 cm ± 3 for the Korean soil and tine, and 32 cm ± 5 in the IRRI soil for the winged tine and for the wingless tine with or without shallow leading tines. For the winged tine and for tillage at all depths in 15-35 cm, specific resistance was less at 3 than at 8 or 18 DAD, but measurement was not precise enough to detect any effect of DAD on critical depth.

These results indicate that deep tillage for postrice DS crops should be undertaken as soon as soil has dried enough for operations at a work rate of 0.1 ha/h and without soil damage by tractor wheels. Tillage should not extend below 35 cm.

Yield benefit from deep soil loosening (*Soils and Agricultural Engineering*). The potential for deep tillage to increase legume production was determined by measuring mungbean growth and yield

on sites (root-sample pits of about 1.0 m^2 area and 1.0 m depth) previously excavated and refilled — thus creating a less compact structure.

At 50 DAS, plants on excavated sites were 41% ± 8 taller than on unexcavated soil (average of all combinations of AF and AR, and T0 and T6); but for AR only, height increase due to pits was 54% ± 12 for T0, and 33% ± 7 for T6. The smaller increase for T6 was expected, because T6 tillage — like the pits — also promoted loosening and reoxidation.

Grain yield (Table 5) on excavated sites was higher than on unexcavated sites by 0.7-0.8 t/ha (a 55% increase) for all combinations of AF and AR and T0 and T6. At excavated sites on AF-T6 plots, the average yield without fertilizer or irrigation was 2.4 t/ha (about 4 times the average Southeast Asian mungbean yield), and was 2.6 t/ha for seeding at 9 or 12 DAD; these are target yields for deep tillage technology.

Table 6 shows the extent to which the target has been reached in tillage experiments in IRRI fields, and the interacting effect of preceding soil submergence. Deep-tine strip tillage, with or without supplementary surface plowing and harrowing, has increased yields, though sometimes insignificantly, and not by the 0.8 t/ha margin indicated in Table 5. When rainfall was lower, yield response to deep tillage was greater because subsoil matric water made accessible by deep tillage was then more valuable to the plants. Moreover, if yield

Table 5. Grain yield of DS rainfed CES 1d-21 mungbean in excavated and unexcavated soil as related to preceding land use and tillage.[a] IRRI, 1987.

Item	Grain yield (t/ha)				
	Preceded by rice		Preceded by fallow		Mean
	No tillage	Deep plus shallow tillage	No tillage	Deep plus shallow tillage	
Excavated	1.8 ± 0.2	2.1 ± 0.2	2.2 ± 0.2	2.4 ± 0.2	2.2 ± 0.1
Unexcavated	1.0 ± 0.1	1.3 ± 0.1	1.5 ± 0.1	1.7 ± 0.1	1.4 ± 0.1
Difference[b]	0.8 ± 0.2 (80)	0.8 ± 0.2 (65)	0.7 ± 0.2 (45)	0.7 ± 0.2 (40)	0.8 ± 0.1 (55)

[a]Average over 5 seeding delays; no fertilizer, no irrigation, 10 mm rainfall; IRRI Vertic Tropaquept silty clay over clay loam. [b]Figures in parentheses represent percentages.

Table 6. Grain yield of DS CES 1d-21 mungbean as related to tillage and duration of possible reoxidation of previously submerged rice soils.[a] IRRI, 1984-87.

Tillage	1984	1985		1986		1987	
	AF	AR[b]	AF[b]	AR[b,c]	AF[b,c]	AR[d]	AF[d]
	Days of possible reoxidation (d)						
	406	20	70	16	146	16	89
	Grain yield[e] (t/ha)						
None				1.8	2.1	1.0	1.6
Conventional[f]	1.9	1.2	1.4	1.8	2.2		
Narrow tine and tractor	1.9						
Narrow tine and winch	2.1						
Deep-winged tine		1.3	1.5				
Deep + shallow tines		1.3	1.5				
Deep-winged + conventional[f]				1.8	2.2	1.4	1.9
	Rainfall (mm)						
	33	47		64		10	

[a]AF = after fallow, AR = after rice. [b]Excluding plots located on unrepresentatively shallow soil. [c]For seeding at 6 d after draining. [d]For soonest possible seeding. [e]From 2 primings for 1984-86, 4 for 1987; standard error of difference: 0.1 t/ha for 1984-86, 0.3 t/ha for 1987. [f]Plowing to 9 cm followed by harrowing.

decrease due to preceding submergence is less in a wetter season (as suggested in Table 6). DS rain (if not excessive) can possibly compensate for the poor initial growth AR, resulting from chemically reduced conditions.

Yield response to deep strip tillage in 1987 DS was measured on soils of much higher clay content than the 40% at IRRI. These were farmers' fields in Laguna, Philippines: in Santa Rosa on a Vertic Tropaquept with 55% clay in 0-40 cm, and in Victoria on a Lithic Mollic Tropaquept of 60% clay. Tillage treatments were T0, T6, and T1 moldboard plowing to 9 cm fb harrowing. Mungbean CES 1d-21 was seeded manually at 35-cm row spacing at 15 d after rice harvest (about 20 DAD), but at high moisture content of 0.5 cm^3 cm^{-3} (caused by rain and shallow groundwater) on 11 and 18 Dec 1986 in Santa Rosa and Victoria, respectively. Measurements and crop management were similar to those in Field F11 at IRRI.

Grain yields at the 2 sites (compared in Table 7 with yields for corresponding DAD for AR at IRRI) were high, particularly for the low-input T0 system. Yields (especially in Santa Rosa) with treatment T0 benefited from rains at 8 DAS that promoted higher emergence on nontilled than on tilled soil, but weed masses at 30 DAS (0.5 t/ha in Santa Rosa and 1.2 t/ha in Victoria) were 2.6 ± 0.8 times higher than on tilled soil. At both sites, T1 yields were least, because tillage of wet soil produced cloddy seed zones of high strength that lessened emergence and seedling growth. For T6, the deep tine loosened the seed-zone soil sufficiently that subsequent plowing and harrowing created a more aggregated seed zone of lower strength. The high T6 production in Victoria was partly the result of 9% higher emergence. At either site, however, adjusting yields for emergence differences gives a yield response to deep tillage of 0.2 t/ha (or [illegible] %).

This response was a consequence of soil strength in 15-40 cm (measured by cone penetrometer) lower by 1.0 MPa on T6 than on T0 and T1, and lower consistently than 2.0 MPa, beyond which legume roots are unable to elongate. This lower strength allowed taller and leafier plants with greater root mass for T6 than for T0 and T1, particularly in Victoria. At both sites, plant height correlated inversely and significantly with seasonal average soil strength in both 0-20 and 20-40 cm.

At both sites, grain yield Y (by plot) in t/ha correlated weakly with root mass as determined from core samples at harvest. On IRRI Field F11, root yield R (t/ha) at harvest was determined by pinboard sampling: for plots seeded during 1-9 DAD, R in 0-90 cm AR was 0.32 t/ha for T0, 0.41 t/ha for T6; at 5-90 cm (i.e., excluding thick primary roots), R was 0.20 t/ha for T0 and 0.28 t/ha for T6. AF, R values were equal for T0 and T6: 0.39 t/ha for 0-90 cm, and 0.26 t/ha for 5-90 cm (all values ± 0.02 t/ha).

Deep tillage thus increased rooting (probably by promoting better aeration) in chemically reduced

Table 7. Grain yield of CES 1d-21 mungbean at IRRI (40% clay) and in Philippine farmers' fields (55-60% clay) as affected by tillage and duration of possible reoxidation following previous submergence, 1987 DS.[a]

Tillage	IRRI[b] (40% clay, Vertic Tropaquept)		Santa Rosa (55% clay, Vertic Tropaquept)	Victoria (60% clay, Lithic Mollic Tropaquept)
	AR	AF	AR	AR
			Days of possible reoxidation (d)	
	20[c]	89	20	20
			Grain yield[d] (t/ha)	
None (T0)	1.1	1.6	1.6	1.6
Conventional[e]			1.5	1.3
Deep[f] + conventional[e]	1.5	1.9	1.6	1.9
SED	0.3	0.3	0.1	0.1
			Depth to water table (m)	
	>1.4		0.7	0.9

[a]AF = after fallow, AR = after rice. [b]Field F 11. [c]For seeding at 4 and 5 d after draining. [d]From 4 primings at IRRI, 3 at other sites; no irrigation, no fertilizer. [e]Plowing to 9 cm followed by harrowing. [f]Winged tine at IRRI, narrow wingless tine at other sites.

soil (AR) but had little effect when soil was already reoxidized (AF). Moreover, Y (per plot) correlated with root yield through the same equation that was determined in 1986 (Annual report for 1986), and that was consistent with the direct proportionality $R = k \cdot R$. Mean values of k (constant of proportionality) (for 1-9 DAD) were 3.2 ± 0.3 for AR-T0, 3.9 ± 0.3 for AF-T0, and 4.2 ± 0.3 for AF-T6; thus, roots in reoxidized soil (AF) were more effective than those in reduced soil (AR), and deep tillage enhanced this effectiveness.

In the farmers' fields, Y related to seasonal soil strength q in both 0-20 and 20-40 cm. One function for each depth was sufficient to represent the 2 sites' combined data, and each showed that yield declined linearly with q beyond some limit—0.7 ± 0.2 MPa for 0-20 cm and 1.3 ± 0.2 MPa for 20-40 cm. These findings indicate the crucial importance of both surface-soil and subsoil strength.

At each site, Y correlated strongly with depth D (cm) of root-exploitable soil above a natural tuffaceous horizon of high soil strength:

Santa Rosa:

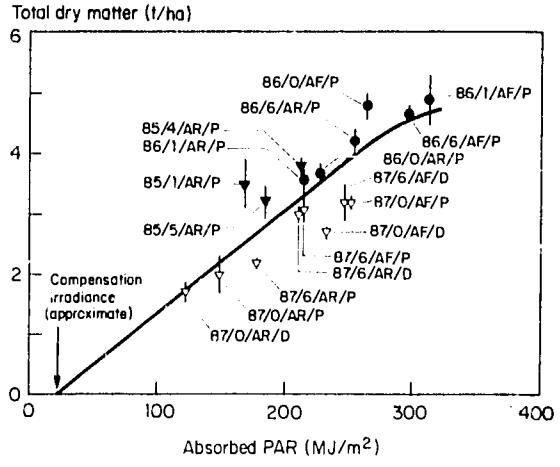
$$Y = (0.50 \pm 0.13) + (0.012 \pm 0.002)D \quad (r = 0.77^{**}, n = 18)$$

Victoria:

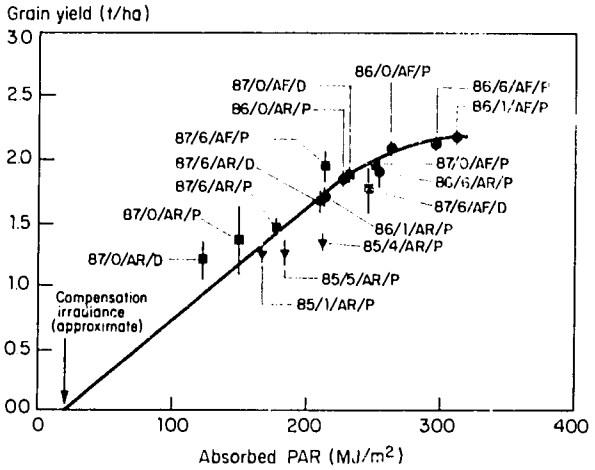
$$Y = (0.62 \pm 0.26) + (0.015 \pm 0.005)D \quad (r = 0.62^{**}, n = 18)$$

These equations are consistent with those reported for IRRI fields in Annual reports for 1984 and 1985. In Field F11 at IRRI in 1987, however, there were inverse relations of Y to D for early seedings — and no strong correlations for other treatments — for reasons that need investigating. Nonetheless, the equations for the 2 farmers' fields and the equations from earlier IRRI experiments do indicate that exploitable soil depth is a component of soil fertility, and that in soils with root-impeding layers in 0-40 cm, disrupting those layers by deep tillage should increase yield.

Absorption of solar irradiance (*Soils*). Deep tillage and other management practices increase yields by enabling crops to make more effective use of photosynthetically active irradiance (PAR). Figures 9 and 10 show for Field F11 and for 1985, 1986, 1987, and for various management practices, the relations of TDMY and grain yield Y to PAR, with PAR represented by the total during 0-57 DAS of PAR actually absorbed, i.e., corrected for 10% reflection. Both graphs indicate that production increased linearly with PAR to about 230 MJ/m^2, and less rapidly thereafter. If PAR is also



9. Total dry matter at harvest of DS rainfed CES 1d-21 mungbean in relation to absorbed photosynthetic irradiance (PAR) and preceding land use, tillage, and seeding delay on previously puddled Vertic Tropaquept silty clay over clay loam, IRRI Field F11, 1985-87. Irradiance total for 0-57 DAS. Data codes: year (1985, 86, 87), tillage (0 = none, 1 = plow and harrow, 4 = deep winged tine, 5 = deep + shallow tines, 6 = deep winged tine fb plow and harrow), land use (AF = after fallow, AR = after rice), seeding delay (prompt [P] = 1-6 d after draining [DAD], delayed [D] = 8, 9 DAD).



10. Grain yield of DS rainfed CES 1d-21 mungbean in relation to absorbed photosynthetic irradiance (PAR) and preceding land use, tillage, and seeding delay on previously puddled Vertic Tropaquept silty clay over clay loam. IRRI Field F11, 1985-87. Irradiance total for 0-57 DAS. Data codes as in Figure 9.

corrected for compensation irradiance (about 20 MJ/m^2), the following relations are valid for 20 MJ/m^2 < PAR < 230 MJ/m^2:

$$Y = (0.0088 \pm 0.0003)(PAR - 20)$$

$$TDMY = (0.0169 \pm 0.0008)(PAR - 20)$$

corresponding respectively to thermodynamic efficiencies in using *PAR* of 1.4% ± 0.1 for *Y* and 2.6% ± 0.2 for *TDMY* values equal to those reported for mungbean in 1986 (Annual report for 1986).

The positions of the various data along and around the lines in Figures 9 and 10 can guide interpretations of the effects of weather and management. Thus, *PAR*, *TDMY*, and *Y* were generally higher in 1986 than in 1987 because of higher rainfall (Table 6). For 1985, *TDMY* data occur above, and *Y* data below, the respective fitted lines. High *TDMY* was due to rain, but *Y* was not correspondingly high because of insects and an early monsoon that forced premature harvest. In 1987, conversely, *TDMY* occurs below the line because of low rainfall, but *Y* values are above the line because of effective pest control and dry weather that extended harvest. Crops AR (the 8 points farthest down each fitted line) generally absorbed less PAR, and hence had lower *TDMY* and *Y* than crops AF. For 1986, the 3 points farthest up each line were for AF conditions. Effects of seeding delay are difficult to interpret because of interactions with AR-AF (Fig. 7, 8), but deep tillage (T4, T5, T6) affected *Y* and *TDMY* by increasing the absorbed PAR (in comparison to T0, T1) in all 3 yr, especially AR.

Use of shallow groundwater by legumes (*Soils*). After harvest of irrigated or rainfed lowland rice at the end of a wet season (WS), groundwater often remains at 0.5-1.0 m depth available to roots of a nonrice DS crop. Conversely, if water tables are too shallow, they can depress growth of nonrice crops. Greenhouse experiments examined the effects on legume production of groundwater maintained at fixed depths, using 7.0-× 3.6-× 1.3-m soil tanks with subsurface water inlets and outlets, and with soil tilled to 10-cm depth and wetted to field capacity at seeding, but with no surface irrigation thereafter.

Grain yield for both IT82D-889 cowpea and CES 1d-21 mungbean was maximal for water table depth (WTD) maintained between 0.5 and 0.9 m, and was 20% below maximal for WTD of 0.2 or 1.1 m. The findings thus quantify the penalties of too shallow groundwater and the potential benefits of groundwater at 0.4-1.5 m depth.

Soil tests for choosing postrice tillage method (*Soils*). Choice of postrice tillage method from options in Table 6 might be guided by the soil classes defined in Table 2. Thus, soils in Classes 1 and 2, though ideal for rice, need drainage to decrease salinity, and gypsum to lessen exchangeable sodium.

Puddled Class 3 soils include the soils of our three IRRI experiments and of Guimba, Santa Rosa, and Victoria soils. They have few large pores through which air may enter to initiate cracking as they begin drying. Cracks are therefore widely spaced (about 20 cm apart) with dense aggregates in between, and further cracking occurs only after drying to −3 MPa water potential, when plant-available water in 0-30 cm would have evaporated. Such soils, therefore, should benefit from deep tillage that creates root-exploitable fractures at potentials less negative than −3 MPa.

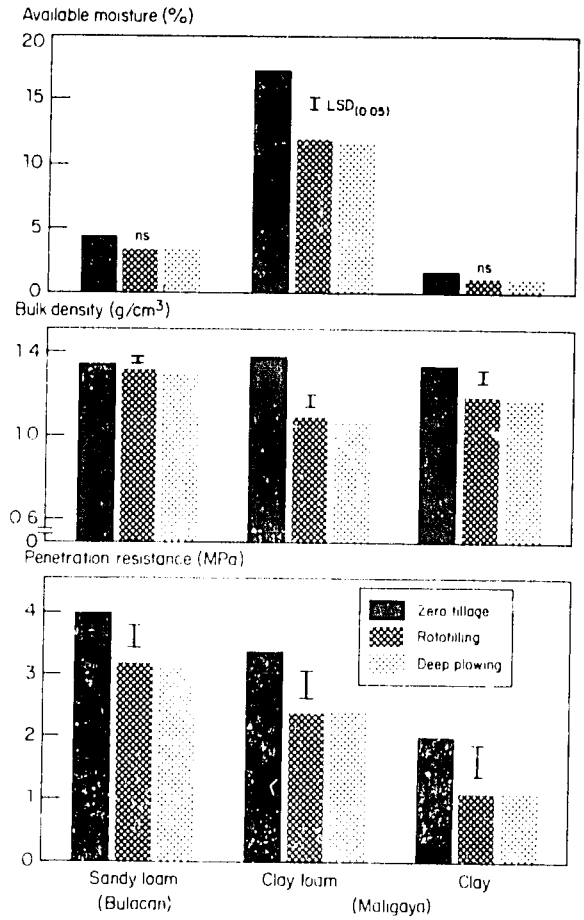
Surface soils in Classes 4 and 5 may restructure themselves naturally during drying to give usable seed zones, and their subsoils may crack sufficiently to help root proliferation. For Class 5, there may be need to increase available-water-holding capacity.

Soils of Classes 6 and 7 are too permeable for wetland rice.

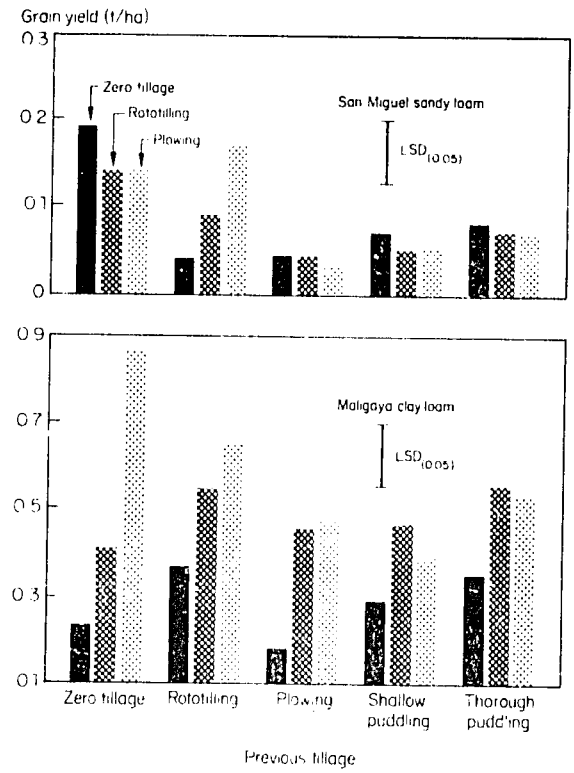
Interactions of soil texture and wetland tillage with postrice tillage for maize and legumes (*Agronomy*). This study examined how tillage history, water regime, and soil texture affect tillage requirement for nonirrigated dryland crops after rice. In 1987 DS, maize (DMR Composite 1) and mungbean (M350) were planted in three Central Luzon soils: San Miguel sandy loam (Aeric Tropaquept), Maligaya clay loam (Vertic Tropaquept), and Maligaya clay (Vertic Tropaquept). At IRRI, maize was the test crop on two soils: Lipa clay loam and Maahas clay (Andaqueptic Haplaquoll).

In Central Luzon, a severe drought resulted in low maize yield. In Maligaya clay, maize and mungbean gave zero yields because a very narrow soil moisture range for dry tillage resulted in zero soil-moisture availability (Fig. 11).

In coarse-textured San Miguel sandy loam and Maligaya clay loam, crops were sown immediately after rice harvest, thus enabling them to use the stored soil moisture. Maize in these soils performed relatively better in previously untilled soil than in previously tilled plots (Fig. 12), especially in San Miguel sandy loam.



11. Effect of tillage for the dryland crop after rice on seasonal average profile-available moisture, soil bulk density, and penetration resistance in 3 soils in Central Luzon, Philippines, 1987 DS.

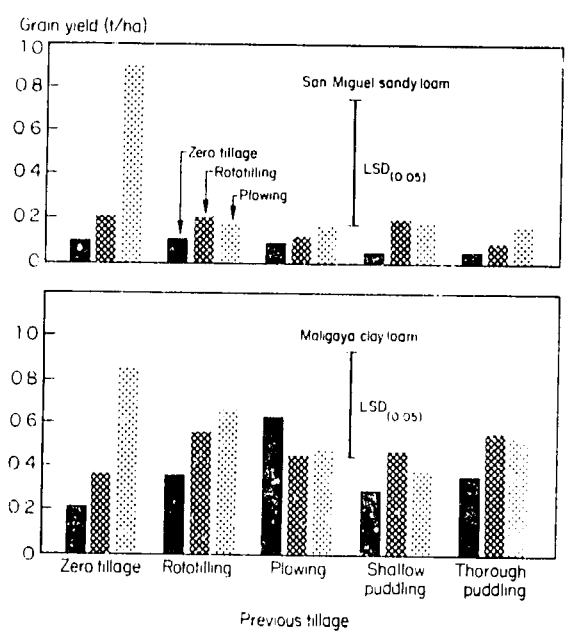


12. Effect of tillage on maize *Zea mays* L. after rice in 2 lowland soils in Central Luzon, Philippines, 1987 DS.

Available seasonal profile moisture was highest in Maligaya clay loam (Fig. 11). This allowed higher yields for both crops than those in San Miguel sandy loam (Fig. 12, 13). Similar mungbean yield was obtained by plowing previously untilled or rototilled clay loam soil. In sandy loam, only plowing previously untilled plots produced substantial mungbean yield (Fig. 13).

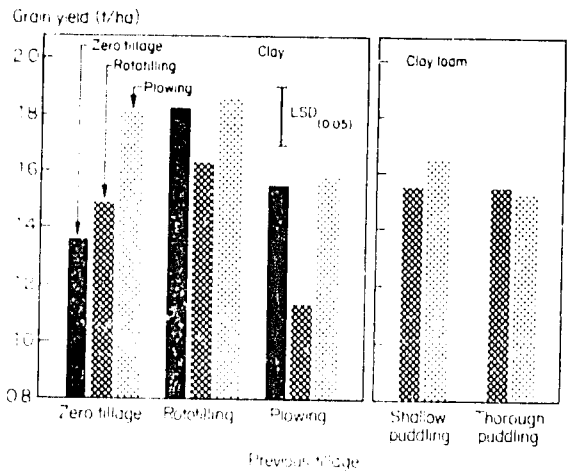
Effects of rototilling for dryland crops on soil physical parameters (Fig. 11) were always similar to those of deep plowing.

At IRRI, in a moderately severe DS, tillage was not required to alleviate soil physical constraints for maize in permeable medium-textured soil like Lipa clay loam (Fig. 14). In Maahas clay, tillage



13. Effect of tillage on mungbean *Vigna radiata* L. after rice in 2 lowland soils in Central Luzon, Philippines, 1987 DS.

was not required for growing maize in previously rototilled plots, but was needed in previously untilled plots.



14. Effect of tillage on maize *Zea mays* L. after rice in 2 lowland soils on the IRRI farm, 1987 DS.

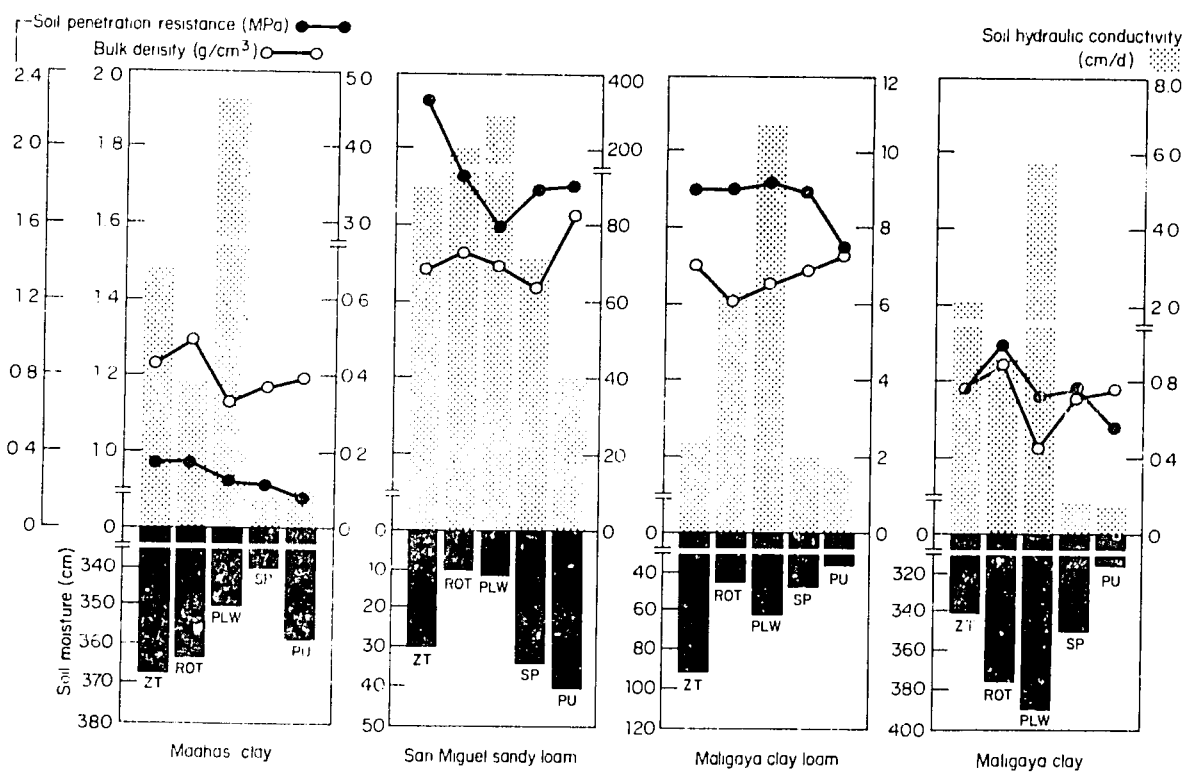
WEATHER AND TILLAGE INTERACTIONS FOR RAINFED LOWLAND RICE

Agronomy Department

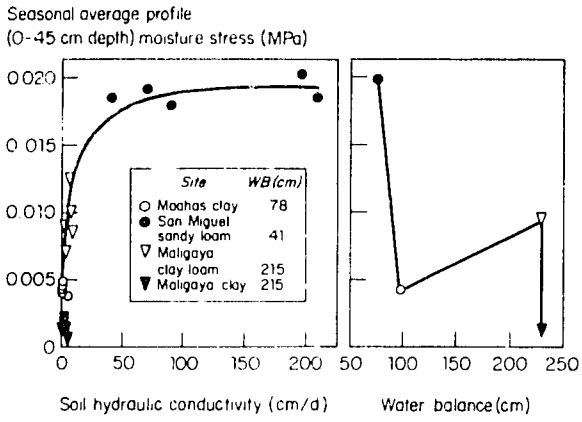
Tillage effects on four lowland soils and rice response to water balance (WB) (defined as the difference between cumulative rainfall amount and evaporation) were studied in 1986 WS. The objective was to understand factors that determine soil and plant responses to tillage in each production system.

Five tillage treatments were 1) zero tillage (spraying of glyphosate at 1 kg ai/ha), 2) rototilling, 3) conventional animal plowing, 4) shallow puddling, and 5) thorough puddling. Soils were Maahas clay (Andaqueptic Haplaquoll), San Miguel sandy loam (Aeric Tropaquept), Maligaya clay loam (Vertic Tropaquept), and Maligaya clay (Vertic Tropaquept).

Conventional animal plowing increased saturated hydraulic conductivity (Ks) in all four soils (Fig. 15). With high WB (>100 cm), increasing



15. Effect of tillage on soil physical properties and profile seasonal moisture regime in 4 lowland rice soils, Philippines, 1986 WS. ZT = zero tillage, ROT = rototilling, PLW = conventional plowing, SP = shallow puddling, PU = thorough puddling.



16. Effect of soil hydraulic conductivity and water balance (WB) on seasonal moisture stress at 0-45 cm soil depth, Philippines, 1986 WS. WB = (rainfall) - (evaporation).

tillage intensity decreased soil strength but did not consistently affect the soil profile's seasonal matric water content. With low WB (<100 cm), conventional plowing achieved the most favorable soil tilth, but this did not lead to higher yields.

Table 8. Effect of tillage on grain yield of IR20 in 4 lowland soils. Philippines, 1986 WS.

Tillage	Grain yield (t/ha)			
	Maahas clay	San Miguel sandy loam	Maligaya clay loam	Maligaya clay
Zero tillage	4.31 a	1.23 b	1.22 a	3.12 a
Rototilling	4.60 a	1.54 b	1.30 a	3.24 a
Conventional plowing	4.31 a	1.54 b	1.20 a	3.31 a
Shallow puddling	4.86 a	2.04 a	1.35 a	4.44 a
Thorough puddling	4.45 a	2.04 a	1.39 a	3.10 a

Decreasing the hydraulic conductivity improved the profile moisture retention in San Miguel sandy loam (Fig. 16) but not in Maahas clay, which has a shallow water table (<30 cm), or in soils with high WB. Tillage affected grain production only in sandy loam (Table 8), with wet tillage treatments giving highest yields.

Climatic environment and rice

International Rice Testing Program and Soils and Entomology Departments

VARIETAL RESPONSES TO CLIMATIC STRESSES IN IRTP TRIALS **416**

AGROHYDROLOGY OF UPLAND RICE AND LEGUMES, AND SIMULATIONS OF STEM BORER DAMAGE BY DETILLERING **416**

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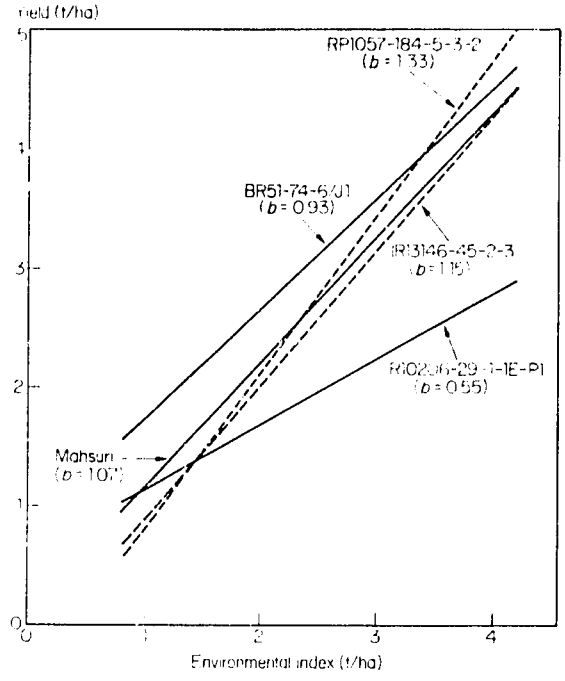
VARIETAL RESPONSES TO CLIMATIC STRESSES IN IRTP TRIALS

International Rice Testing Program

The 1986-87 multilocation trials of the International Rice Testing Program (IRTP) identified several breeding lines and varieties tolerant of various climatic stresses. Complete results are published separately in the annual IRTP nursery reports. Some of the entries that performed well across locations against various stresses are as follows:

- *Drought tolerance*
  - From rainfed lowland nurseries: Mahsuri, IR13610-72-2-2E-P2, KDML65-GU-45, IR21064-48-2-1E-P1, KKN7205-39-3-SKN-1-1-1, RP1064-14-2-2, IR13149-43-2-P1, IR13610-72-2-2E-P2
  - From upland nurseries: IR25588-7-3-1, IR43, China 988, CR222-MW10, IRAT112, IAC164, NDR116, NDR117, CR115-5029-216, IAC233/79, IR18599-68-1, IR2307-247-2-2-3, IR25890-82-5-3, IR25898-57-2-3, KMP34, IR9761-40-3-2, KU82, NDR102, NDR111, NDR118, NDR80, Palghar 31-1-3, UPR231-28-1-2
- *Submergence tolerance*: IR18272-27-3-1-2-2, FR13A, RTN15-2-1-1-1, BH2, BRB11-461-1, BR11, BR113-47-1-2-1-2, BR229-B-88, CN505-5-3-1, Dudkalash, Tilakkachari, BR222-B-358, IR5857-4-1E-3, Jalaplaban, NC487-77
- *Low temperature tolerance*: JKAU(K)450-126-10, JKAU(K)450-126-2, Ching shi 15 (Acc. 36852), JKAU(K)450-172-10, Z-Yah-Tsan (Acc. 4648), Akiyudaka, Suweon 303

BR51-74-6 J1, a medium-duration entry from Bangladesh in the 1986 International Rice Rainfed Shallow Water Yield Nursery (IRRSWYN), showed good tolerance for salinity. Analysis of yields obtained over 9 sites indicated that it has good yield potential combined with stable performance (Fig. 1).



1. Regression of yields of 5 selected varieties on site means (18 varieties, 9 sites), 6th IRRSWYN-Medium, 1986.

AGROHYDROLOGY OF UPLAND RICE AND LEGUMES, AND SIMULATIONS OF STEM BORER DAMAGE BY DETILLERING

Soils and Entomology Departments

Toposequence water balance and yield of upland rice. For upland rice grown along a gently sloping hill toposequence, 1983-86 wet season (WS) experiments determined the conditions under which uptake of shallow groundwater can increase growth and yield. The 1986 and 1987 experiments also sought to evaluate two numerical simulations: UPRICE, for growth, yield, and water relations of upland rice along a toposequence; and UPRIPE, a variant of UPRICE that predicts yield loss due to stem borers. Data against which to test UPRIPE were obtained in 1986 and 1987 by artificial detillering of chosen proportions of rice plants on designated plots at specific growth stages; in 1986, detillering was mechanical, and in 1987 mechanical and chemical (herbicide injection) detillerings were compared.

Experiments in 1987 used the same field (Typic Hapludoll soil) and the same rice variety (IR36) as in 1986. For the agrohydrology studies, the 1987 experiment measured rice growth and yield at 5 toposequence elevations and hence at 5 water table regimes (compared with 3 in 1986); however, the 2 lowest elevations differed by a few centimeters only, as did the 2 highest (Table 1). The detillering studies were confined to Elevations 1A and 1B, so that effects would not be confounded by variations in depth to groundwater. Elevations 1A and 1B each comprised 9 plots, and the higher elevations 5 replicate plots, all measuring 9 × 11 m. To lessen soil erosion, vertical wooden boards were placed

Table 1. Relative elevation, soil moisture content (0-10 cm depth) at rice seeding, and upland IR36 total dry matter and grain yields, for 5 toposequence positions in Field UQ2, IRRI, 1987 WS.

Position/ elevation code	Elevation[a] (cm)	Soil moisture[b] (g/g)	Total dry matter[b,c] (t/ha)	Grain yield[b] (t/ha)
1A	0	0.37	4.4	0.69
1B	14	0.34	4.8	1.06
2	54	0.34	4.7	0.69
3A	80	0.35	5.5	1.07
3B	97	0.36	5.3	1.06
SE	±2	±0.01	±0.2	±0.11

[a]Zero is defined as mean elevation for position 1A. [b]Mean of 5 replicate plots at each elevation. [c]Average of measurements at 10 and 12 wk after seeding.

between and upslope of all plots. Detillering was at 3 growth stages (maximum tillering [MT], panicle initiation [PI], and grain filling [GF]), at 3 intensities (0, 15, and 30% of tillers destroyed). Detillering at PI was by two methods (cutting by scissors, and herbicide injection into the growing point).

Land preparation consisted of 1 rototilling and 2 harrowings, with basal fertilization at 60-30-30 kg NPK/ha, and an additional 30 kg N/ha as foliar urea spray at MT (49 d after seeding [DAS]). IR36 seeds were sown by hand on 17 Jul 1987 into furrows opened by a lithao. Plots were hand weeded at 17, 32, and 60 DAS, and insects and diseases were controlled by appropriate sprays. Soil and crop variables needed for the simulations were monitored weekly or biweekly.

Hydrologically, 1987 WS was exceptionally dry: rainfall of 5 mm or more occurred on only 27 d, and rain of 1 mm or more on fewer than half the growing season days; total WS rainfall (632 mm) was only 60% of the long-term mean (Table 2). In consequence, water tables at all elevations were generally deeper than 0.8 m, and frequently deeper than 1.2 m—except during brief periods following typhoons. Results from 1983-86 experiments predicted that such water tables are too deep to affect rice growth, and the measured 1987 total dry matter and grain yields (Table 1) confirmed this prediction. Yield was low at Elevation 1A in part because of seedling submergence, and at Elevation 2 because of shallower depth of fertile soil.

Average grain yield in 1987 was only 1.0 t/ha—considerably less than the 2.9 and 2.6 t/ha from the same plots in 1985 and 1986. The harvest index in 1987 was particularly low (average 0.14), and only 36% of grains were filled. Leaf area index at 8 wk after seeding similarly was smaller (2.4) in 1987 than in 1985 (3.3) or 1986 (2.7) (all ± 0.2). The low growth, yield, and harvest index were due to the lack of rainfall: rice plants wilted from 88 DAS. But IR36 planted 2 wk earlier (in a supporting study located between Elevations 1B and 2) yielded 2.4± 0.1 t/ha.

Soil and crop data against which to test the UPRICE simulation were recorded throughout the growing season: initial seed-zone moisture was similar at all elevations (Table 1); soil moisture at various depths thereafter varied in response to crop-water abstraction, rainfall, and water-table fluctuations. Values for absorbed photosynthetic irradiance were similar at all elevations—although slightly higher at elevations 3 and 4, probably reflecting nutritional rather than hydrological causes. The formulation of UPRICE was extensively revised during 1987 following intensive tests of the model and its subroutines, and a new version became operational at year's end.

Table 2. Hydrological features of 1983, 1984, 1985, 1986, and 1987 WSs.

Year	Crop season	Season's total rainfall (mm)	Season's no. of days of rain > 1 mm	Season's no. of days of rain > 5 mm
1983	1 Jun-30 Sep	1158	64	39
1984	1 Jun-30 Sep	910	72	48
1985	1 Jul-31 Oct	1616	68	48
1986	18 Jul-3 Nov	1689	73	55
1987	17 Jul-30 Oct	632	49	27
1960-84	1 Jun-30 Sep	1034	67	42

Simulated stem borer damage in upland rice. Measurements in 1986 showed that IR36 yield was barely affected by mechanical detillering at MT. For detillering at PI or during GF, yield-loss percentage was equal to the percentage (15 or 30%) of tillers removed. Yield loss due to artificial detillering was larger in 1987 than in 1986. Moreover, for tiller cutting, yield-loss percentages were similar for cutting at MT, PI, and GF (Table 3), and were greater than the percentages of tillers removed. The effects of detillering may have interacted with water stress. Herbicide injection caused proportionately larger yield losses than tiller cutting, possibly because the herbicide was translocated to nontarget tillers.

Table 3. Decrease of upland IR36 grain yield resulting from detillering by mechanical cutting and by herbicide injection, IRRI, 1987 WS.

Method and time of defoliation	Grain yield decrease[a] for detillering intensity of			
	15%		30%	
	t/ha	%	t/ha	%
Cutting at maximum tillering	0.41	47	0.48	55
Cutting at panicle initiation	0.39	44	0.47	53
Injection at panicle initiation	–[b]	–[b]	0.79	90
Cutting at grain filling	0.45	51	0.52	59

[a]Grain yield with no detillering = 0.88 ± 0.18 t/ha. [b]Not measured.

PRODUCTION BENEFITS FROM SOIL EROSION CONTROL IN UPLAND AND RAINFED LOWLAND WET SEASON CROPPING

Soils Department

Soil erosion on sloping lands can be controlled by contour-planted bands of perennial grass such as *Panicum maximum*; such control is needed for both upland rice and nonrice crops. Alternatively, but at higher initial cost, nonbunded sloping land in suitable rainfall regimes can be protected if it is terraced, bunded, and puddled to allow rainfed lowland rice production. By lessening rainfall runoff as well as soil erosion, grass bands and terrace bunds may also conserve rainfall where it falls, and thus increase the reserve of soil water available for crop production. Conversely, in wet seasons of high rainfall, impounded water may injure or kill nonrice crops through submergence and waterlogging; and in dry years, total rainfall and its distribution may be insufficient to allow puddling and transplanting, and rainfed lowland rice production is nil. The choice of crop and land management that will give higher production in a particular year will therefore depend on that year's WS rainfall pattern. A livelihood- and soil-conserving strategy for the farmer may therefore consist of parallel along-slope strips of land allocated among upland (nonbunded) rice, rainfed lowland (bunded) rice, and (nonbunded) nonrice crops, but with the nonbunded land being protected by grass bands.

A medium-term experiment started in 1987 on a 2% hillslope of previously nonpuddled loam soil therefore seeks to determine, during a succession of wet seasons, what benefits of moisture conservation and crop production derive from the grass bands, and what the relative productions of upland rice, rainfed lowland rice, and legumes are. The five treatments are rainfed lowland rice, upland rice grown with and without grass bands, and mungbean with and without grass bands. Within each of 4 replicate along-slope blocks of 66 m length, each treatment occupies a strip 3.6 m wide, extending the whole block length, with each strip consisting of six 11-m-long plots delimited at their sides by wooden boards and at their ends by bunds, grass strips, or marker strings, depending on treatment. Within each plot, soil variables, including depth to water table, and crop growth and yield are measured.

In 1987, the water table, was for all plots in this experiment, too deep to affect crop growth—as it was also in the previously reported study of water balance for upland rice. But measurements of soil matric water showed that, throughout the crop season, plots with grass bands had a moisture content consistently higher than that of plots without bands, to the extent that within the 0-40 cm layer there was in the grass-banded strips an additional 10 mm of plant-available water—a significant augmentation of that layer's available water-holding capacity of about 60 mm, and of the root-zone water capacity of about 120 mm.

This additional water generated numerical but nonsignificant increases in upland rice and mung-

bean production (Table 4); unfortunately, these slight increases would to some extent be offset by the roughly 20% decreases in rice and mungbean production caused by intercrop competition in the rows immediately next to the grass strips. However, the value of mungbean production (about $500/ha) was significantly 5 times greater than for upland rice, for which yield at 0.8 ± 0.1 t/ha (Table 4) was as low as in the previously reported water balance experiment. (The yield of nonfertilized IR36 on an adjacent field that was planted 7 d earlier was 1.0 ± 0.1 t/ha.) Moreover, the pattern of rainfall at IRRI in 1987 WS—as in much of the Philippines—was insufficient to allow puddling and transplanting, so production from the bunded rainfed lowland strips was zero. But 1987 WS was unusually dry, and in much wetter years, mungbean may have been destroyed, and best income achieved from rainfed lowland rice.

Natural water tables in 1987 WS were too deep to affect rice and legume production; however, shallower water tables were generated in the field and maintained at a range of fixed depths using a novel system of 2 parallel ditches, 15 m apart, with 1 ditch continuously filled by water, the other continuously drained at 2.0 m depth; crops were seeded in between the ditches, into soil wetted to field capacity, but with no subsequent surface irrigation. The system generated a less useful range of field water-table depth (WTD) than was intended: the shallowest WTD achieved was 0.7 m in WS and 0.5 m in dry season (DS). Nonetheless, for WS upland IR36, plant height at maturity was constant for 0.7 m < WTD < 0.85 m and decreased by 0.4% of mature height for each cm that WTD exceeded 0.85 m; yield, however, showed no such dependence on WTD. In DS, IT82D-889 cowpea had a constant yield of 0.9 ± 0.1 t/ha for 0.5 m < WTD <0.7m and a yield decrease of 0.1 t/ha for each 6 ± 2 cm that WTD exceeded 0.7 m; for CES1d-21 and M79-13-60 mungbean, yield was 1.1 ± 0.1 t/ha for 0.5 m < WTD < 0.7 m, and decreased by 0.1 t/ha for each 10 ± 2 cm that WTD exceeded 0.7 m.

Table 4. Grain yield and grain value[a] from alternative upland crops and erosion control management practices. IRRI, 1987 WS.

Crop	Erosion control practice	Yield (t/ha)	Estimated grain value ($/ha)
Lowland rice	Bunds	0	0
Upland rice	None	0.72 ± 0.06	90
Upland rice	Grass bands	0.82 ± 0.06	100
Mungbean	None	0.85 ± 0.03	510
Mungbean	Grass bands	0.87 ± 0.03	520

[a]Assuming $0.12/kg for rice and $0.60/kg for mungbean.

Consequences of new technology

Agricultural Economics Department

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DIFFERENTIAL ADOPTION OF MODERN VARIETIES AND LABOR MARKET ADJUSTMENT

The adoption of modern rice technology, particularly modern varieties (MVs), is constrained by environmental conditions, especially the degree of water control. As a result, the productivity gap between favorable and unfavorable rice production environments has widened throughout South and Southeast Asia over the last two decades. The fear has been widely expressed that modern rice technology has created large disparities in the regional income distribution.

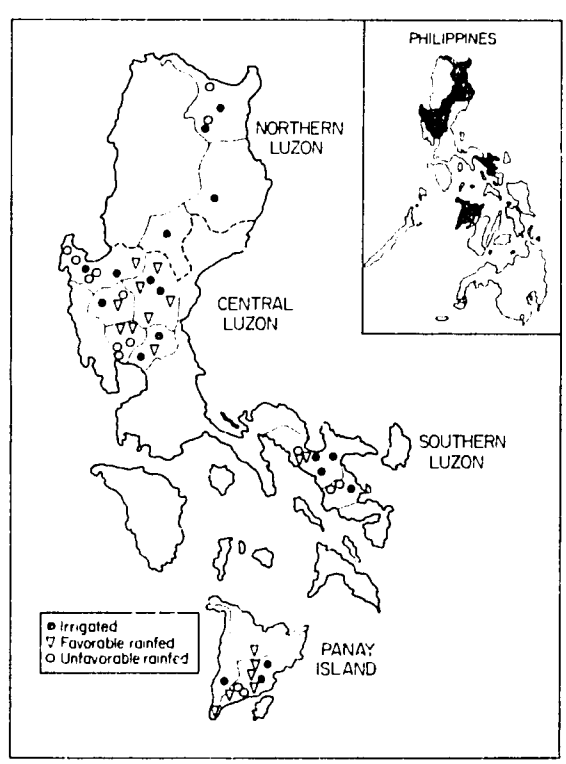
In 1987, the Agricultural Economics Department organized collaborative research among seven Asian countries Philippines, Indonesia, Thailand, Bangladesh, India, Nepal, and China to assess the distributional consequences of the differential adoption of modern rice technology across different production environments. The research considers the direct as well as the indirect effects of technical change on the well-being of both farm and landless households, particularly in the unfavorable areas bypassed by new technology.

Technology affects the farm population's income directly through its effects on productivity and factor use, and indirectly through its effects on output and the labor, land, and credit markets. The ultimate distributional impact of modern rice technology will critically depend on the adjustment of the labor market, since labor is the most mobile production factor and the main production resource owned by the landless households constituting the poorest segment of the rural population.

It is hypothesized that, as new technology is adopted in irrigated areas, increased demand for labor will induce permanent and seasonal migration from unfavorable to favorable regions, reducing the interregional income disparity initially created by the differential adoption of modern rice technology. It could also increase the labor supply in favorable areas through greater participation by women, or it could lead to the adoption of mechanical or other labor-saving technologies. While these labor market adjustments will tend to equalize wages between favorable and unfavorable areas, they will have different implications on the level of wages and employment, and thus on income distribution.

This report presents an empirical test of whether the differential adoption of modern rice technology has induced interregional migration so as to equalize regional wage income based on two sets of Philippine data. The first is an extensive survey of 50 villages from representative production environments, i.e., irrigated, favorable rainfed, and drought- and flood-prone rainfed areas, encompassing northern, central, and southern Luzon and Panay Island (Fig. 1). Two or three interviews were conducted with a group of knowledgeable farmers in each village to obtain data relating to demographic factors, production environment, technology, and output and input market characteristics of each village in 1970, 1980, and 1986.

The second set of data is based on an intensive survey of 300 farm households and 96 landless households in 5 villages in Nueva Ecija and Iloilo Provinces, referring to 1985. Two of these villages (Maragol in Nueva Ecija and Pandan in Iloilo) are irrigated, allowing two rice crops a year. The three others (Gabaldon in Nueva Ecija, and Rizal and Signe in Iloilo) are basically rainfed areas, with



1. Distribution of sample villages by environmental conditions, Philippines, 1987.

varying favorableness for rice growing. In addition to data on demographic characteristics, data on migration history, land tenure patterns, input use, yields, factor prices, and time allocation were also collected. We have presented the analysis of the impact of the new technology on productivity based on this intensive survey (Annual report for 1986). Here we have used the data primarily to examine the impact of new technology on the nature of labor demand and the migration history of landless households. The extensive survey data provided a broad picture of wage patterns, demographic characteristics, technology, and production environments to analyze the labor market adjustment hypothesis.

Direct impact of new technology on labor demand. A large number of farm-level studies on the impact of new rice technology on rural labor markets have shown significant effects on the structure and operation of rural labor markets. Modern rice technology increases demand for labor directly through its effect on rice cropping intensity and labor requirements per rice crop. Technical change in rice also contributes to greater labor demand in the nonrice sector. Through intersectoral growth linkage effects, rapid growth in farm income will have strong growth and multiplier effects on the rest of the economy, because the bulk of expenditures in the rural sector are for food and labor-intensive industrial goods. Moreover, because rice is a critical wage good, cheaper rice resulting from greater supply will lower the price of labor relative to capital and will raise the competitive position of the country's labor-intensive industrial sector vis-à-vis the rest of the world, increasing total employment.

The major employment generation effect of modern rice technology comes from its effect on cropping intensity. Modern rice varieties have raised the profitability of investments in irrigation, leading to accelerated construction and rehabilitation of public irrigation systems during the late 1960s and early 1970s that increased the water supply during the dry season (DS). Together with the photoperiod insensitivity of MVs, which ensures the profitability of DS cultivation, rice cropping intensity has increased since 1970. Moreover, the early maturity of MVs made it possible to grow two rice crops during the wet season (WS) in rainfed areas, notably in Panay Island and in southern Luzon, where the rainfall pattern is more even than in northern and Central Luzon.

The adoption of MVs also increases labor demand by raising the labor requirements for weeding, fertilizer application, harvesting, and threshing. However, the adoption of yield-increasing MV technology was followed by the adoption of labor-replacing mechanical technology in land preparation and threshing. Direct seeding, which saves time and labor, is another labor-replacing technology that has been gradually adopted this past decade. In some areas such as Iloilo, direct seeding did not reduce overall labor demand because it was adopted in conjunction with short-duration MVs that enabled a second crop to be planted. But in many areas in Luzon, direct seeding and herbicides were adopted simply to reduce the cost of hired labor as a response to rising wages relative to rice prices.

Data from the intensive-survey villages indicate that farms in favorable areas generally employ higher labor input per hectare than those in unfavorable areas in both WS and DS (Table 1). This is so despite the observation that adoption of tractors for land preparation, and use of herbicides, both labor-replacing technologies, are higher in irrigated areas and lowest in the less favorable areas. The exception is Signe, where the high labor input is explained by the continued use of draft animals for land preparation. Signe has a mountainous terrain that makes it very costly to transport machines across fields.

To identify the impact of new rice technology, a labor demand equation in log-linear form was estimated econometrically. Assuming wages and other prices as exogenous, farm-level labor input was assumed to depend on the real wage rate, biological technology (irrigation and MVs), labor-replacing technology (tractors, threshers, direct seeding), farm size, season, and use of hand weeding through *sagod* or *gama* labor contract arrangements.

Table 2 shows a high goodness of fit for the regressions made separately by season and by combining both seasons. Except for MVs and threshers, all the coefficients for independent variables are statistically significant and have the expected signs. The effect of MVs cannot be effectively distinguished from that of irrigation

Table 1. Labor (labor-days/ha) and modern technology (%) used for activities classified by production environment, based on intensive surveys of 5 Philippine villages, 1985 WS and DS.

Activity or technology	WS					DS				
	Favorable or semifavorable			Unfavorable		Favorable or semifavorable			Unfavorable	
	Maragol	Pandan	Gabaldon	Rizal	Signe	Maragol	Pandan	Gabaldon	Rizal	Signe
Land preparation (d/ha)	15	13	15	17	31	13	14	19	20	23
Farms (%) using hand tractors	93	92	78	38	0	92	94	58	5	0
Crop establishment (d/ha)	28	5	18	5	24	19	4	9	5	11
Farms (%) using direct seeding	21	84	50	97	52	70	84	83	95	73
Care of crops (d/ha)	6	28	8	7	9	9	31	10	12	17
Using herbicide (%)	81	84	61	75	20	83	93	92	79	14
Using *sagod*[a] (%)	0	59	0	0	0	0	37	0	0	0
Harvesting, threshing, and postharvest activities (d/ha)	37	35	36	31	27	33	28	37	23	25
Using mechanical thresher (%)	100	97	100	100	86	100	96	100	97	82
Others (d/ha)	1	5	2	2	1	3	2	3	0	3
All activities (d/ha)	87	86	79	62	92	77	79	78	60	79

[a]Labor market arrangement that gives the right to harvest a field to workers willing to hand-weed for the same share of the harvest.

because the two are highly correlated. Furthermore, farms planting MVs in rainfed areas have all adopted direct seeding so they can plant a second crop during DS, which may explain the negative, although insignificant, coefficient for MVs. If the variables have been expressed on an annual basis so that the effect of MVs on cropping intensity and its indirect effect on irrigation investments have been taken into account, MVs would have undoubtedly had a significantly positive effect on employment. In any case, in these crop season level regressions, the positive impact of MVs can be gleaned from the coefficient for irrigation, which represents the combined effect of irrigation and MVs.

Table 2. Estimated elasticities of total labor demand based on intensive farm survey data from 5 Philippine villages, 1985.[a]

Variable	WS	DS	WS and DS
Wage-price ratio	−0.215	−0.153	−0.178
	(−4.890)**	(−3.471)**	(−5.949)**
Irrigation	0.011	0.024	0.014
	(2.438)**	(2.991)**	(3.589)**
Modern varieties	−0.006	−0.011	−0.011
	(−0.613)	(−0.722)	(−0.386)
Farm size	0.917	0.949	0.938
	(39.736)**	(33.057)**	(52.266)**
Thresher	0.004	0.020	0.013
	(0.285)	(1.148)	(1.163)
Tractor	−0.014	−0.012	−0.012
	(−2.825)**	(−1.675)*	(−2.975)**
Direct seeding	−0.026	−0.037	−0.030
	(−5.867)**	(−6.106)**	(−8.581)**
Sagod	0.015	0.037	0.024
	(1.862)*	(3.594)**	(3.767)**
Season	–	–	0.077
			(2.598)**
Intercept	4.996	4.803	4.845
	(42.986)**	(33.330)**	(56.042)**
$\bar{R}^2$	0.87	0.88	0.87
n	294	211	505

[a]t-values are given in parentheses. ** = significant at the 1% level, * = 5%.

Tractors and direct seeding, as expected, have significantly negative effects on employment. To the extent that direct seeding and shorter duration MVs allow a second crop to be planted, then its impact on labor use on an annual basis should be highly positive in at least a few locations in the Philippines. However, adoption of small threshers had apparently little effect on employment. This result, however, may be illusory rather than real, because nearly all farms in the sample were already using threshers.

Aside from a higher labor use per hectare in the favorable villages, the type of labor, i.e., family or hired, also differed by production environment. The irrigated villages of Maragol and Pandan had

higher proportions of hired labor than the unirrigated villages in Nueva Ecija and Iloilo, respectively, in both the WS and DS (Table 3). This could be due to higher returns to alternative employment opportunities for family labor, family labor constraint at peak periods, and the positive income effect generated by the higher income of farm households. The relatively high proportion of hired labor in favorable areas reflects greater income and employment opportunities, which may enable migrant workers from unfavorable areas to capture part of the income gains accruing to the favorable areas.

Demographic effects of modern rice technology. Have the benefits from increased demand for labor in rice and the nonfarm sector through indirect growth linkage effects in favorable areas been shared with the population in unfavorable areas? In the following sections, we attempt to answer this question by examining whether or not adoption of modern rice technology has induced migration of labor from unfavorable areas bypassed by technical change to regions with favorable production environments.

Data on migration rates were difficult to obtain. We therefore explored the extent by which differential adoption of modern rice technology has brought about differential growth in population and man-land ratios across different production environments so as to equalize the wage rate over time. The analysis implicitly assumes that differences in rate and direction of migration largely account for differences in population growth and man-land ratio.

Extensive survey. Extensive survey data indicate a similar relationship among adoption of MVs, production environment, and adoption of labor-replacing technologies as in the intensive-survey villages reported in the previous section and in the Annual report for 1986. Adoption of MVs (Table 4) was rapid in both the irrigated area and favorable rainfed areas, suggesting that the degree of water control during WS is not significantly different between the two areas. In contrast, the adoption of MVs in the unfavorable rainfed area characterized by severe flood- or drought-prone conditions was slow and much less complete. Among the irrigated villages, the irrigated area accounted for only 58% of the total area in 1970, but almost 100% in 1986, confirming that the massive investments in irrigation were made during the 1970s. A small portion of the total area in the rainfed area was irrigated by pumps and natural creeks.

Table 3. Composition of labor use[a] (labor-days/ha) based on an intensive survey of 5 Philippine villages, 1985 WS and DS.

Activity	Favorable				Semifavorable		Unfavorable			
	Maragol		Pandan		Gabaldon		Rizal		Signe	
	Family	Hired	Family	Hired	Family	Hired	Family	Hired	Family	Hired
				Wet season						
Land preparation	11	4	3	10	12	3	10	7	28	3
Crop establishment	5	24	1	4	4	14	1	4	16	9
Crop care	5	1	6	22	8	0	5	2	8	0
Harvesting, threshing, and postharvest	8	29	3	32	10	26	4	27	4	23
Others	1	0	5	0	2	0	1	0	1	0
All activities	30	58	18	68	36	43	21	40	57	35
Percent of total labor	(34)	(66)	(20)	(80)	(46)	(54)	(34)	(66)	(62)	(38)
				Dry season						
Land preparation	7	3	4	10	17	2	12	7	23	1
Crop establishment	4	15	1	2	3	1	2	3	6	4
Crop care	7	2	6	25	8	2	9	4	17	0
Harvesting, threshing, and postharvest	3	29	2	27	7	30	4	19	5	20
Others	3	0	2	0	3	0	0	0	3	0
All activities	24	49	15	64	38	35	27	33	54	25
Percent of total labor	(33)	(67)	(19)	(81)	(53)	(47)	(45)	(55)	(69)	(31)

[a]Family labor includes exchange labor at all sites.

Table 4. Changes in adoption of modern rice technology by production environment based on an extensive survey of 50 Philippine villages.[a]

Parameter	Irrigated	Favorable rainfed	Unfavorable rainfed
Sample size (no.)	17	17	16
Irrigation (%)			
1970	58	4	1
1980	84	7	2
1986	97	8	2
Modern varieties (%)			
1970	38	29	16
1980	89	95	41
1986	97	98	40
Tractor (%)			
1970	37	24	8
1980	63	43	39
1986	76	56	38
Thresher (%)			
1970	28	37	30
1980	66	75	62
1986	93	95	86
Direct seeding (%)			
1970	2	3	27
1980	24	33	22
1986	33	51	19

[a]Except for irrigation, data refer to WS.

Table 5 shows the pattern of population growth across production periods since 1970 and its impact on the population density. During 1970-80, when MVs were rapidly disseminated and investments in irrigation accelerated, the population growth rate was highest in the irrigated area (implying net in-migration) and lowest in the unfavorable rainfed area (implying net out-migration). For 1980-86, when MV technology adoption had largely tapered off, the average population growth rates among the three production environments became much more similar. Reflecting the differential population growth rates, man-land ratio increased most rapidly in the irrigated area and least rapidly in the unfavorable rainfed area, suggesting the significant effects of technology factors on demographic change.

The land reform program, which prohibits the transaction of a tenancy title to "protect" the tenancy right, has been widely implemented in irrigated and favorable rainfed areas. This policy has prevented the downward adjustment in farm size in favorable areas which could have been induced by in-migration of farm population from unfavorable areas as evidenced by the similarity in

Table 5. Population growth rate, man-land ratio, and ratio of landless households by production environment based on an extensive survey of 50 Philippine villages.

Parameter	Irrigated	Favorable rainfed	Unfavorable rainfed
Average annual population growth rate (%)			
1970-80	2.89	2.03	1.07
1980-86	1.67	1.63	2.14
1970-86	2.45	1.90	1.46
Man-land ratio (persons/ha)			
1970	4.26	4.01	3.66
1980	5.59	4.93	4.08
1986	6.29	5.13	4.70

farm size among the three production environments. Indeed, in the intensive survey, farm size was even smaller in the unfavorable area, where implementation of land reform has been weaker. Because of population pressure and the general contraction of the Philippine economy, reverse migration from the lowlands to the unfavorable upland areas has been reported in migration studies based on national census data. Table 5 also shows a higher population growth rate in the unfavorable rainfed area in the 1980s in contrast to the 1970s.

To identify the impact of new technology on demographic changes, the following regression equation was estimated:

$$\Delta MLR = a_0 + \Sigma_i a_i \Delta X_i$$

where ΔMLR is a change in man-land ratio between two points in time, a's are regression coefficients, and ΔX's are corresponding changes in the adoption rates of technologies.

This above equation was estimated separately for 1970-80 and 1980-86. Besides the technology variables, three regional dummies in addition to the man-land ratio in the initial year were included in the regression to control possible effects of various nontechnology factors. Furthermore, to check the robustness of the estimation results, a population growth rate equation using the same set of independent variables was estimated.

Table 6 presents the results of the estimation. As expected, the fit of the regression equation is better for 1970-80 than for 1980-86, because technology was more stagnant in the latter period. It is

Table 6. Regression coefficients for changes in man-land ratio and population growth rate based on an extensive survey of 50 Philippine villages, 1970-80 and 1980-86.[a]

Variable[b]	Changes in man-land ratio (persons/ha)		Av annual population growth rates (%)	
	1970-80	1980-86	1970-80	1980-86
MLR	.23**	.09	.02	−.13
	(5.68)	(1.43)	(.26)	(−.74)
Δ MV	.45*	1.24*	.99*	3.98**
	(1.77)	(1.99)	(1.92)	(2.42)
Δ IRR	.89**	−.10	2.56**	.29
	(3.04)	(−.12)	(4.31)	(.13)
Δ TRACT	−.09	.54	−.40	.94
	(−.34)	(.87)	(−.72)	(.57)
Δ THRESH	.02	.06	.22	1.12
	(.08)	(.15)	(.45)	(1.01)
Δ DS	.84**	−.49	1.39*	−2.06
	(2.45)	(−.72)	(2.02)	(−1.15)
R^2	.61	.33	.52	.37

[a]t-values are in parentheses. ** = significant at the 1% level, * = 5%. All technology adoption variables are expressed in terms of ratios, which fall between zero and unity. Three regional dummies are also included in the regression [b]MLR = man-land ratio in initial year; Δ MV = adoption rate of modern varieties in 1980 for 1970-80 regression and change in adoption rates between 1980 and 1986 for 1980-86 regression; Δ IRR = change in ratios of irrigated areas; Δ TRACT = change in tractor adoption rates; Δ THRESH = change in thresher adoption rates; Δ DS = change in adoption rates of direct seeding.

remarkable that coefficients for MVs are significantly positive in all equations. Coefficients for ΔIRR are significant only for the 1970-80 regression, because the irrigated area expanded in only three locations for 1980-86. MV adoption and the construction of irrigation facilities clearly attracted the migration flow to favorable areas in the 1970s. There appears little indication, however, that changes in mechanical technology and direct seeding affected the demographic change significantly.

Intensive survey. A similar analysis was conducted using the intensive survey data that provided 25 observations from 5 villages for 5-yr intervals between 1960 and 1985. Pooling these time-series cross-section data, the man-land ratio was specified as a linear function of irrigation, MVs, adoption of labor-replacing technology (i.e., tractors, threshers, and direct seeding), an index of inequality of distribution of land ownership, and a dummy variable indicating favorableness to rice growing. In contrast to the analysis based on the extensive survey, the variables here were not specified in terms of first differences of values, to have more degrees of freedom.

Table 7. Regression coefficients for factors affecting man-land ratio, based on an intensive survey of 5 Philippine villages from 1960 to 1985.[a]

MV	0.010*
	(1.929)
IRR	0.010*
	(1.425)
TRACT	−0.007
	(−0.563)
THRESH	−0.017*
	(−1.856)
DS	0.029**
	(3.275)
FAV	2.955**
	(3.816)
INQTY	−0.047**
	(−4.232)
R^2	0.91

[a]t-values are in parentheses. ** = significant at the 1% level, * = 5%.

Table 7 shows a highly significant fit of the equation to the data (R^2=0.91). Coefficients for MVs and irrigation are positive and statistically significant. Both tractors and threshers have negative signs, as may be expected from labor-replacing technology. However, the man-land ratio does not appear to be significantly affected by tractors, because tractors tend to be widely used in villages where the cropping intensity is higher. The positive coefficient for direct seeding also reflects the observation that, in our sample villages, particularly in Iloilo, direct seeding and cropping intensity were positively correlated. Villages where land ownership is unequally distributed tended to be less densely populated. This implies that migration is hindered by land regulations preventing changes in size of farm ownership or farm operation.

Factors affecting regional wage differentials. Although demographic changes are observed to be consistent with the hypothesis of interregional labor market adjustments, the extent to which such adjustments have contributed to the equalization of wage income can be explored only by an analysis of the regional wage differential. In theory, the wage differential between areas can be easily shown to reflect the costs of migration if the labor market adjustments are perfect; there is no

expected association *a priori* between the technology and wage rates cross-sectionally if the "perfect" labor market hypothesis is empirically acceptable. Therefore, as a null hypothesis, we postulate no technology effects on wage differentials against the alternative hypothesis that the adoption rate of MVs and the ratio of irrigated areas affect wage rate positively, whereas the tractor, direct seeding, and thresher have negative effects on wage rates.

Table 8 compares daily wages of various activities, together with daily bullock rental and thresher rental rate. Because the geographical mobility of the bullock is low, we hypothesize that its rental will be determined by local supply and demand conditions. Unlike the bullock, the thresher is mobile, so that the determination of its rental is expected to be largely free from local market conditions.

Thresher rental rates and daily wages, except the transplanting wage, which is lowest in the most favorable area, are largely similar across environments. In contrast, the daily bullock rental is highest in the most favorable area. Note also that imputed wages under piece rate contracts tend to be higher than the corresponding daily wages. This is consistent with the theory of contracts, which argues that daily wage workers are less motivated and less able.

Table 8. Daily wage, daily bullock rental, and thresher rental rates by rice production environment, based on an extensive survey of 50 Philippine villages, 1986 WS.

Activity	Rate		
	Irrigated	Favorable rainfed	Unfavorable rainfed
Land preparation with bullock (₱/d)			
Daily wage	35.5	34.6	33.8
Daily rental of bullock[a]	31.8	23.5	26.1
Transplanting (₱/d)			
Daily wage	22.1	24.8	29.2
Imputed wage[b]	25.8	21.4	–
Harvesting (₱/d)			
Daily wage	25.0	25.0	34.8
Imputed wage[b]	53.7	56.8	49.6
Threshing			
Imputed wage (₱/d)[b]	53.7	55.8	49.5
Rental rate of thresher (₱/100 kg)	9.7	9.8	9.9

[a]Rental without bullock operator. [b]Total wage payment divided by work-days under piece rate contract.

Estimation results of wage and rental regressions, which can be regarded as the reduced form relation between technology shifters and wage or rental rates, are shown in Table 9. No technology variable has any significant coefficient for wage and thresher rental regressions (except the MV variable in transplanting, of which the coefficient is negative), suggesting that the wage and thresher rental rates are largely equalized between favorable and unfavorable environments. For bullock rental, although the MV variable has no significant effect, the irrigation variable is highly significant. The fact that the wage rates are equalized but the bullock rentals are higher in irrigated areas strongly supports the hypothesis that the tractor is adopted more widely in irrigated areas not because wage rates are relatively higher but because the bullock is more expensive due to the lack of grazing land.

The negative coefficient for the MV variable in the transplanting equation does not imply that the adoption of MVs per se affects wage rates negatively. We have observed that in the unfavorable environment where traditional varieties are still grown, many farmers tend to transplant on the same day immediately after rain, because of poor water control. Therefore, the demand for transplanters will have a higher peak in unfavorable areas. Migrants, however, will not come, because transplanting dates are unpredictable. In any case, there is no indication that wage rates are higher in more favorable areas because of the higher adoption of modern rice technology.

Characteristics of landless households. Labor market adjustments induced by a differential rate of technology adoption will result in a higher ratio of landless households in favorable areas. This has been observed both in the extensive and intensive survey database (Table 10). If land reform regulations were not in place, as pointed out in the previous section, migrants from unfavorable areas could have been employed as share-tenants, reducing average farm size in favorable areas rather than increasing the ratio of landless households. Examination of the characteristics of the

Table 9. Regression coefficients for wage rates of major rice production activities, daily bullock rentals, and thresher rental rates, based on an extensive survey of 50 Philippine villages, 1986 WS.[a]

Variable	Wage (₱/d)				Bullock daily rental (₱/d)	Rental rate of thresher (₱/100 kg)
	Land preparation	Transplanting	Harvesting	Threshing		
MV	1.97	−6.77*	7.40	−.03	−3.32	.23
	(.50)	(−1.88)	(1.18)	(−.04)	(−1.06)	(.31)
IRR	3.14	−.93	−2.38	1.52	7.63**	−.17
	(.95)	(−.43)	(−.59)	(.37)	(2.87)	(−.40)
TRACT	−1.30	–	–	–	−5.47	–
	(−.28)				(−1.48)	
DS	–	−1.24	–	–	–	–
		(−.35)				
THRESH	–	–	–	1.62	–	−.68
				(.21)		(−.71)
R^2	.63	.29	.61	.22	.79	.72

[a]t-values are in parentheses. ** = significant at the 1% level, * = 5%. The following variables are also included in the regression: average farm size, price of rice, distance from Manila, piece rate contract dummy, and three regional dummies.

Table 10. Landless households (%) by rice production environment in the Philippines.

Environment	Extensive[a] survey	Intensive[b] survey
Irrigated	31	31
Favorable rainfed	18	28
Unfavorable	15	15

[a]Covered 50 villages. [b]Covered 5 villages.

landless households based on the intensive survey confirms our hypothesis regarding labor market adjustments.

Table 11 indicates that increases in the demand for labor in favorable villages including Gabaldon attracted landless workers even from distant areas. Most of the household heads in these villages were born in other villages, towns, and even provinces. In contrast, in the unfavorable areas, not a single person was born in another province. Therefore, the greater population pressure in favorable villages is due to in-migration rather than to differences in natural population growth.

Most of the household heads in the favorable villages arrived before 1980, whereas in the unfavorable areas many of them migrated during the early 1980s (Table 12). The arrival of most household heads occurred much earlier in Gabaldon, which is a relatively old settlement. Although it is generally a rainfed village with about 16% of its present area being supported by irrigation pumps, new technologies were adopted at least partially in

Table 11. Landless household heads (no.) by place of origin.[a]

Place of origin	Favorable		Semifavorable	Unfavorable	
	Maragol	Pandan	Gabaldon	Rizal	Signe
Within the village	22	20	14	12	5
	(39)	(35)	(29)	(52)	(46)
From the same province	15	23	16	11	12
	(26)	(40)	(33)	(48)	(54)
From other provinces	20	14	18	0	0
	(35)	(25)	(38)	(0)	(0)
Total	57	57	48	23	17

[a]Figures in parentheses are percentages.

Table 12. Migrant household heads (no.) by in-migration period.[a]

Period	Favorable		Semifavorable	Unfavorable	
	Maragol	Pandan	Gabaldon	Rizal	Signe
Before 1940	9	5	12	2	1
	(17)	(10)	(25)	(14)	(11)
1940-45	1	0	2	0	0
	(2)		(4)		
1946-50	2	1	1	0	0
	(4)	(2)	(2)		
1951-55	2	1	2	0	0
	(4)	(2)	(4)		
1956-60	0	5	1	0	0
		(10)	(2)		
1961-65	3	1	2	1	0
	(6)	(2)	(4)	(7)	
1966-70	6	6	10	1	2
	(11)	(12)	(21)	(7)	(22)
1971-75	12	10	4	1	0
	(22)	(20)	(8)	(7)	
1976-80	7	14	4	3	1
	(13)	(28)	(8)	(21)	(11)
1981-85	12	7	10	6	5
	(22)	(14)	(21)	(43)	(56)
Total	54	50	48	14	9

[a]Figures in parentheses are percentages.

the late 1960s. In Maragol and Pandan, the peak of in-migration among household heads occurred later than in Gabaldon, viz., during the 1970s. In Maragol, this period coincided with the rapid adoption of MVs after the Upper Pampanga River Irrigation System was made operational in 1974. Also, MVs were rapidly introduced in Pandan in this period. In unfavorable areas, the migrant landless laborers not only were very few but also arrived much later, after the modern technologies had been partially adopted.

Technical change induces labor migration. The analysis thus far suggests that differential technical change across production environments induces permanent and seasonal labor migration, that tends to equalize wages regionally. Benefits from technical change in favorable areas will be shared at least in part with the population from the unfavorable areas. The extent to which benefits are shared among regions depends crucially on the factor bias (whether labor-using or saving) of the new technology and equally on the operation of rural factor markets. Further research is being conducted on land and product market adjustments to complete our understanding of the distributional consequences of differential adoption of new technology in rice.

Cropping systems program

Analysis of the physical and biological environment

Multiple Cropping and Agronomy Departments

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HYDROLOGY IN RAINFED RICE-GROWING LANDFORMS

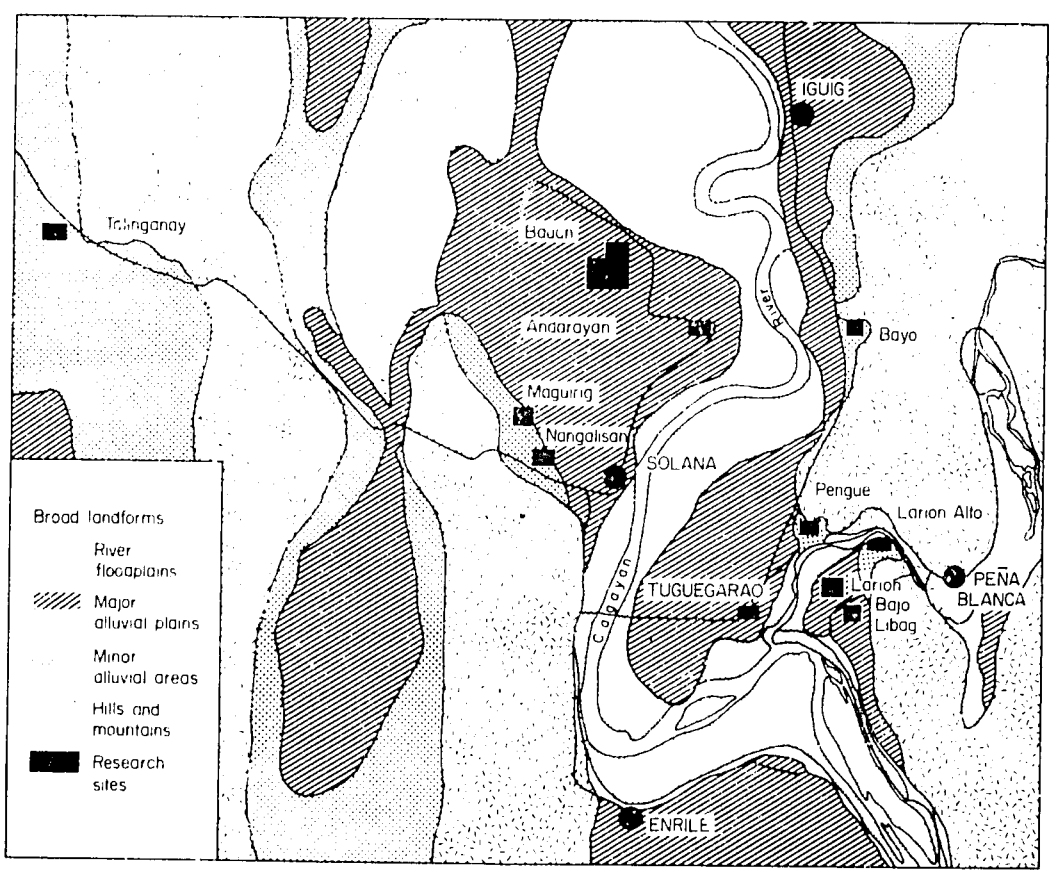
Multiple Cropping Department

We analyzed the hydrological dynamics of nine rainfed rice-growing areas in the Cagayan Valley of northern Luzon, Philippines, during 1986-87. We related the variation in hydrology across and within landforms to farmer rice production practices and to rice varietal performance. We monitored the surface hydrology of 45 intensive data plots (IDPs) in the 9 areas located in 5 different landforms. The IDPs were identified along transects of the prevailing toposequences in each landform. We used 20-, 40-, and 80-cm tubes for groundwater monitoring, and depth gauges for surface water measurements.

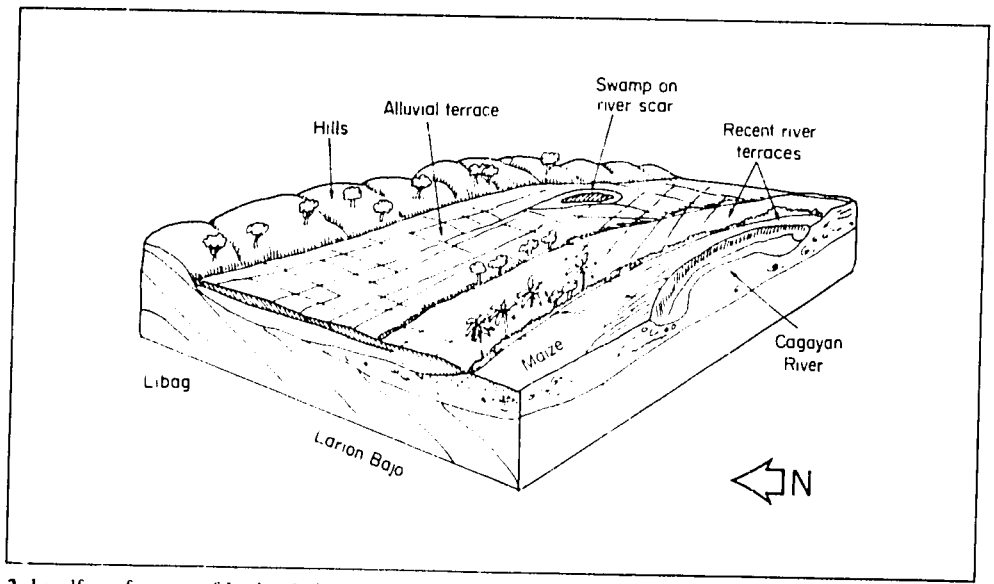
Landform units. Landform units were recent river terraces (RTs) (3d level), alluvial terraces (ATs), alluvial fans (AFs), interhill miniplains (IPs), and interfluves (IFs), comprising 95% of the 176,000 ha in the alluvial land system of the Cagayan Valley. They differ in microtopography and soil-related characters. Sites are within a 30-km radius in 4 municipalities (Fig. 1). The Larion Bajo landform unit is shown in Figure 2.

Hydrology. Surface hydrology varied widely among landforms. Figure 3 gives the hydrographs for two sites on an AT, where only traditional varieties (TVs) are grown. During rainless periods the surface water level dropped rapidly. No perched water table was observed in the plow layer, because the free water level was usually deeper than 20 cm below the soil surface even with standing water. When surface water drained, groundwater level receded rapidly. Substantial rainfall was required for surface flooding after a dry period.

In contrast, the surface hydrology on an IP (Fig. 4) favored rice. The surface water level fluctuated between 5 and 20 cm throughout the entire rice cycle. Modern varieties (MVs) are grown.



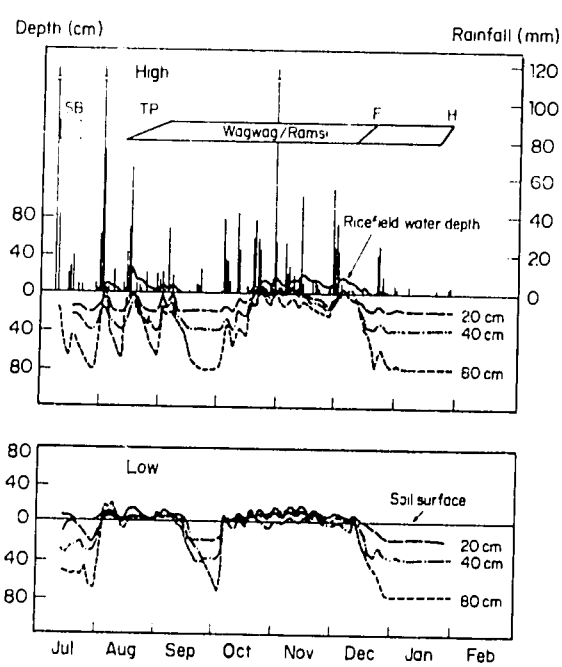
1. The rainfed lowland research area in Cagayan, northern Luzon, Philippines, 1986.



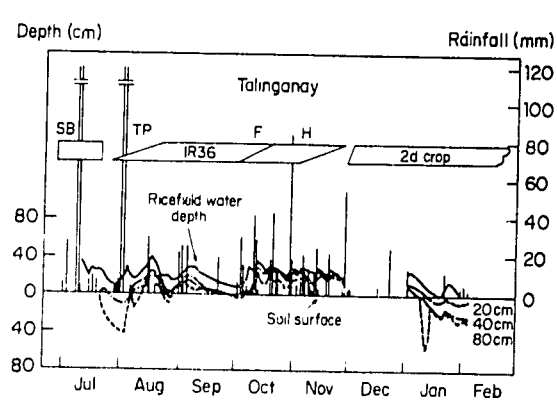
2. Landform features of Larion Bajo, Cagayan, Philippines, 1986-87.

Surface water retention. We developed a surface water retention index (SWRI) to express the time that a 50-mm water depth remains on the ricefield surface. SWRI = 50 mm (S&P + ET), where ET is crop evapotranspiration, and S&P is seepage and percolation (mm/d). SWRI ranged from 2.8 d in AFs to 5.8 d in ATs. These values reflect S&P rates of 13.9 and 4.6 mm/d, respectively, assuming an average ET of 4.00 mm/d in the growing season (July-December 1986). Farmers can crudely estimate SWRI for their ricelands, but expressing water retention in S&P units requires calculation.

Groundwater table. Rainfed rice needs a water table that remains within the root zone during low rainfall periods. In most landforms, however, the level readily drops below 40 cm as surface soil becomes unsaturated (moist). At the IP and AF sites, the water table was maintained near the



3. Hydrographs of 2 ricefields at high and low microtopographic positions in a recent river terrace, Larion Bajo, Cagayan, Philippines, 1986-87 WS. SB = seedbed, TP = transplanting, F = flowering, H = harvest.



4. Hydrograph of a ricefield in an interhill miniplain in Talinganay, Tuao, Cagayan, Philippines, 1986-87 WS.

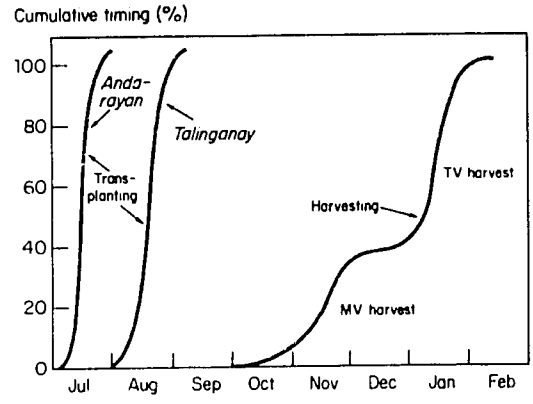
surface longer because of interflow from the adjoining catchment.

The groundwater level dropped 3.7-6.8 cm/d following a rainless period. ATs lose groundwater level faster than other landforms.

Cultivar choice by landform. MV adoption differed among landforms, ranging from 0 to 100%. TVs included Wagwag, Bensir, and Ramisid (Ramsi). They are photoperiod sensitive, with relatively low yield potential, but are highly tolerant of late transplanting, drought, and flood. MV adoption was low in ATs (0 and 20%), IFs (7 and 15%), and recent RTs (7 and 16%), but uniformly high in AFs (87 and 90%).

Timing of crop operations. Land was prepared and rice transplanted in July and August 1986 in all landforms (Fig. 5). Transplanting was earliest on recent RTs (Andarayan and Larion Bajo) and ATs, and latest on the AFs and APs (Talinganay), with a gap of 30 d. Farms with more favorable hydrology had earlier soil submergence, but there was less urgency to transplant early in those landforms.

Landform analysis can predict the fit of rainfed rice technologies at sites with problem hydrologies. Field agronomists lacking training in geomorphology or soil survey methods can learn to recognize landforms.



5. Cumulative timing of transplanting and harvesting across locations, Cagayan, Philippines, 1986 WS. MV = modern variety, TV = traditional variety.

SLOPE ANALYSIS OF AN ACID UPLAND RESEARCH SITE

Multiple Cropping Department

Slopes vary in most upland rice-growing areas, including the research site in Claveria, Misamis Oriental, northern Mindanao, Philippines. Water erosion has produced slopes ranging from a few degrees to steep escarpments. As population pressure has increased, cultivation has extended onto steep slopes.

We studied slopes in a 7- × 10-km block encompassing most of 8 villages studied since 1985. From 1967 vertical aerial photographs (scale of 1:15,000), we estimated the slopes using a Topcon mirror stereoscope, employing photointerpretation and photogrammetric techniques.

Slope classes Table 1 shows the six slope classes and their areas.

Level land ideal for cultivation is limited. Only 730 ha (10%) have 0-3% slopes. At the other extreme, 2,938 ha (40%) are steep and very steep (>30% slope), corresponding to hills and escarpments along rivers and other waterways. The remaining 50% is gently undulating to moderately steep.

The site lacks contiguous areas with uniform slopes because of intense stream dissection, especially toward higher elevations in the northeast. The nearly level areas are isolated as either narrow plateaus or valley floors. Generally, lower eleva-

Table 1. Slope class areas at the acid upland research site in Claveria, Misamis Oriental, Philippines, 1987.

Slope class	Slope range (%)	Description	Area[a] ha	Area[a] %
A	0 - 3	Flat to very gently sloping	730	10
B	3 - 8	Gently sloping	1153	15
C	8 - 15	Sloping	1249	16
D	15 - 30	Moderately sloping	1482	20
E	30 - 60	Steep	1633	22
F	> 60	Very steep	1305	17
Total			7552[b]	100

[a]Measured by planimeter from a map (approximate scale = 1:15,000) constructed by uncontrolled methods from aerial photographs of the same scale. [b]Represents a 10- X 7-km rectangular block covering Claveria town proper to Bangon-bangon (east-west). The area (7,552 ha) is about 17% of the total land area of Claveria municipality (44,040 ha).

tions (e.g., west and northwest of Barangay Ane-i) have <30% slopes.

Implications. With increasing population pressure, upland agriculture will extend to the more steeply sloping areas. With conventional agronomic technology, crop intensification may increase productivity on the gentle slopes (0-8%). However, sustaining productivity on steeper land (>8% slope) will require specialized soil conservation (e.g., alley cropping with contour hedgerows). In developing crop technologies for sloping uplands, research should integrate erosion control measures with soil fertility improvement.

SOIL FACTORS AND CROP PERFORMANCE IN ACID UPLAND

Multiple Cropping Department

Before the 1986-87 cropping season, soil samples were collected from the plow layer of farmers' fields at the Claveria research site. Analysis (Table 2) showed that soil acidity and nutrient deficiency limit crop production.

A correlation matrix shows relationships among the soil attributes (Table 3). Significant relationships are between total N and organic C (0.77**); exchangeable K and cation exchange capacity (CEC=0.64*) or percent clay (-0.63*); and available P by the Olsen and Bray II methods (0.86**).

This analysis was used to group related soil attributes communally (Table 4). Factor 1 is named a *P and K availability factor* because of its high positive loading for exchangeable K, CEC, Bray P, and Olsen P. Factor 2 is called *OM and acidity factor* because of its high negative loading for pH and its high positive loading for organic C and total N. Factors 1 and 2 together explain as much as 80% of the total variance.

Table 2. Means and standard deviations of soil attributes in Claveria, Misamis Oriental, Philippines, 1986-87.

Soil attribute	Mean	Standard deviation
pH	4.9	0.29
Organic C (%)	1.83	0.23
Total N (%)	0.19	0.03
Exchangeable K (meq/100 g)	0.24	0.14
CEC (meq/100 g)	12.43	2.13
Bray P (ppm)	7.80	2.15
Olsen P (ppm)	3.92	2.13
Clay (%)	69.00	7.91

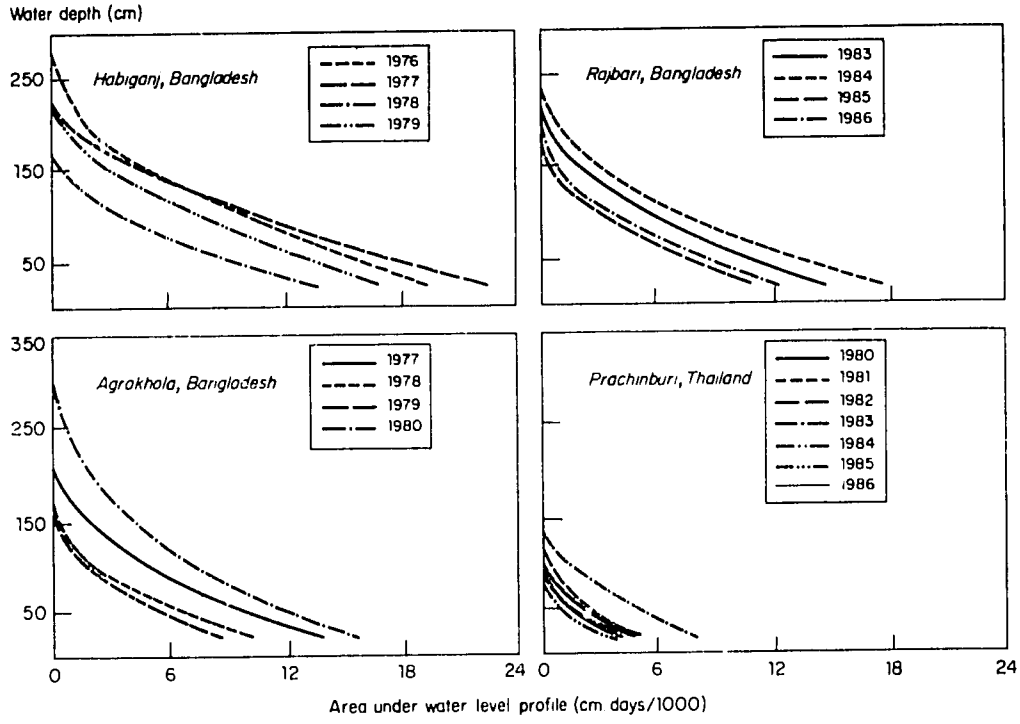
Table 4. Factor loading for soil attributes.[a] Claveria, Misamis Oriental, Philippines, 1986-87.

Soil attribute	Factor 1 (P and K availability)	Factor 2 (Organic matter and acidity)
pH	0.2064	-0.5866
Organic C	0.6008	0.6937
Total N	0.4372	0.8075
Exchangeable K	0.6949	-0.4229
Cation exchange capacity	0.7499	-0.1056
Available P (Bray II)	0.7367	0.1000
Available P (Olsen)	0.8635	0.0465
Percent clay	-0.6425	0.6064
Variance explained	3.34	2.04
% total variance explained	52	28

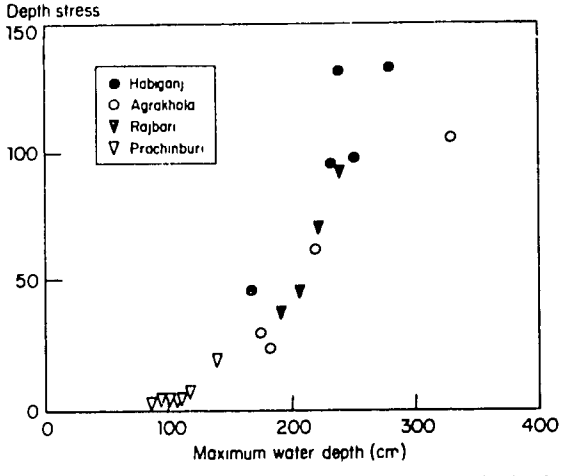
[a]Factor loadings underlined contribute most to that factor.

Table 3. Correlation matrix of soil attributes in Claveria, Misamis Oriental, Philippines, 1986-87.

Soil attribute	pH	Organic C	Total N	Exchangeable K	Cation exchange capacity	Available P (Bray II)	Available P (Olsen)	Percent clay
pH	1.00							
Organic C	-0.30	1.00						
Total N	-0.21	0.77**	1.00					
Exchangeable K	0.29	0.13	0.04	1.00				
Cation exchange capacity	-0.02	0.51	0.19	0.64*	1.00			
Available P (Bray II)	0.26	0.36	0.37	0.29	0.21	1.00		
Available P (Olsen)	0.25	0.43	0.39	0.43	0.41	0.86**	1.00	
Percent clay	-0.25	-0.03	0.28	-0.63*	-0.66	-0.30	-0.47	1.00



6. Water level plotted against area (cm•days) under the seasonal water level profile for successive 10-cm increments of height above the soil surface. Bangladesh and Thailand, 1976-86.



7. Relationship between maximum water depth and "depth stress," defined as the area under the curves of Figure 6 (units = cm•days for increments of 10 cm in depth). Bangladesh and Thailand, 1976-86.

Factors 1 and 2 were regressed against the grain yields of UPLRi-5 for each field. These factors did not significantly explain yield variation; neither did individual soil attributes. A severe drought affected grain yields and complicated their interpretation using native soil nutrient levels.

FLOODWATER PATTERNS IN DEEPWATER RICE

Agronomy Department

Deepwater rice (DWR) grows under rainfed dryland conditions for 2-3 mo, and is then flooded deeper than 50 cm for a month or longer. DWR research stations record daily water levels and use them to interpret crop performance.

We developed a computer program to calculate the characteristics of water level changes. We integrated the area under the season's water level profile by summing the water depth in centimeters over consecutive days during the flooding period for successive increments of 10 cm in depth. We plotted these values against water depth, producing smooth curves that show clear differences between sites and seasons (Fig. 6). The area under each of these curves gives a value for each flood that reflects "depth stress." These "depth stress" values have a curvilinear relationship to maximum depth (Fig. 7), which illustrates flooding severities. It may be possible to classify DWR cultivars in relation to depth stress along with rate of increase of water level at the start of flooding, which is also calculated by the computer program.

Cropping systems program

Analysis of the social and economic environment

Agricultural Economics and Water Management Departments

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MEASURING THE RELATIVE EFFICIENCY OF FARMERS' TECHNICAL CHOICES

Agricultural Economics Department

In 1975, IRRI's Cropping Systems Program began research on rainfed lowland rice in Iloilo, Philippines. The intention was to increase productivity (yields and cropping intensity) through introducing modern rice varieties (MVs) and new crop management practices. The project has promoted MVs and direct seeding of pregerminated seed (see previous annual reports).

In this project, 45 farmers record farm activities and expenditures daily for 5 yr. The data allow us to measure changes in technical efficiency, which reflect estimates of production risks.

The model. Models of expected utility contain a component to measure the stochastic (random) impact of technology and the risk attitudes of farmers. The expected utility theory states that farmers estimate risks of choices they face and try to make choices with favorable outcomes. We first estimated the stochastic technology. The flexible moment-based (mean, variance, skewness. . . .) model links the effects of production inputs to the probability distribution of output:

$$\mu_{1j}(x) = \mu_1(x_j, z_j, \beta) = \int \Pi f(\Pi \mid x_j, z_j \beta) d\Pi,$$
$$\mu_{ij}(x) = \mu_i^*(x_j, z_j, \beta) = \int (\Pi - \mu 1)_i f(\Pi \mid x_j, z_j, \beta) d\Pi, \; i \geq 2$$

The leftmost portion shows the moments of the distribution to be functions of input levels and thus links the probability of profit to the farmer's input decisions. The expression μ_{ij} is the effect of the ith moment of the jth input. Fixed and variable inputs are designated as x and y, while β represents the vector of technology parameters whereby the inputs define the moments of the distribution. If output is random, then profit Π, defined as total revenue less total costs, is a probability distribution of output conditioned by levels of x and z. The moments of this conditional function are shown in the middle expression, more formally expressed in the rightmost expression.

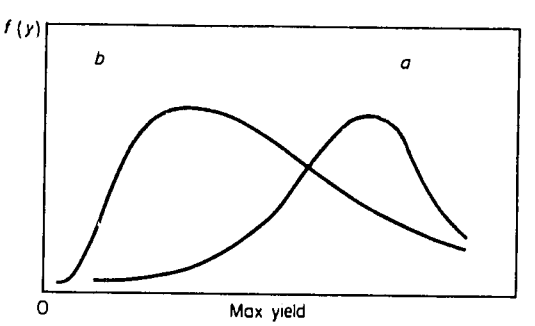
We used the model to estimate the first three moments of the benefit distribution. In studies of risk, farmers are often characterized as risk neutral (caring only about the mean), risk averse (concerned about the variance and the mean), and downside risk averse (preferring an increased chance of a bumper crop rather than a crop with a very low yield). Faced with choices, a downside risk averse farmer would prefer a distribution such as (a) (Fig. 1) with a negative skew—higher chance of getting a high yield.

The structure of stochastic technology is estimated with a model specified as a net revenue function in a full quadratic expansion of planting (Plabor), crop establishment (Elabor), and crop management (Mlabor) labor; land; and N fertilizer. Included as linear terms are solar radiation, a solar radiation-N interaction term, a simulated water stress variable, and a dummy variable for irrigation. The models are estimated on four data sets: MVs for crop years 1-2 and 4-5, and traditional varieties (TVs) for crop years 1-2 and 3-5. This linear version of the model results in estimation equations for the jth farmer of

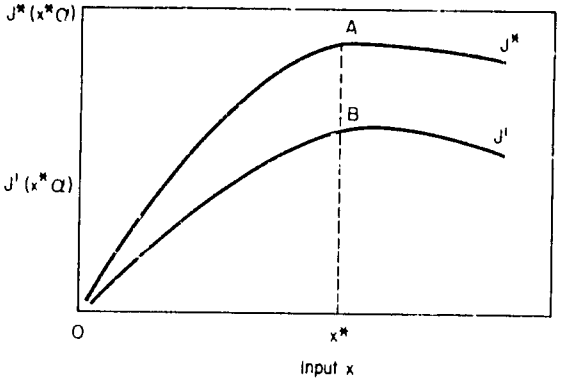
$$\mu_{1j}(x_j) = E(\Pi) = x_j \beta_1,$$
$$\mu_{ij}(x_j) = x_j \beta_i, \; i \geq 2$$

for the mean and higher moment functions. A unique technology parameter is estimated for each input for each moment. A range of risk attitude parameters based on earlier risk attitude research in the Philippines completes the model.

We can use the expected utility model to make relative comparisons of efficiency and production. By using the farmer's objective function, rather than profit, output, or costs, we can include more information relevant to the farmer's decision-making (Fig. 2). J(x, α) is the objective function where x is a vector of inputs and α is a vector of parameters. Points on J^i are inefficient relative to points on J^* but may be more or less efficient than points on other J^is.



1. A schematic of possible shifts in a yield distribution. IRRI, 1987.



2. Theoretical model of technical efficiency in the firm's objective function space. IRRI, 1987.

In this study, we compare TVs and MVs. To calculate their relative efficiency, we must specify a functional form for expected utility. We selected the third-order Taylor series expansion of the negative exponential utility function. The negative exponential utility function is

$$\mu(\Pi) = 1 - e^{(-\gamma\pi)}$$

where γ is the Arrow-Pratt risk aversion coefficient. The third-order expansion gives the expectation of utility and risk aversion coefficients for the three moments. Relative technical efficiency (RTE), comparing the expected utility outcomes of changing input levels of MV and TV rice production, is given by

$$RTE = J^{*}(x^{*}, \alpha)/J^{'}(x^{*}, \alpha)$$

Results. Systematic relationships exist between the inputs and the first three moments of the farmers' net revenue function. The quadratic technical coefficients were computed as elasticities, and four technology models were estimated. The results for MVs in crop years 1-2 and 4-5, and for TVs in crop years 1-2 and 3-5 appear in Table 1. In TV1-2, farmers use long adapted production practices; in MV1-2, farmers try new practices on new varieties.

Table 1. Mean elasticities of moments with respect to inputs.[a] Iloilo, Philippines, 1987.

Elasticity with respect to	Moment one		Moment two		Moment three	
	Elasticity	*t*-value	Elasticity	*t*-value	Elasticity	*t*-value
MVs, crop years 1-2						
Elabor	.1779	5.899	-.1858	-2.639	-.7187	-3.314
Plabor	.1164	1.910	.0959	.803	.8189	2.785
Mlabor	-.1993	-3.909	.2130	1.945	.6239	2.290
Land	.3662	5.386	.9976	5.986	.6607	1.506
Nitrogen	.1621	2.065	.2156	1.320	-.8776	-1.914
MVs, crop years 4-5						
Elabor	.0337	1.301	-.3810	-3.196	2.5074	2.556
Plabor	.2409	3.817	-1.3834	-6.521	1.5788	.829
Mlabor	.2151	2.979	.8931	3.623	.9136	.367
Land	.6612	6.932	2.0468	4.726	-1.4453	-.373
Nitrogen	.2454	3.393	-.3548	-1.389	1.4832	.621
TVs, crop years 1-2						
Elabor	.5485	5.743	.8400	3.501	28.786	6.630
Plabor	-.1705	-1.931	-.8420	-3.754	-11.268	-3.893
Mlabor	.0457	1.005	.0922	1.061	5.332	4.321
Land	.1752	1.546	1.1386	3.945	-14.802	-3.593
Nitrogen	.2345	2.475	.2188	.915	6.397	1.522
TVs, crop years 3-5						
Elabor	-.1803	-2.707	-.1999	-1.025	-1.4955	-4.007
Plabor	.3185	3.001	.1907	.668	3.4453	5.685
Mlabor	-.1279	-1.634	.0344	.187	1.6176	3.097
Land	1.0648	11.351	-.0067	-.007	-1.0822	-1.380
Nitrogen	.1615	2.245	.2551	1.478	.1814	.379

[a]MVs = modern varieties, TVs = traditional varieties, Elabor = crop establishment labor, Plabor = land preparation labor, Mlabor = crop management labor.

Later, in MV4-5, farmers have several years of experience with new varieties; and in TV3-5, farmers continue with TVs that fill a special niche, such as aromatic rices.

The first moments are the usual production function estimates—changing levels of an input will shift the distribution mean in or out, depending on the sign. A positive sign on the second moment implies that increased input will increase the variance of the distribution, while a positive third moment implies that the mass of the distribution is shifted right, a direction downside risk averse farmers prefer.

The switch from transplanting to direct seeding eliminated much of the labor applied to nursery and transplanting operations. Crop establishment labor can be a proxy for planting method, transplanting in TV1-2, and direct seeding in MV4-5. In MV4-5, establishment labor is a risk-reducing input — increasing the mean, reducing the variance, and shifting the mass of the distribution right. Establishment labor here can be an input that contributes more toward shaping the distribution within a frontier than shifting the frontier out. Conversely, the interaction term of solar radiation and N helps the plant realize its genetic potential and contributes relatively more to shifting out the frontier of the distribution. In MV4-5, N is a risk-reducing input, contradicting several earlier studies.

The Schultzian hypothesis of efficiency posits that, through experience, farmers learn the shape of the output distribution and adjust their inputs accordingly. During rapid technical change such as in Iloilo during the project period, farmers did not have good ideas about the shape of the output distribution. Tnus, depending on their risk preferences, farmers may choose to experiment with input levels to learn about the structure. The relevant question is: once faced with different technology choices, how fast do farmers learn the new technology and achieve previous levels of efficiency in their input use?

Table 2 gives results of the technical efficiency comparisons calculated across a range of risk aversion coefficients drawn from a Philippine rice farmer risk attitude study by Sillers. AP represents the Arrow-Pratt risk aversion measure and DS the downside risk aversion measure. Comparisons are made at the average input levels for both groups. For example, results show that, regardless of the type of risk attitude or factor portion, farmers in TV1-2 produced more efficiently than farmers in TV3-5. (By the end of the period, most farmers had assigned their irrigated fields to MVs; thus, in TV1-2, comparatively better resources were applied to TV production than in TV3-5.)

These estimates of relative technical efficiency imply that farmers are sacrificing short-run returns

Table 2. Relative technical efficiency in rice production. Iloilo, Philippines, 1987.

Comparisons	Scale of risk aversion coefficient[a]				
	LoLo	LoHi	MedMed	HiLo	HiHi
TV1-2 relative to TV3-5					
TV 1-2 factor proportions	1.43	1.28	1.24	1.23	1.13
TV 3-5 factor proportions	1.23	1.48	1.27	1.17	1.26
TV1-2 relative to MV1-2					
TV1-2 factor proportions	1.49	1.62	1.41	1.32	1.39
MV1-2 factor proportions	1.23	1.56	1.24	1.10	1.23
MV4-5 relative to TV3-5					
MV4-5 factor proportions	2.29	1.93	2.05	2.28	1.81
TV3-5 factor proportions	1.27	.17	.99	1.17	.95
MV4-5 relative to MV1-2					
MV4-5 factor proportions	1.52	1.30	1.29	1.28	1.14
MV1-2 factor proportions	1.38	1.18	1.19	1.17	1.09
MV4-5 relative to TV1-2					
MV4-5 factor proportions	1.42	1.14	1.14	1.15	1.00
TV1-2 factor proportions	1.99	3.15	1.66	1.30	1.44

[a]Risk aversion coefficients are Arrow-Pratt risk aversion measure: 0.3 1.0 1.7, and down-side risk aversion measure: 1.0 2.5 5.0.

for long-run gains by learning about the effect of input responses on the output distribution. Farmers experimented and learned that TV1-2 production is more efficient than MV1-2, but the relationship is reversed between MV4-5 and TV3-5. The relationship between efficiency and experience is demonstrated in the MV4-5 vs MV1-2 comparison. The relative speed of learning is seen in the MV4-5 vs TV1-2 comparisons. Farmers demonstrated an ability to gather information rapidly and to apply it beneficially.

These results reflect the value farmers place on on-farm generated information. They show how fast a group of resource-poor farmers can turn the disruptive effects of new technology into gains.

DECISIONMAKING OF PHILIPPINE FARMERS IN TRANSITION

Agricultural Economics Department

We analyzed the decisionmaking of several categories of farmers in a rural Philippine community (near IRRI) under changing social, economic, and ecological conditions. The changes involved 1) transition from landlord-owned, tenant-operated ricelands to post-land reform, amortizing owner-operated smallholdings; 2) diversification from rice monoculture to a rice - aquaculture system, with some vegetable and ornamental gardening; and 3) the influx of migrant, landless workers.

We investigated decisionmaking, knowledge, and choices pertaining to agriculture, fishery, and nutrition. We considered social differences, including socioeconomic standing and gender. The landless workers are disadvantaged compared with their more established and affluent neighbors. However, tilapia aquaculture and ornamental gardening provide opportunities beyond those possible with secure land tenure.

As an aid to measuring the farmers' knowledge of local resources and opportunities, we asked them to draw maps of the area. Low status males, mostly migrants, knew more about free-access resources and channels of navigation and transport than did their spouses, who were more sensitized to community resources that offer free public services. High socioeconomic status males knew the most about community resources and natural resources; high socioeconomic status females knew more about many aspects of their environment than did other categories of females. Middle status couples were least aware of the change in landscape to accommodate a new production alternative — tilapia aquaculture. These results show that social and sexual divisions of labor have sensitized males and females to different features of their environment.

We asked informants to identify plants and arthropods. In distinguishing among noncultivated plants, informants knew life habits and morphological features that have little bearing on agronomic properties. In discriminating among harmless arthropods, they emphasized physiological or behavioral attributes, e.g., how they move, smell, and sound. When identifying cultivated plants and harmful arthropods—both quite culturally relevant to farming—functional criteria dominated: negative human-directed effects with arthropods, and gastronomic criteria with rice.

The results reinforce the need to consider farmers as consumers rather than just producers, and to consider gastronomic preferences in breeding rice cultivars. Integrated pest management programs need to examine indigenous knowledge before supplanting it with "scientific" information. Serious attention needs to be paid to "ethnoagronomy" and "ethnogastronomy" (or folk models in production and consumption) in designing and promoting agricultural recommendations.

High socioeconomic households go for options that increase productivity, while middle status ones give priority to stability. Low socioeconomic households, knowing their limitations, "watch" and note details in agricultural production and marketing. Salient for them are experiences of moving around as hired laborers in others' fields—they note the sharpness of leaves and spikelets, the itchiness of pollens, the density of shoots, the tenacity of weeds, and the appetites of different pests. They make "closer to the ground" observations and more detailed representations, which seem to inhibit abstraction and generalization.

While upper socioeconomic informants emphasize the flavor, aroma, and texture of rice, those lower in the socioeconomic ladder emphasize the grains' expanding, satisfying, and staying power.

The latter note the value of subsistence crops for feeding and "fattening" their children and pay close attention to avoiding unwanted side effects.

The results of this study illustrate differential access to knowledge and to resources. Choices of time allocation, food consumption, and land use are constrained, requiring compromises that lead to behavioral outcomes that may not be logical for maximization or adaptation.

VIABILITY OF PUMP IRRIGATION COOPERATIVES IN GUIMBA, PHILIPPINES

Water Management Department

Pumping water for irrigation, as from deep tubewells, is more expensive than drawing water from diversion or reservoir-backed irrigation systems. To reduce pumping costs, the National Irrigation Administration (NIA) in 1985 organized farmer users of the deepwell pump systems in Guimba, Nueva Ecija, into Farmer Irrigators Associations (FIAs) to operate pumps and pay for operation. Each FIA distributes water to members, and collects irrigation fees to pay for electricity.

Of the 23 deep tubewells in Guimba, only 7 were operational in 1987. The other FIAs failed to pay the minimum 90% of the electricity cost of the previous season. Each farmer pays an irrigation fee equal to 1,200 kg of rough rice/ha for 2 crops each year.

In the 1987 dry season (DS), we studied 3 successfully operating FIAs: P8, GP108, and GP132. We interviewed all officers and a sample of 30-40% of the members.

Mean farm size was about 1 ha. The total areas irrigated were 46, 60, and 51 ha, respectively. GP108 started pumping in mid-December 1986, P8 in late December 1986, and GP132 in mid-January 1987. Land preparation was finished in 63 d at GP132 and GP108, and in 56 d at P8.

Monthly average discharges for pumps (75-HP engines) did not change from January to March 1987. All except some GP132 areas received adequate water during the crop growth period. The mean relative water supply—the ratio of water supplied to water required in the ricefield—was 0.7 in the GP132 service area, 1.3 in P8, and 0.9 in GP108. The average rice yields were 4.8 t/ha for P8, 4.2 t/ha for GP108, and 4.1 t/ha for GP132.

All FIAs rotated water distribution. The cost of pump operation was highest (about $136/ha) in P8, which served the smallest area (46 ha), and lowest in GP108 (about $102/ha) with the biggest area (60 ha). GP132 expended about $110/ha.

None of the three FIAs had legal status. They operated informally, without maintaining permanent records, written policies, or guidelines. Trust and satisfaction of members with their leadership influenced payment of the irrigation fees. In GP108, where leadership was solely with the president, irrigation fee payment was high. Members perceived their contribution to be safe with the president, who was rich, fair, honest, and a source of farm credit.

GP108 members hired two watertenders to distribute water and help collect irrigation fees. A collector employed by the FIA collected irrigation fees from the members. In P8, FIA leaders were also watertenders, receiving $5/mo. In GP132, separate watertenders distributed water, cleaned canals, and collected fees.

Costs could be reduced in all 3 systems if the cropping activities were better planned and the land preparation period shortened to at least 6 wk.

FARMER SOIL NUTRIENT AND EROSION PRACTICES AND PERCEPTIONS

Agricultural Economics Department

Claveria (Misamis Oriental) farmers complain about declining yields due to soil erosion and continuous cropping. We studied land management practices, perceptions, and knowledge to help develop appropriate research for erosion-prone sloping uplands. We interviewed 55 farmers, visited their fields, and sampled and analyzed soils and weeds.

Claveria lands include volcanic plateau and alluvial plain. Soils are moderately well-drained clays of pH 3.9-5.2. Total annual rainfall is 2,200 mm, with the maximum in July-December. A first crop season (*panuig*) spans May-October, a second (*buklas*) October-March. Second season rainfall is uncertain, leading to more seasonal fallows. More than half of the land has more than 15% slope. The Bureau of Soils estimated that about 47% of Claveria lands is severely eroded (1985).

Table 3 shows respondent land tenure, farm sizes, and crops.

Lands, soils, and crop choice. Claveria farmer soil categories are characterized primarily by slope, but also by color, fertility, texture, acidity, and friability (Table 4). For example, red (*puwa puwa*) soils are poor (*niwang*, literally thin) and acidic (*aslom*, literally sour); poor soils are red.

Farmers generally associated several weeds with richer soils: 1) *Mimosa invisa*, 2) *Crassocephalum crepidiodes*, 3) *Calopogonium mucunoides* and *Centrosema pubescens*, 4) *Helianthus annuus*, 5) *Ipomoea pes-tigridis*, 6) *Hyptis suaveolens*, and 7) *Pteridium aquilinum*. Weeds most commonly associated with poorer soils were 1) *Imperata cylindrica*, 2) *Digitaria longiflora*, 3) *Pennisetum polystachyon*, 4) *Themeda triandra*, and 5) *Paspalum conjugatum*. Except for *Pteridium aquilinum*, which grows on the poorest soils, these observations are correct. Several said *I. cylindrica* made soils poorer or carried substances toxic to crops. The grass does produce allelopathic substances affecting plant growth.

Farmers usually plant maize on better soils and rice or cassava on poorer soils; however, greater weed control costs (32 labor d/ha) prevent some from planting rice. After water, farmers named adequate, timely weed control as the main rice crop need. Farmers grew 10 traditional rice varieties (1987) and continually tested others for charac-

Table 3. Land tenure, farm size, and cropping patterns for 55 farmers[a] in Claveria, Misamis Oriental, Philippines, 1987.

Category	No.	Av farm size (ha)	Plantings (no.)					
			Rice - fallow	Maize - maize	Hybrid maize	Perennial crops	Cassava	Tomato
Owner	16	4.4	9	16	8	6	8	3
Tenant	15	2.6	8	15	1	3	7	2
Caretaker tenant	5	2.8	0	5	1	0	2	2
Land reform								
CLT[c] holder	7	4.4	3	6	3	3	3	1
Local organization	5	2.1	4	4	1	0	2	0
Takeover	4	3.3	3	3	0	1	2	0
Rent or contract	3	2.3	3	3	2	1	1	2

[a]Seven had a mix of tenure types; main type was counted. [b]CLT = Certificate of Land Transfer.

Table 4. Claveria farmer lands and soils categories, 1987.

Soils		Lands	
	Undesirable characteristics		
puwa puwa	red	bakilid	sloping
niwang, umau	poor, thin	buntod buntod	hilly
walay sustancia	nothing left	batohon	rocky
aslom	"sour" or acidic	nagasgasan	washed out, literally "scratched"
pundok pundok	spotty fertility		
pagkumot magbuwag/ magkabuwag	disintegrates when held		
	Desirable characteristics		
tambok tambok	fertile, rich	patag patag	flat
itom itom	black, dark	bunkag	newly opened
bukakhaon	absorbs/holds water	kabugon	low-lying area
madali madayao	not easily dried	basak	waterway or lowland
pughay na, humok	friable		
balason	sandy		
medyo mopilit	quite sticky		
bonbon	silt (rich)		
	More neutral characteristics		
mogahi, mobagtik	crusty	nananay hay, nahandig sakom	gently sloping *kaingin*
tibuok	coarse		

teristics including tolerance for acid soils and low fertility. The widest planted traditional variety Speaker was prized for high yield without fertilizer (1.5-2.6 t/ha). Farmers reported that Dinorado gives disappointing yields in Claveria. Landowners and holders of certificates of land transfer planted perennials on steep slopes.

Fertilizers, manure, lime, and biomass. Most informants said they needed inorganic fertilizers, lime, and chicken manure to boost production and to maintain or improve soils. Most said they could not afford credit for these inputs, but wanted it. They learned fertilizer and lime application rates from government programs (e.g., Maisagana), chemical firm representatives, other farmers, and personal experience and testing.

Many rice farmers wanted to try UPLRi-5 (improved upland variety tested by IRRI) with fertilizers. Although they did not know the quantities needed, several were sure they could not afford the fertilizer. Those trying UPLRi-5 got 1.1 to 3.7 t/ha using 0-25 kg N and 30 kg P/ha.

About half of the respondents had used fertilizers for hybrid maize or tomato. Most had received credit. Several landowners planted hybrid maize when government programs gave credit for seed, lime, and fertilizers. Some quit planting hybrids after late fund releases led to late planting and armyworm *Mythimna separata* damage.

To produce tomato, farmers provided land and labor, and entrepreneurs provided credit for lime, fertilizers, chicken manure, insecticides, fungicides, stakes, and twine. Although crop prices varied greatly, farmers sought the guaranteed residual fertility that benefits up to 2 succeeding maize crops. Tomato field soils sampled after cropping averaged a significant additional equivalent of 39 kg P/ha over fallow (16 kg/ha) in the top 15 cm.

Farmers agreed that soil amendments were wasted on steeper slopes because of erosion. Many had applied lime (up to 3.5 t/ha) and expected its effects to last for 3-4 yr. Some were applying small amounts directly to crop rows at first season planting. A maize and rice farmer said he preferred, in order, a basal application of complete fertilizer, weeding, a urea sidedressing, and lime. If costs—including those of application—were zero, he would replace complete fertilizer with chicken manure. Others said fertilizer without lime was useless.

Although they recognized that animal dung adds nutrients to areas used as pasture, Claveria farmers grazed draft animals and did not manufacture farmyard manure. Chicken manure for tomato was purchased in Cagayan de Oro.

No one reported green manuring. Several grew legumes, but none observed soil nutrient benefits from either crop or incorporated biomass. Eight switched from burning to incorporation of rice or maize crop residues for improved soil fertility. Many mentioned the benefits of composting, but only six had compost pits. Compost was usually used for vegetables or perennial seedlings. Labor (including hauling water) and lack of raw materials were constraints to compost production.

Fallows. Only 11 respondents had fallowed areas, mostly because of steep slopes or labor constraints. Four farmers claimed that soils improved; six said there were no negative effects. *I. cylindrica* domination and toxicity were a problem, and three said trees or pasture legumes were needed.

About 50% of the respondents thought that fallows regenerate soils. They explained that fallow soils improve because lands "rest" and rebuild nutrients; or grasses grow, die, decompose, and add organic matter. Estimates varied (1-10 yr) as to time needed to regenerate nutrients.

Overall, farmers were ambivalent about weeds in fallows. They cited benefits and recognized that "good" weeds *C. pubescens*, *Calopogonium mucunoides*—and *Mimosa invisa*—improve soils because decayed leaves and stems are rich in nutrients. They observed, however, that fallows do not regenerate beyond perennial grasses associated with poor compacted soils and with substantial labor to reopen parcels.

Soil erosion and erosion control. Ninety percent of the respondents said soil erosion was a problem in their fields. All were aware of downslope soil and nutrient erosion due to rainfall runoff. Farmers readily pointed out and discussed parts of fields and crops damaged by erosion, and identified and had terms for sheet, rill, and gully erosion and for nutrient leaching. About 15% said plowing contributed to the problem.

Many said that soils are dark on top and reddish underneath, and over time the dark top layer had eroded, exposing red, poorer soils. Many farmers cited specific diminishing depths over time (e.g., 50 cm in 1976 to 10 cm in 1986).

Respondents mentioned the benefits of soil nutrients eroding *onto* their fields from neighboring fields and pastures.

Knowledge of solutions to soil erosion was fair. Perennials or banana planted in upper areas, digging of protective drainage or diversion canals, and planting banana in erosion gullies to create soil traps and to take advantage of the eroded nutrients were each mentioned by about 50% of the informants. Other measures each mentioned by about 20% were 1) grassy strips across slopes or along field borders; 2) *Leucaena leucocephala* strips; 3) piling grasses, banana stalks, and crop residues across erosion channels; 4) contour plowing; and 5) legume cover crops.

Erosion control was limited. About 20% had constructed drainage-diversion canals along upper plot borders; and several left weedy strips between plots. A common low-effort, low-return method was to pile weeds and crop residues across and within erosion channels. Banana planted in erosion channels was more common.

While a few landowners planted perennials on sloping plots, no one planted trees in strips or on upper slopes to protect lower areas. Some with adequate land resources left trees on longer fallowed areas. Others who said tree planting was needed lacked land for it.

True contour plowing was extremely rare. Farmers commonly cultivated curving hillsides along a single direction so that furrows followed the contour tangentially and ran downslope. Some steep slopes were not tilled but were planted as *sacom*, using only a *bolo* to reduce erosion.

Farmer practice and technical knowledge are a resource for on-site farmer participatory research. Farmer practices and perceptions suggest further areas of research needed for developing an appropriate integrated nutrient management strategy for acid uplands: 1) actual fallow succession and potentials for legume-based improved fallows, 2) appropriate methods of erosion control, and 3) improved legume biomass use.

EMPLOYMENT AND INCOME WITH FARMERS' CROPPING PATTERNS

Agricultural Economics Department

Cropping intensity, and labor and power use. The upper barangays—Anei, Hinaplanan, and Patrocinio—in Claveria were intensively cropped in 1987 with 63% planted to a second crop. In lower barangays—Gumaod, Plaridel, and Cabacungan—23% was multiple cropped (Table 5). Because of civil unrest, small farms in the lower barangays were less intensively farmed than medium or larger farms.

Farms used twice as much labor for the first crop as for the second, partly because of widespread drought and crop failure. Labor use per hectare

Table 5. Cropping intensity and labor use by size of farm. Claveria, Misamis Oriental, Philippines, 1986-87.

Location, size	Av farm size (ha)	Cropping intensity	Labor use (d/ha)		Power use (d/ha)	
			First crop	Second crop	First crop	Second crop
Upper barangays						
Small	1.0	154	82	43	23	13
Medium	2.2	162	63	27	19	12
Large	4.3	168	42	21	14	8
Av	2.3	163	58	26	18	11
Lower barangays						
Small	0.8	94	102	49	23	16
Medium	2.1	136	67	34	12	12
Large	5.0	119	59	25	13	8
Av	2.7	123	65	30	13	10

averaged from 21 labor d/ha on large farms in the second crop to 102 labor d/ha on small farms in the first crop. Labor was twice that on small farms (43-102 labor d/ha) as on large farms (21-59 labor d/ha), and more animal power was used on small farms.

Employment. Labor data on eight cropping patterns were analyzed (Table 6). The maize - maize monoculture used 43% of available labor. The tomato - maize pattern employed the most laborers and provided full employment for 7 mo. It offered employment during seasonal slack periods. The upland rice - maize pattern used 71% of the labor supply and provided full employment for 1 mo. Seasonal slack periods call for developing cropping patterns like tomato - maize that employ labor more fully.

Returns to labor appear in Table 7. The tomato - maize pattern provided the most employment (242 d/ha) and family labor income ($160/ha). The

Table 6. Labor use in farmers' cropping patterns in Claveria, Misamis Oriental, Philippines, 1986-87.[a]

Item	Cropping pattern							
	Maize - maize	Upland rice - fallow	Upland rice - maize	Cassava - fallow	Tomato - maize	Cowpea - maize	Perennial crops	Maize - cassava
Annual labor requirement								
days	76	94	123	44	242	77	106	83
% available supply	43	53	71	25	137	44	60	48
Monthly use of labor:								
% of available supply								
Jan	21	0	18	19	18	18	30	12
Feb	21	0	15	12	15	15	28	9
Mar	24	9	16	39	30	13	137	53
Apr	29	19	22	19	2	7	71	55
May	38	45	46	28	134	25	36	40
Jun	47	87	88	13	138	79	38	84
Jul	24	131	135	12	124	29	107	51
Aug	28	47	57	30	176	103	12	41
Sep	73	12	40	20	191	27	14	73
Oct	35	61	93	13	195	32	12	0
Nov	19	52	70	1	166	18	25	0
Dec	18	4	21	12	16	16	19	0
Coefficient of variation (%)	48	99	71	54	74	87	88	82

[a]Average 2.5 family laborers per farm provide 528 labor d/yr or 44 labor d/mo.

Table 7. Income and labor use in farmers' cropping patterns, Claveria, Misamis Oriental, Philippines, 1986-87.

Item	Cropping pattern							
	Maize - maize	Upland rice - fallow	Upland rice maize	Cassava - fallow	Tomato - maize	Cowpea - maize	Perennial crops	Maize - cassava
Labor use (labor d/ha)								
Family labor	41	57	74	35	128	53	60	43
Hired labor	35	37	49	8	114	24	46	41
Power use (animal d/ha)								
Family owned	22	16	27	11	32	23	10	16
Hired	10	5	9	3	14	4	12	6
Total net returns ($/ha)	49	-2	8	41	393	14	153	114
Net returns to family labor ($/ha)	33	41	55	30	160	39	58	36
Rates of return ($/$1)								
Labor and power costs	1.4	1.0	1.1	1.8	1.6	1.2	2.3	2.1
Material costs	12.1	0.6	3.6	91.1	4.2	3.9	3.4	16.5
Total variable costs	1.4	1.0	1.1	1.8	1.3	1.1	1.8	2.0

upland rice - maize pattern and perennial crops provided similar returns to family labor and employment. The rates of return to labor and power costs ranged from $0.97/$1 on upland rice monoculture to $2.30/$1 on perennials. The return to material inputs was uniformly high on farmers' cropping patterns except for upland rice, which was severely affected by drought.

RICE PRODUCTION SYSTEMS OF THE MAROVOAY PLAINS, MADAGASCAR

Agricultural Economics Department

The Rice Program of the National Center for Applied Research on Rural Development of Madagascar collaborated with IRRI in a farming systems study in the Marovoay Plains involving a review of previous research, an exploratory survey of the region, and a farm-level study of 127 rice-farming households. Details are given in the section on Cooperative Country Projects.

Cropping systems program

Pest control in rice-based cropping systems

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INSECTS

Entomology Department

Insect pests and yield loss in upland rice. Trials over the past 3 yr in Claveria, Misamis Oriental, Philippines, have consistently shown that upland rice is under intense pressure from insects. Yield losses average 32% over 3 yr (Table 1). The greatest loss (13%) was caused by soil pests, dominated by 5 species of white grub, in order of prevalence: *Holotrichia mindanaoana* Brenske, *Adoretus luridus* Blanchard, *Leucopholis irrorata* (Chevrolat), *H. flacki* Brenske, and *A.* (= *Lepadoretus*) *ranunculus* Burmeister. The larvae occur year-round, but not all species occur in all seasons. They feed on the roots. Large tracts of pasture and perennial grassy fallows favor white grubs. Other soil pests were root aphids *Tetraneura nigriabdominalis* (Sasaki) and *Rhopalosiphum rufiabdominalis* (Sasaki). Both adults and nymphs remove the sap from roots and cause stunting and yellowing. Termites, dominated by *Macrotermes gilvus* Hagen, and mealybugs, notably *Trionymus* spp., occurred in low numbers.

Seedling pests attack the newly emerged plants aboveground. The combined damage averages 10% and is caused mostly by the seedling maggot *Atherigona oryzae*, which causes deadhearts. A small flea beetle, *Chaetocnema basalis* (Baly), also attacks seedlings, causing the leaves to turn brown when many feed.

Reproductive phase pests are dominated by stem borers (SBs) and leaffolders (LFs). Their importance varies from year to year but has, on the average, caused a 7% yield loss. The seven SB species are, in order of prevalence, pink SB *Sesamia inferens*, striped SB *Chilo suppressalis*, gold-fringed SB *C. auricilius*, white SB *Scirpophaga innotata*, yellow SB *Scirpophaga incertulas*, and two lesser known species *Acigona chrysographella* (Kollar) and *Maliarpha* spp. There are also two LFs: *Cnaphalocrocis medinalis* and *Marasmia patnalis*. Armyworm *Mythimna separata* occurs from time to time.

The ripening phase pests are the least important, with only 2% recorded yield loss. The seed bugs, dominated by *Leptocorisa oratorius*, are most responsible. Other seed bugs include *Pachybrachius nietneri* (Dohrn) and *Paraeucosmetus* (= *Pachybrachius*) *pallicornis* (Dallas).

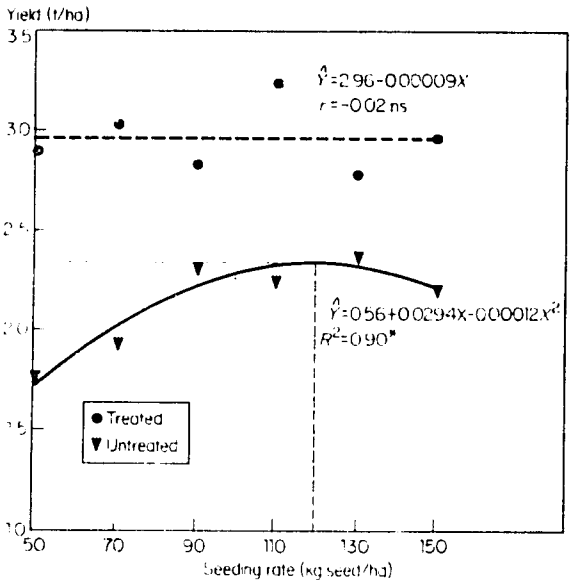
Table 1. Yield losses from insect pests in upland rice, Claveria, Misamis Oriental, Philippines, 1985-87.

Parameter	1985	1986[a]	1987	Mean
Protected yield (t/ha)	5.1	3.7	3.1	4.0
Unprotected yield (t/ha)	3.1	2.5	2.3	2.6
Yield loss (t/ha)	2.0	1.2	0.8	1.3
Yield loss (%)	39	32	26	32
Yield loss (%) by insect guild				
Soil pests	14	12	13	13
Vegetative phase pests	11	7	13	10
Reproductive phase pests	9	11	0	7
Ripening phase pests	5	2	0	2

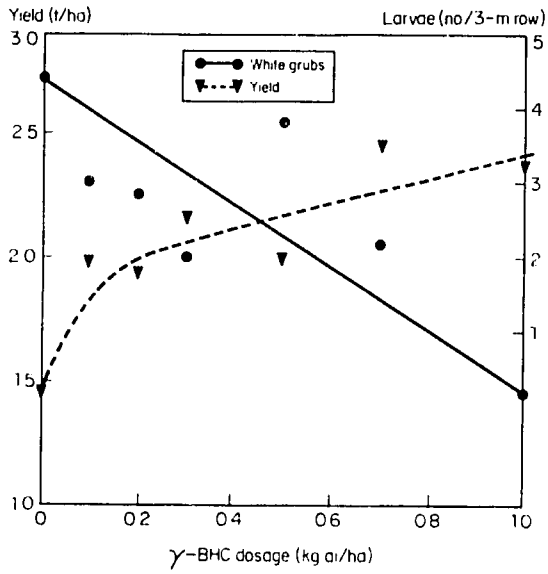
[a]Included one field with no yield because of neck blast.

Seeding rate and chemical control of seedling maggot on upland rice. The seedling maggot attacks upland rice up to 4 wk after crop emergence. The resulting deadhearts reduce tiller number and yield. Early plantings escape attack, but not all farmers can prepare their land on time. Late plantings can be protected either by increasing the seeding rate or by an insecticide seed treatment. Increased plant stand compensates for deadhearts. IRRI entomologists tested 6 seeding rates—50, 70, 90, 110, 130, and 150 kg/ha—with and without 0.3 kg ai carbosulfan ST/ha as seed treatment for a total of 12 treatments in a late planting. The highest yield of untreated seed occurred with 120 kg seed/ha (Fig. 1), but the least expensive option was 50 kg seed/ha, unprotected, which cost $6.10/ha for the seed. Insecticide-protected seed gave the highest yield regardless of seeding rate (Fig. 1). Seed treatment was valued at $17.85, including a 60% interest rate. The greatest rate of return on investment was 90 kg seed/ha, untreated (valued at $11.00/ha) (Fig. 2). If a farmer had more money ($26.40/ha) the next greatest rate of return would come from 70 kg seed/ha, treated.

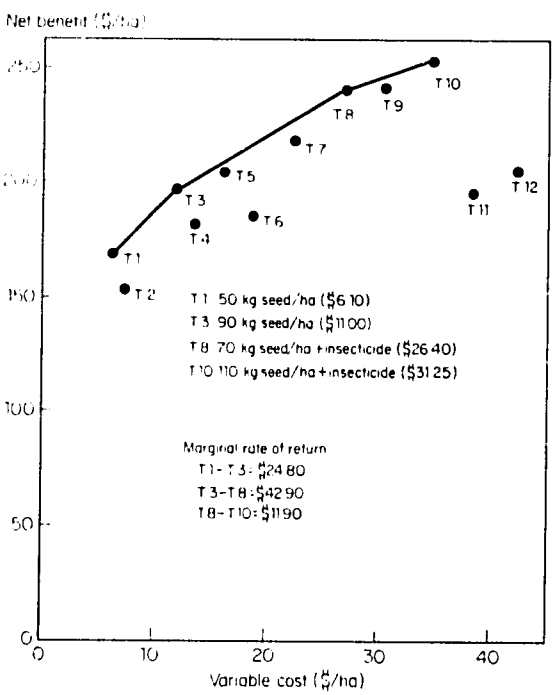
Chemical control. *White grubs on rice.* Granular soil insecticide applied in the seed furrow is the most practical way of controlling white grubs in upland rice. Nonchemical methods are not available. Six dosages of γ-BHC, an inexpensive soil insecticide, were tested in a field trial in Claveria. The white grub population declined in a linear fashion as dosage increased from 0.1 to 1.0 kg ai/ha (Fig. 3). A sharp yield increase of 0.5 t/ha occurred between 0 and 0.1 kg ai/ha. The slope of the yield response to increasing dosage was less



1. Effect of increasing seeding rate and insecticide protection on yield of UPLRi-5 upland rice. Claveria, Misamis Oriental, Philippines, Jul-Nov 1986.



3. Yield response to increasing rates of γ-BHC soil insecticide applied in seed furrows of UPLRi-5 upland rice. Claveria, Misamis Oriental, Philippines, 1987 WS.



2. Net benefit curve of UPLRi-5 upland rice seeding rates with and without insecticide protection in the vegetative phase. Claveria, Misamis Oriental, Philippines, Jul-Nov 1986.

from 0.2 to 1.0 kg ai/ha. Therefore, the economically optimal dosage of γ-BHC is 0.1-0.2 kg ai/ha.

White grubs on peanut. Peanut after upland rice is particularly vulnerable to white grub damage. Plants wilt and die once the taproot is severed.

Upland farmers have low cash resources. Therefore IRRI entomologists tested low dosages of common soil insecticides against white grub on peanut. Carbofuran and γ-BHC granules were drilled in the seed furrow at planting. Four insecticides were impregnated in cassava flour paste applied to the seed. Isofenphos seed treatment at 0.1 kg ai/ha resulted in the greatest plant stand and a low number of damaged plants (Table 2). Granular γ-BHC applied as a seed treatment also gave excellent grub control.

Mungbean insects. Recent research has sought to reduce the amount of insecticide required to control mungbean insect pests. The current practice is four to five sprays. Preflowering protection involves 0.25 kg ai monocrotophos/ha sprayed at 2 and 12 d after emergence (DE), which could be replaced by a single seed treatment resulting in substantial savings of insecticide and labor. Four seed treatment chemicals were compared, each at two dosages, in a field trial in South Cotabato on mungbean after lowland rice. Two seed treatment methods were compared: water slurry and pelleting. Pelleting with cassava flour paste (10 parts cassava flour heated with 90 parts water) is safer

Table 2. Insecticides evaluated against white grubs on peanut.[a] Claveria, Misamis Oriental, Philippines, Jul-Nov 1987 wet season (WS).

Insecticide[b]	Dosage (kg ai/ha)	Plant stand (no. of plants/25 m²) at 105 DE	White grubs[c] (no. of damaged plants/10-m row) at 60 DE
Carbosulfan STD PSC	0.1	111 ab	4 b
Isofenphos ST PSC	0.1	124 a	2 ab
Carbofuran G PSC	0.1	94 c	4 b
Carbofuran G drill	0.3	117 ab	4 b
Gamma BHC G PSC	0.1	104 bc	1 a
Gamma BHC G drill	0.3	116 ab	2 ab
Untreated control	–	108 bc	5 b

[a]Av of 5 replications across farmers' fields. DE = days after crop emergence. [b]PSC = pelletized seed coating using cassava flour. Drill = chemical applied together with basal application of recommended fertilizer. [c]*Holotrichia mindanaoana* and *Leucopholis irrorata*.

than the slurry, because in pelleting dry flour is added as a final coating. Seed is sown by hand, and the cassava flour coats the insecticide. The water slurry treatments were no better than the untreated control. Pelleted carbosulfan gave excellent beanfly control even at 0.15 kg ai/ha (Table 3). A second field trial tested a lower dosage (0.1 kg ai/ha) of pelletized carbosulfan seed treatment and achieved good control of preflowering pests (Table 4). The seed treatment reduced the preflowering insecticide requirement fivefold.

Earlier trials established deltamethrin as a superior insecticide for pod borer control. In this experiment, 2 applications at 10 g ai deltamethrin/ha were inferior to 3 (recommended practice vs alternative practice 1) (Table 4). A slight yield loss occurred when the dosage was lowered from 30 to 10 g ai deltamethrin/ha (complete control vs alternative practice 1). Lowering the dosage to 5 g ai/ha with 3 applications was inferior to a higher dosage of 10 g ai/ha (alternative practice 2 vs alternative practice 3). Therefore, the current practice would be seed treatment at 0.1 kg ai carbosulfan and 3 applications of 10 g ai deltamethrin/ha.

Table 3. Evaluation of pelleted insecticide seed treatments on mungbean.[a] Koronadal, South Cotabato, Philippines, 1986 dry season (DS).

Treatment	Dosage (kg ai/ha)	Beanfly larvae and pupae[b] (no./35 plants) at 21 DE
Bendiocarb 50 WP	0.15	11 bcd
	0.30	6 abc
Carbosulfan 40 ST	0.15	4 ab
	0.30	2 a
Omethoate 50 EC	0.15	7 abcd
	0.30	9 abcd
Isofenphos 40 SD	0.15	16 cd
	0.30	7 abcd
Untreated		17 d

[a]Av of 3 replications. Postflowering spray with 15 g ai deltamethrin EC/ha at 30, 40, and 50 DE was applied to all treatments including the untreated. Seeds, water, and insecticides agitated in plastic bag and coated with cassava paste plus an outer coating of dry cassava flour. [b]*Ophiomyia phaseoli*; 35 plants sampled.

Table 4. Chemical insect control for Pagasa 1 mungbean planted after wetland rice.[a] Guimba, Nueva Ecija, Philippines, Mar-Jun 1986 DS.

Flea beetles[b] (no. of holes/plant) at 14 DE	Beanfly[c] larvae + pupae (no./35 plants) at 21 DE	Damaged green pods[d] (%)	Yield[e] (t/ha)
Complete control = preflowering stage: 0.5 kg ai monocrotophos EC/ha + 0.015 kg ai deltamethrin EC/ha at 2, 9, and 16 DE; postflowering: 30 g ai deltamethrin EC/ha during flowering (50% flower set) and 10 and 20 d later			
1.9 a	0 a	1.2 a	1.11 a
Untreated check			
7.2 d	4.0 b	5.0 b	0.67 c
Recommended practice = preflowering stage: 0.25 kg ai monocrotophos EC/ha at 2 and 12 DE; postflowering stage: 10 g ai deltamethrin EC/ha at 30 and 40 DE			
3.6 ab	0.2 a	2.0 a	0.88 b
Alternative practice 1 = preflowering stage: 0.25 kg ai monocrotophos EC/ha at 2 and 12 DE; postflowering stage: 10 g ai deltamethrin EC/ha at 30, 40, and 50 DE			
5.2 cd	1.2 a	2.4 a	0.97 ab
Alternative practice 2 = preflowering stage: 0.25 kg ai monocrotophos EC/ha at 2 and 12 DE; postflowering stage: 5 g ai deltamethrin EC/ha at 30, 40, and 50 DE			
4.7 bcd	0.6 a	3.4 ab	0.84 bc
Alternative practice 3 = preflowering stage: seed treatment 10 g ai carbosulfan WP/ha (pelleting with cassava flour); postflowering stage: 10 g ai deltamethrin EC/ha at 30, 40, and 50 DE			
4.0 abc	0.6 a	1.4 a	0.97 ab

[a]Av of 5 replications (fields). DE = days after emergence. [b]*Medythia suaturalis*; 35 plants sampled. [c]*Ophiomyia phaseoli*; 35 plants sampled. [d]*Maruca testulalis*; 50 flower clusters and 100 pods sampled. [e]35 m² crop cut.

Cowpea insects. Cowpea was introduced in Claveria in 1984. Insect infestation was low, as farmers grew mainly nonhost cereal crops. Yield losses from insects have progressively increased with year-round cropping of cowpea favored by the long rainy season. Particularly threatening was the appearance of the aphid-borne cowpea mosaic virus disease. A field trial with an early monsoon planting showed the pest-free yield potential to be 1.21 t/ha, but without protection, yield dropped to 0.64 t/ha (Table 5). The recommended practice yielded 1.02 t/ha from 3 insecticide applications (1 seed treatment and 2 sprays against pod borers. Omitting the second spray depressed the yield slightly to 0.94 t/ha. The optimal control practice was the low-cost technology with half dosage of the seed treatment plus two sprays for pod borer, also at reduced dosages. The carbosulfan seed treatment at 50 g ai/ha gave excellent beanfly and aphid control, but only modest control of the virus. If virus pressure were to increase, a dosage of 100 g ai/ha would be warranted. Two deltamethrin sprays against pod borer are minimum. Savings can be gained from reducing the dosage from 10 to 7 g ai/ha.

WEEDS

Agronomy Department

Weed control practices in upland crops. *Rice.* Two experiments were performed. In the first, the major weeds in the experimental area were *Rottboellia cochinchinensis, Borreria laevis, Bidens pilosa,* and *Mimosa invisa.* Growth of *M. invisa* was vigorous in all plots late in the cropping season. This resulted in harvesting problems because of the abundant, sharp, recurved spines on its stem. All weed control practices except the farmer's practice of interrow cultivation at 25 and 40 DE significantly reduced weed weight compared with the untreated check, resulting in grain yield increases (Table 6). The highest yields, net returns (Table 6), and marginal rates of return (Fig. 4), and acceptable marginal benefit-cost ratios (MBCRs) (Table 6) were obtained with hand weeding (HW).

In the second experiment, rice was the first crop in a long-term trial established at two sites in Claveria in the 1987 wet season (WS) to determine the effect of continuous weed control in a cropping sequence on weed growth, composition of the weed flora, and crop yield. At one site, where *B. laevis,*

Table 5. Insect control recommendation development for upland IT82D-889 cowpea.[a] Claveria, Misamis Oriental, Philippines, Jun-Aug 1986.

Beanfly damage[b] (% damaged plants) at 21 DE	Aphid infestation[c] (grade/plant) at 14 DE	Cowpea mosaic virus[d] (% infected plants) at 50 DE	Pod borer damage[e] (% damaged pods) at 17 DAFS	Yield (t/ha)
Complete control = preflowering stage: 0.3 kg ai carbosulfan STW/ha pelletized (cassava flour) seed treatment, 20 g ai deltamethrin EC/ha spray at 7, 14, and 21 DE; flowering stage: 20 g ai deltamethrin EC/ha spray during 50% flower set and 10 and 20 d later				
0 a	1.0 a	0 a	1.0 a	1.21 a
Untreated				
62 d	2.2 b	14 d	14.3 b	0.64 c
Recommended practice = 100 g ai carbosulfan STW/ha pelletized (cassava flour) seed treatment, 10 g ai deltamethrin EC/ha sprays at 50% flower set and 10 d later				
6 bc	1.1 a	5 bc	2.1 a	1.02 ab
Recommended practice minus the last flowering spray				
5 b	1.1 a	3 b	4.7 a	0.94 b
Low cost technology = 50 g ai carbosulfan STW/ha pelletized (cassava flour) seed treatment, 7 g ai deltamethrin EC/ha sprays at 50% flower set and 10 d later				
8 c	1.3 a	11 cd	2.7 a	1.00 b

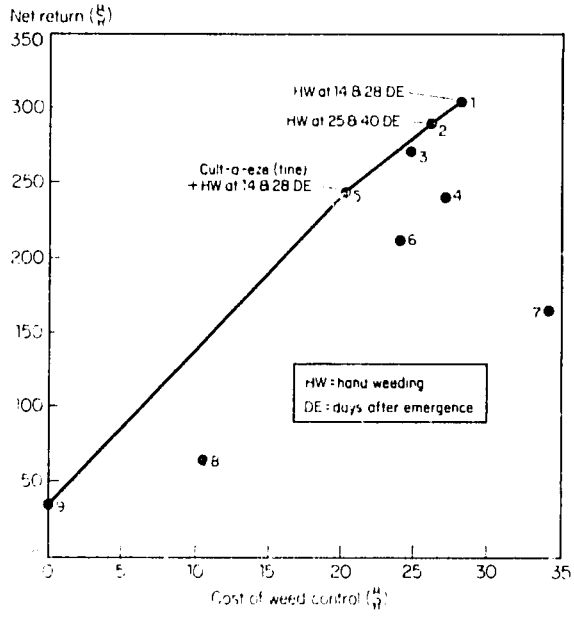
[a]Av of 5 replications (farms). Pelletized seed treatment = carbosulfan added to wet cassava flour paste, seeds coated with paste, then coated with dry cassava flour. [b]*Ophiomyia phaseoli*; 35 plants sampled. [c]*Aphis craccivora*; aphid infestation grade per plant: 1 = none, 3 = winged adults only, 5 = small colony, 7 = several small colonies, 9 = whole plant. 35 plants sampled. [d]10-m-row sample. [e]*Maruca testulalis* and *Etiella zinckenella*; 15 plants sampled. DAFS = days after 50% flower set.

Table 6. Weed weight, grain yield, and cost and return analysis of various weed control practices in UPLRi 7 upland rice.[a] Ane-i, Claveria, Misamis Oriental, Philippines, 1987 WS.

Weed control practice	Weed weight (g/m^2) at 45 DE	Grain yield (t/ha)	Costs ($/ha)			Returns[b] ($/ha)		MBCR[c]
			Labor and power	Materials	Total variable costs	Gross	Net	
1. HW at 14 & 28 DE	3.5 ab	2.5 a	33	–	33	338	305	11.7
2. HW at 25 & 40 DE	8.5 bc	2.4 ab	31	–	31	324	293	12.0
3. UW + HW at 14 & 28 DE	17.3 c	2.2 ab	30	–	30	297	267	11.4
4. Pendimethalin (1.0) & HW at PE & 28 DE	2.8 a	2.0 ab	10	23	33	270	237	8.6
5. Cult-a-eze (tine) + HW at 14 & 28 DE	15.1 c	2.0 ab	25	–	25	270	245	13.5
6. IRC + HW at 14 & 28 DE	21.4 c	1.8 ab	29	–	29	243	214	9.0
7. Whizzle weeder + HW at 14 & 28 DE	15.6 c	1.5 b	39	–	39	203	164	4.4
8. IRC at 25 & 40 DE (FP)	93.1 d	0.6 c	11	–	11	81	70	–
9. No weeding	288.6 d	0.3 c	–	–	–	41	41	–

[a]DE = d after emergence, HW = hand weeding, UW = upland weeder, PE = preemergence, IRC = interrow cultivation, FP = farmer's practice. Figures in parentheses are application rates in kg ai/ha. [b]Gross return = grain yield X price of rough rice at harvest ($0.135/kg); net return = gross return – total variable cost. [c]Marginal benefit-cost ratio (MBCR) = (gross return of treatment – gross return of farmer's weed control practice)/(total variable cost of treatment – total variable cost of farmer's weed control practice).

Digitaria setigera, and *B. pilosa* were the dominant weed species, all the weed control treatments reduced weed weight at 45 DE compared with the untreated check (Table 7). Except for interrow cultivation, weeding produced substantial yield increases. High gross returns and MBCRs were obtained with all treatments compared with the improved farmer's practice of interrow cultivation at 14 and 28 DE.



4. Net return curve of weed control practices to UPLRi-7 upland rice. Ane-i, Claveria, Misamis Oriental, Philippines, 1987 WS. (See Table 6 for key to treatments.)

Because of their comparatively low cost, pendimethalin plus HW and pendimethalin plus 2,4-D dominated the rest of the treatments in terms of net return at a given weed control cost (Fig. 5). At the other site, where *B. laevis* and *R. cochinchinensis* were the dominant weeds, the most effective treatments were interrow cultivation plus HW at 14 and 28 DE plus another HW at 45 DE, and pendimethalin plus HW.

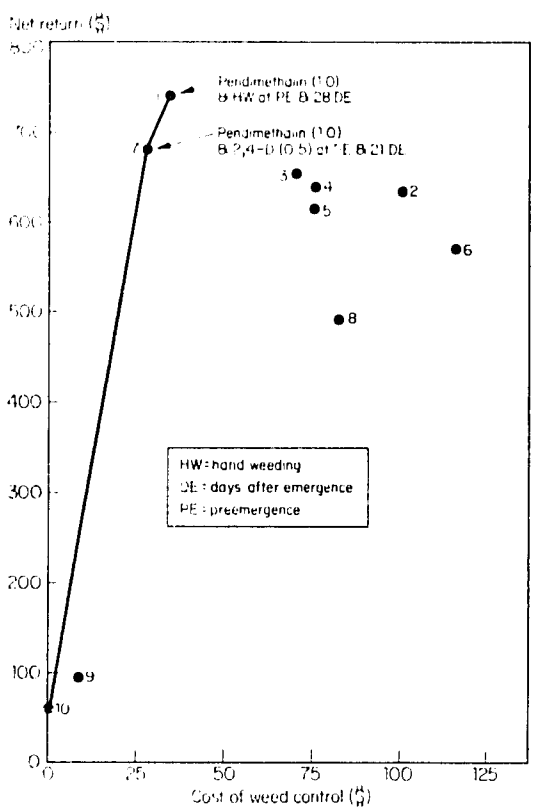
Maize. The dominant weeds in this experiment were *B. laevis* and *D. setigera*. All weed control treatments significantly reduced weed weight compared with the unweeded check (Table 8). All treatments were highly profitable. The highest yields and gross returns were obtained with treatments 1 and 2. The highest marginal rates of return were obtained with treatments 1 and 3 (Fig. 6). Treatment 2 had a lower marginal rate of return because of its higher cost.

Crop rotation. The effect of land preparation and weed control practices on weed growth and yield were studied in three cropping patterns.

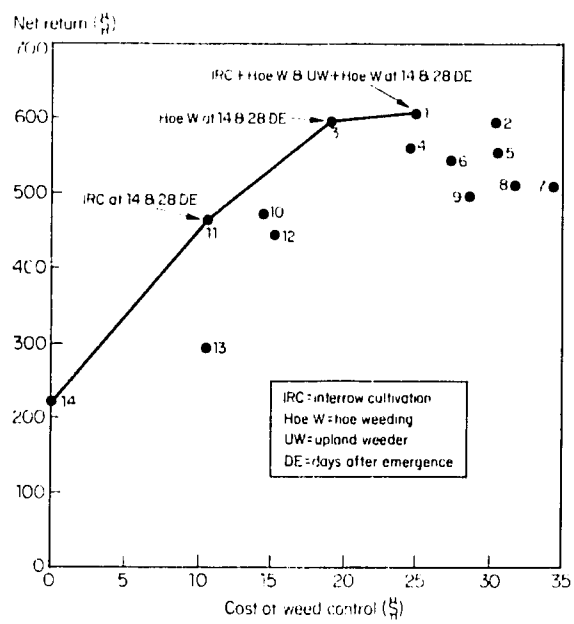
Table 7. Weed weight, grain yield, and cost and return analysis of various weed control practices in UPLRi 7 upland rice.[a] Patrocinio, Claveria, Misamis Oriental, Philippines. 1987 WS.

Weed control practice	Weed weight (g/m²) at 45 DE	Grain yield (t/ha)	Costs ($/ha)			Returns[b] ($/ha)		MBCR[c]
			Labor and power	Materials	Total variable costs	Gross	Net	
1. Pendimethalin (1.0) & HW at PE & 28 DE	2.7 a	5.8 a	15	23	38	783	745	25.0
2. Hoe W + HW at 14, 28, & 45 DE	9.7 a	5.4 a	101	–	101	729	628	6.9
3. HW at 14 & 28 DE	10.2 a	5.3 a	68	–	68	716	648	10.7
4. HW at 14, 28, & 45 DE	8.7 a	5.3 a	76	–	76	716	640	9.4
5. IRC + HW at 14 & 28 DE	9.3 a	5.1 a	65	11	76	689	613	8.9
6. IRC + HW at 14 & 28 DE + HW at 45 DE	16.2 a	5.1 a	102	11	113	689	576	5.7
7. Pendimethalin (1.0) & 2,4-D (0.5) at PE & 21 DE	20.6 a	5.1 a	2	28	30	689	659	30.6
8. Hoe W + HW at 14 & 28 DE	58.8 a	4.3 b	81	–	81	581	500	6.8
9. IRC at 14 & 28 DE (IFP)	238.5 b	0.8 c	11	–	11	108	97	–
10. No weeding	361.9 c	0.4 c	–	–	–	54	54	–

[a]Figures in parentheses are application rates in kg ai/ha. Hoe W = hoe weeding, IFP = improved farmer's practice. [b]Gross return = grain yield X price of rough rice at harvest ($0.135/kg); net return = gross return – total variable cost. [c]Marginal benefit-cost ratio (MBCR) = (gross return of treatment – gross return of improved farmer's weed control practice)/(total variable cost of treatment – total variable cost of improved farmer's weed control practice).



5. Net return curve of weed control practices in UPLRi-7 upland rice. Patrocinio, Claveria, Misamis Oriental, Philippines, 1987 WS. (See Table 7 for key to treatments.)



6. Net return curve of weed control practices in IPB Var 1 maize. Patrocinio, Claveria, Misamis Oriental, Philippines, 1987 WS. (See Table 8 for key to treatments.)

Transplanted rice - transplanted rice. Weeding treatments in the first crop affected the dominant weed species in the unweeded second crop at 4 and 7 wk after transplanting (WT). HW once or twice

Table 8. Weed weight, grain yield, and cost and return analysis of various weed control practices in IPB Var 1 maize. Patrocinio, Claveria, Misamis Oriental, Philippines, 1987 WS.

Weed control practice	Weed weight (g/m^2) at 45 DE	Grain yield (t/ha)	Costs ($/ha)			Returns[a] ($/ha)		MBCR[b]
			Labor hours	Labor and animal hours	Total variable costs	Gross	Net	
1. IRC + HW & UW + Hoe W, 14 & 28 DE	11.3 a	5.0 a	19	5	24	625	621	25.0
2. Cult-a-eze (tine) + HW, 14 & 28 DE	8.9 a	5.0 a	30	–	30	625	595	17.0
3. Hoe W, 14 & 28 DE	9.7 a	4.9 ab	19	–	19	613	594	39.0
4. IRC + HW & UW + HW, 14 & 28 DE	8.0 a	4.7 abc	19	5	24	588	564	22.2
5. IRC + HW, 14 & 28 DE	42.7 ab	4.7 abc	20	11	31	588	557	14.4
6. IRC + Hoe W, 14 & 28 DE	34.8 ab	4.6 abc	17	11	28	575	547	16.2
7. HW, 14 & 28 DE	5.7 a	4.4 abc	34	–	34	550	516	10.9
8. UW + Hoe W, 14 & 28 DE	9.1 a	4.4 abc	32	–	32	550	518	11.9
9. UW + HW, 14 & 28 DE	6.3 a	4.2 abc	29	–	19	525	496	12.5
10. IRC & HW, 14 & 28 DE	116.5 cd	3.9 abc	9	5	14	488	474	62.7
11. IRC, 14 & 28 DE	142.8 de	3.8 bc	–	11	11	475	464	–
12. UW, 14 & 28 DE	103.0 bcd	3.7 c	15	–	15	463	448	40.8
13. IRC, 28 & 40 DE (FP)	187.8 e	2.4 d	–	11	11	300	289	–
14. No weeding	363.2 f	1.8 d	–	–	–	225	225	–

[a]Grosss return = grain yield X price of maize at harvest ($0.125/kg); net return = gross return – total variable cost. [b]Marginal benefit-cost ratio (MBCR) = (gross return of treatment – gross return of farmer's weed control practice)/(total variable cost of treatment – total variable cost of farmer's weed control practice).

in the first crop increased the proportion of *Monochoria vaginalis* in the second but decreased the proportion of *Echinochloa glabrescens*.

Weeding treatments in the first crop affected weed weight at 7 WT in the unweeded second crop. Weeding once or twice in the first crop resulted in lower weed weight in the second crop. The harrowing treatments applied before the second crop was planted had no effect on weed weight at 7 WT.

HW in the second crop reduced weed growth, resulting in yield increases. Harrowing for the second crop did not affect crop yield, but the level of HW in the first crop did. Plots that were hand weeded twice in the first crop yielded significantly higher than those that were not weeded in that crop.

Transplanted rice - mungbean. When zero tillage was used for mungbean establishment, *Fimbristylis miliacea*, *E. colona*, *Lindernia* spp., and *E. glabrescens* were dominant when the previous crop was not weeded. When the previous crop was hand weeded, *E. colona* became more dominant. When the land was rototilled before mungbean establishment, *E. colona* was the dominant weed species, with dominance decreasing with increasing weeding intensity in the previous crop.

HW in the transplanted rice (TPR) crop reduced weed weight in the mungbean crop. There was also less weed growth in the rototilled plots than in the no-tillage plots.

HW in mungbean reduced weed weight, resulting in yield increases. However, weeding in the previous crop did not affect mungbean yield. Yields were greater in the rototilled plots than in the no-tillage plots.

Mungbean - transplanted rice. HW in mungbean reduced the density and weight of *E. colona* in the following TPR crop but did not affect the total weed weight because of the presence of other weed species.

The tillage treatments applied before transplanting rice affected weed growth at 4 WT. Compared with one harrowing, two or three

harrowings reduced the weight of *E. colona* but generally increased that of *Cyperus rotundus*. Total weed weight was also reduced with more harrowings. Differences in weed weights among treatments were no longer observable at 7 WT.

The TPR crop produced no yield in the unweeded plots because of intense weed growth. The hand-weeded plots that were harrowed two or three times before transplanting had higher yields than those that were harrowed once. Tillage and weeding treatments applied to the previous mungbean crop had no effect on rice yield.

Control of weed species. *Scirpus maritimus*. In dry season, the grain yield of rotary-weeded plots in a continuous TPR pattern was significantly higher than that of bentazon-treated plots (Table 9). The untreated check gave no yield because of high *S. maritimus* population.

When maize was intercropped with soybean, the highest yields were obtained with hand weeding. Both herbicide-treated and untreated plots gave low yields because of uncontrolled broadleaf weeds. Where maize was planted alone, hand-weeded plots produced the highest grain yields. The untreated check yielded low because of mixed weed pressure.

In continuous TPR cropping in WS, rotary-weeded and herbicide-treated plots gave similar yields, which were higher than that of the untreated check (Table 10).

Table 9. Effect of weeding method and cropping pattern on crop yield and population density of weeds.[a] IRRI, 1987 DS.

Cropping pattern and weeding treatment[b]	Yield[c]	Weeds (no./m²)				
		Broadleaf weeds	Grasses	Sedges	*Scirpus maritimus*	*Cyperus rotundus*
Continuous TPR	*Rice (t)*					
Rotary weeding	3.8 a	4	0	11	90	0
Bentazon (1.5 kg ai/ha)	2.9 b	0	8	0	99	0
No weeding	0 c	0	0	0	1142	0
Upland crops - TPR	*Maize (ears) + soybean (kg)*					
Hand weeding	31,500 a + 805 a	45	6	8	0	0
Butachlor (1.5 kg ai/ha)	9,500 b + 605 a	151	6	0	0	0
No weeding	7,750 b + 425 a	273	0	0	0	0
Maize - rainfed bunded DSR	*Maize (ears)*					
Hand weeding	25,000 a	37	3	3	1	12
Butachlor	19,000 ab	194	32	0	8	7
No weeding	9,500 b	60	36	18	0	0

[a]Av of 2 replications. [b]TPR = transplanted rice, DSR = dry seeded rice. [c]Within a cropping pattern, values followed by a common letter are not significantly different at the 5% level by DMRT.

Table 10. Effect of weeding method and cropping pattern on rice yield and population density of weeds.[a] IRRI, 1987 WS.

Cropping pattern and weeding treatment[b]	Rice yield (t/ha)	Weeds[b] (no./m²)			
		Broadleaf weeds	Grasses	Sedges	*Scirpus maritimus*
Continuous TPR					
Rotary weeding	3.8 a	37	22	304	47
Bentazon	3.5 a	41	48	101	87
No weeding	0.3 b	17	7	280	956
Upland crop - TPR					
Rotary weeding	3.9 a	24	54	497	14
Bentazon	3.8 a	29	5	320	12
No weeding	1.4 b	14	4	611	128
Upland crop - rainfed bunded DSR					
Hand weeding	1.4 a	34	5	22	2
Butachlor	0.9 b	63	4	9	4
No weeding	0 c	82	9	201	2

[a]Av of 2 replications. [b]There was no *Cyperus rotundus*.

In upland crop - TPR, yield differences were similar to those in continuous TPR. Yields of untreated plots were low because of the annual sedge *F. miliacea*.

In dry seeded, rainfed, bunded rice following maize, yields were higher with hand weeding alone. Butachlor-treated plots gave low yields because of *Macroptilium lathyroides* and *Ipomoea triloba*. Untreated plots gave zero yields because of broadleaf weeds and other annual sedges. *Cyperus rotundus* was not found in any of the plots.

Salvinia molesta. The effect of drying on *Salvinia molesta* was examined in a pot trial. Plastic pails were half-filled with lowland puddled soil, and sufficient *S. molesta* was added so that there was 50 or 100% weed cover. The weed was allowed to grow for 1 wk before it was subjected to 1-7 d of drying. The soil was flooded with 10 cm of water after each drying period to determine the recovery percentage.

S. molesta was very sensitive to drying. Few plants survived after 4 d of drying (Table 11). No weeds recovered with 50% weed cover after 7 d of drying, while only 0.5% recovery was observed when there was 100% weed cover. This illustrates the significance of field drying in the control of *S. molesta* and why it is less important in rainfed ricefields than in irrigated fields.

Table 11. Percent recovery of *Salvinia molesta* as affected by length of drying. Iloilo, Philippines, 1987 DS.

Length of drying (d)	Recovery (%) with weed cover of	
	50%	100%
1	95.0 c	95.0 c
2	57.5 b	88.8 c
3	14.0 a	31.5 b
4	1.3 a	6.0 a
5	0.8 a	1.3 a
6	0.4 a	0.9 a
7	0 a	0.5 a

Cropping systems program

Design and evaluation of cropping patterns

Multiple Cropping, Agronomy, and Agricultural Economics Departments

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PARTIALLY IRRIGATED ENVIRONMENT

Multiple Cropping and Agronomy Departments

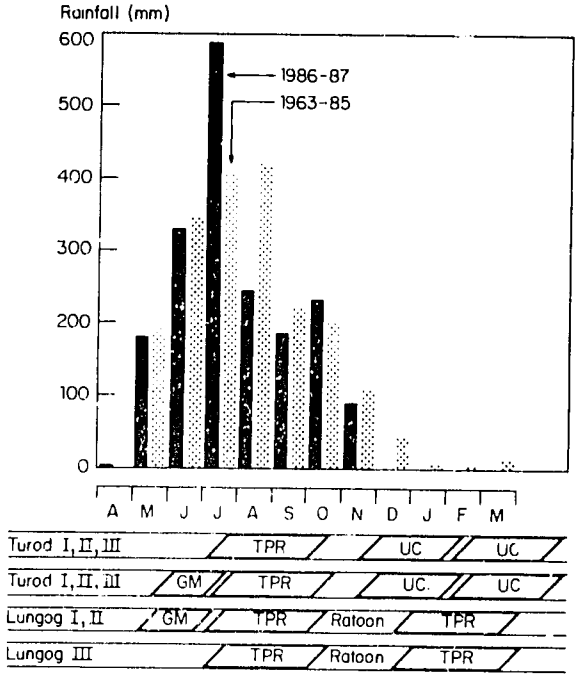
The partially irrigated project in Guimba, Nueva Ecija, Philippines, was begun in 1984 to diagnose constraints to crop diversification and to develop component technologies to enhance the productivity of land, labor, and capital. Details about the site and research methodologies were given in the Annual reports for 1984 and 1985. The cropping patterns and rainfall are summarized in Figure 1.

Crop sequence evaluation. The objective of the trials was to develop cropping patterns that farmers can manage on turod (upper stratum) and lungog (lower stratum) land to produce higher returns to land, cash inputs, and labor than present patterns and, in the process, to determine irrigation management that would distribute limited and costly water efficiently.

Thirty-one farmer-cooperators tested cropping patterns designed for a partially irrigated environment in two deepwell systems within the villages of Bantug and Macateatuit. Thirteen of the test fields were on turod and 18 on lungog land. (Lungog land is lower lying than turod land and therefore easier to irrigate for rice but harder to drain for upland crops in the dry season [DS].) The present service areas of Bantug and Macateatuit are 75 and 60 ha, respectively.

Agronomic performance. For evaluating the agronomic performance of individual crops included in the cropping pattern design, the crop year (CY) at the research site was divided into three seasons: the wet season (WS) (June to October), the transition season (November to January), and the late DS (February to May).

A major difference with respect to field operations and crop adaptation occurs during the transition season. Turod fields drain more quickly than lungog fields, enabling upland crops to be established in turod fields sooner after WS rice harvest. As the water table recedes during the onset of DS, lungog fields also drain, but not as quickly as turod fields, so a second rice crop following WS rice would be the best use of lungog fields during the transition period. But because of weather constraints, yields of the second rice crop on lungog had been low; hence the establishment of the second rice crop was suspended during CY



1. Rainfall distribution and cropping patterns at the partially irrigated site in Guimba, Nueva Ecija, Philippines, 1963-87. TPR = transplanted rice, GM = green manure, UC = upland crop.

1985-86, and research was conducted to determine the extent of yield limitations imposed by solar radiation, high temperature, and strong winds, and how to overcome their negative effects. On turod, maize and other upland crops were tested during the 1986 transition season.

1986 transition season maize on turod. The mean yield of maize on 9 cropping pattern test fields using IPB was 4.33 t/ha (Table 1), an increase of 1.70 t/ha over yields obtained in 1984. The mean yield of SMC 305 (4.63 t/ha) was comparable to the yield obtained in 1985 (4.52 t/ha) using the same hybrid maize. The soil

Table 1. Grain yield of maize on turod in Guimba, Nueva Ecija, Philippines, 1985-86.

Variety	Yield (t/ha)	
	Mean	Range
IPB	4.33	3.23-5.90
SMC 305	4.63	3.09-6.22

was allowed to dry sufficiently after WS rice, and flush irrigating followed by land preparation when the soil moisture approached field capacity enabled farmers to prepare their fields easily. Secondary tillage reduced the size of large clods formed during primary tillage and improved soil-seed contact. The consequent increase in crop emergence resulted in yields >6 t/ha in some fields.

The substantially improved maize yields during CY 1986-87, are still below the 8 t/ha possible with hybrids. Experiments were conducted to evaluate the feasibility of seeder planting over hand planting under different tillage conditions and also to determine the effect of irrigation frequency and N rate on maize yield.

The study on the effects of tillage and planting methods suggested that maize yield is dependent on crop stand at harvest (Table 2). The no-tillage treatment showed significantly higher crop stand than the tillage treatments, probably because of the higher moisture losses when the soil was disturbed during tillage. In tilled soil, better grain yield was obtained from seeder planting than from hand planting.

Grain yield increased with N rate and irrigation (Table 3). Higher N rate and irrigation frequency caused greater dry matter production and translocation of photosynthetic products, and consequently larger effective ear size and seed size. NPK uptake increased with irrigation frequency (Fig. 2). Significantly higher N uptake occurred with 120 kg N/ha than with 80 kg N/ha at all irrigation levels. Increased NPK uptake improved the yield linearly (Fig. 3).

Table 2. Effects of tillage and planting method on maize yield and plant stand. Guimba, Nueva Ecija, Philippines, 1985-86.

Tillage method	Hand planting	Seeder planting
	Plant stand (plants/m²)	
No tillage	6.8	6.8
Conventional tillage	5.1	6.8
Rototillage	4.3	6.6
CV (%)	13	
LSD (0.05)	1.2	
	Grain yield (t/ha)	
No tillage	3.759	3.144
Conventional tillage	3.976	3.144
Rototillage	2.268	3.669
CV (%)	14	
LSD (0.05)	00.96	

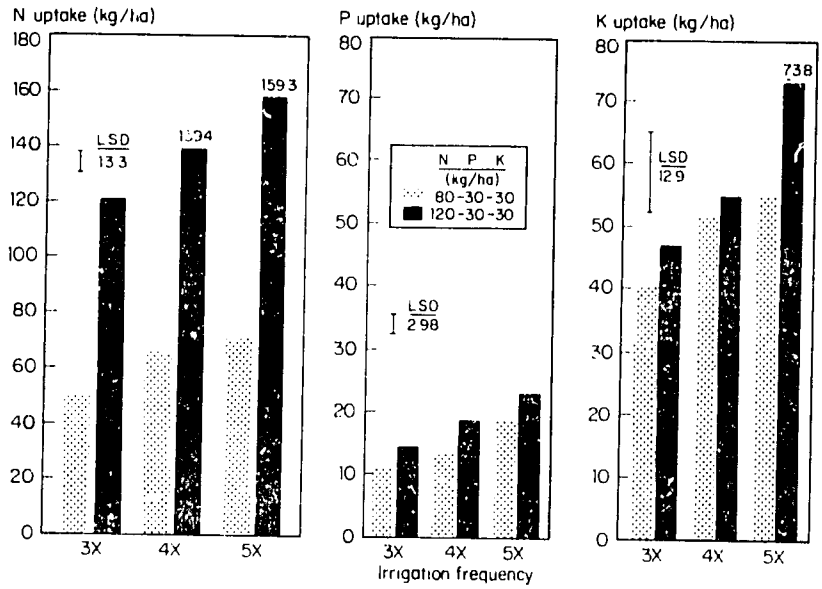
Table 3. Maize yield and yield components as influenced by N rate and irrigation frequency, Guimba, Nueva Ecija, Philippines, 1986.

Treatment	Grain yield (t/ha)	100-grain weight (g)	Ear length (cm)
	80-30-30 kg NPK/ha		
3 irrigations	3.6	20.6	10.1
4 irrigations	4.7	22.1	11.1
5 irrigations	5.0	23.5	11.5
	120-30-30 kg NPK/ha		
3 irrigations	5.9	24.5	12.6
4 irrigations	6.0	23.9	13.2
5 irrigations	6.9	25.2	14.0
CV (%)	7.8	5.7	5.0
LSD (0.05)	0.01	2.0	0.9

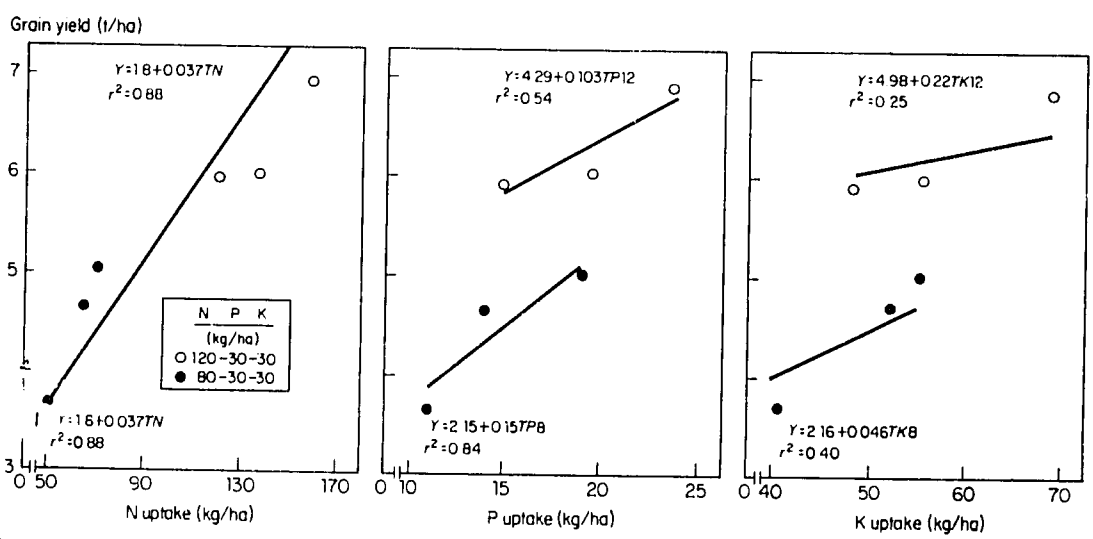
1986 transition season rice on lungog. Studies indicated that three weather factors—solar radiation, temperature, and wind—limited the yield of rice grown during the transition season. A wind barrier experiment was conducted within the service area in Bantug to evaluate the performance of IR64 when fully or partially protected from strong winds. A plastic wind barrier was constructed along three sides of the fully protected plots. Full protection gave significantly higher grain yield, taller plants, and more filled grains than did either partially protected or unprotected treatments (Table 4).

Effect of planting date on rice yield. One major constraint to growing a second rice crop in the transition period is low yield. To determine the cause of low yield, an experiment with 7 transplanting dates at 3-wk intervals was conducted from 7 Oct 1986 to 10 Feb 1987 with 2 N levels—60 and 120 kg N/ha. The study was laid out in a split-plot design, with N levels as main plots and date of planting as subplots. N was applied 1/2 basal and 1/2 at panicle initiation. The treatments were replicated four times, and the experiments were established at three locations: Bantug, Macateatuit, and Curva.

Increasing N rate did not increase IR64 grain yield at any location. Early planting dates (7 Oct - 18 Nov) in Bantug and Macateatuit yielded significantly lower than late planting dates (Table 5). In



2. Nitrogen, phosphorus, and potassium uptake by maize at 2 nutrient levels and 3 irrigation levels, 1987 DS.



3. Relationship between grain yield and NPK uptake at 2 nutrient levels, 1987 DS.

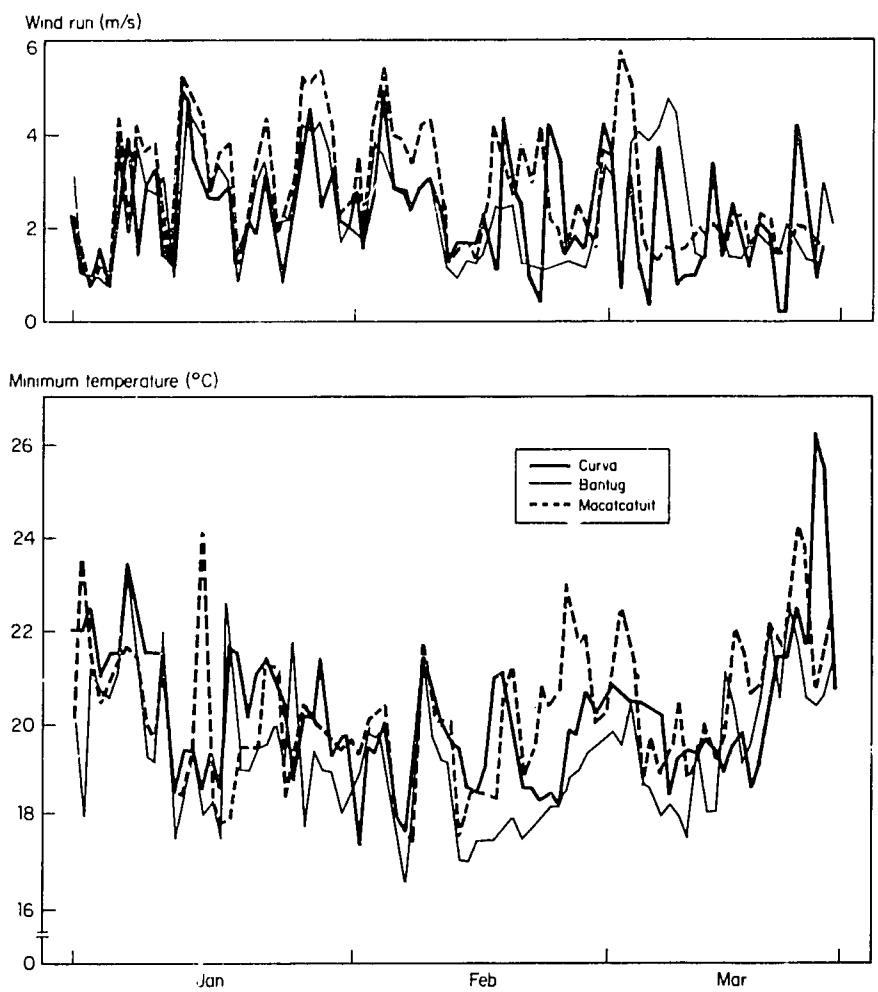
Table 4. Effects of wind barrier on the yield and agronomic characteristics of IR64, Guimba, Nueva Ecija, Philippines, 1986.

Treatment	Grain yield (t/ha)	Plant height (cm)	Panicle length (cm)	Filled grains (no./panicle)	1000-grain weight (g)
Full protection	3.5 a	65.5 a	17.0 a	59.9 a	25 a
Partial protection	3.2 b	60.2 b	16.2 a	51.7 a	24 a
Open field	3.0 b	62.7 b	16.0 a	46.1 b	25 a

Table 5. Effect of N and planting date on IR64 yield in a partially irrigated environment. Guimba, Nueva Ecija, Philippines, 1987 transition season.

Planting date	Grain yield (t/ha)		
	Bantug	Macatcatuit	Curva
7 Oct	2.7	3.0	3.1
28 Oct	3.4	2.9	3.2
18 Nov	2.7	2.3	4.5
9 Dec	3.2	2.9	4.2
30 Dec	3.4	3.6	4.3
20 Jan	3.8	4.5	4.5
LSD (0.05)	0.3	0.5	0.5
CV (%)	10.0	14.7	13.1

Curva, the October plantings yielded significantly lower than the November-January planting dates. The wind run and the minimum temperature at the three locations were compared. With early planting dates, exposure to high wind velocities was more frequent in Bantug and Macatcatuit than in Curva (Fig. 4), probably because the thick bamboo groves and other trees near the experimental field in Curva acted as wind barriers. The number of days of exposure to temperatures below 19 °C was about 50% less in Curva than in Bantug and Macatcatuit. Panicle exsertion and sterility (number of unfilled spikelets) were not affected by exposure to low temperatures, as they had been in



4. Wind run and minimum temperature during January-March 1987 in Curva, Bantug, and Macatcatuit, Guimba, Nueva Ecija, Philippines.

IR58 during the 1985 transition season (Annual report for 1986).

1986 late dry season mungbean on turod. Mungbean (Pagasa 1) was established on turod to complete the cropping pattern rice - maize - mungbean. Mungbean is of interest to farmers in the project area as a late DS crop because it yields well, is relatively easy to establish, does not require fertilizer, competes well with weeds, requires only 70 d in the field, and has a good price in the local market.

Mungbean yields ranged from 0.97 to 1.13 t/ha in different strata. Mungbean was not planted on lungog because test fields had standing water at planting time.

IR64 performance during 1986-87 wet season. Mean yields on the two landforms are summarized in Table 6. Yields in Macatcatuit were higher than in Bantug. The response of rice to P and K was not significant; however, grain yield responded up to 120 kg N/ha, but the increase was only 0.6 t/ha over the yield with 80 kg N/ha.

Establishment of rice. Labor and power are two potential constraints in partially irrigated environments that often increase the cost of rice production. The performance of the IRRI transplanter was compared with that of the row and random transplanting methods. Two land preparation methods were tested to determine if the mechanical transplanter could perform equally well under the farmer's land preparation method of one plowing followed by two harrowings. No significant mean yield differences were observed among establishment and land preparation methods, indicating that the IRRI transplanter can perform equally well under farmer's traditional land preparation methods without yield reduction. The transplanter can transplant 1 ha in about 6 labor days, compared with 14 labor-days for the random planting method and 23 labor-days for the row planting method.

In another experiment, the IRRI drum seeder was compared with broadcast wet seeding and hand transplanting using IR58 and IR64. Hand transplanting gave significantly higher grain yield than wet seeding by the drum seeder or hand broadcasting (Table 7). However, transplanting took about 14 labor-days for 1 ha, against 5 labor-days for the same area using the drum seeder.

Effect of plant density on rice yield. We studied the performance of IR64 at three N levels and four planting distances. Closer planting caused significantly higher grain yields than did the recommended 20 × 20 cm (Table 8). The yield increases were attributed to more productive tillers. N rate did not affect grain yield.

FAVORABLE RAINFED ENVIRONMENT

Multiple Cropping and Agronomy Departments

Work at the favorable rainfed lowland site was begun in 1987 WS. The major research issues are to 1) increase crop intensity and improve the productivity of land, labor, and capital of small rice

Table 6. Grain yields of IR64 on 2 landforms. Guimba, Nueva Ecija, Philippines, 1986 wet season (WS).

Location	Grain yield (t/ha)		Mean
	Turod	Lungog	
Bantug	4.9	4.2	4.6
Macatcatuit	4.9	5.4	5.2
Mean	4.9	4.8	

Table 7. Performance of IR58 and IR64 undor 3 methods of crop establishment. Guimba, Nueva Ecija, Philippines, 1987 WS.

Variety	Grain yield (t/ha)			
	Drum seeder	Broadcasting	Transplanted	Mean
IR58	4.1	4.4	5.0	4.5
IR64	4.1	4.0	5.1	4.4
Mean	4.1	4.2	5.1	
LSD (0.05)		0.3		

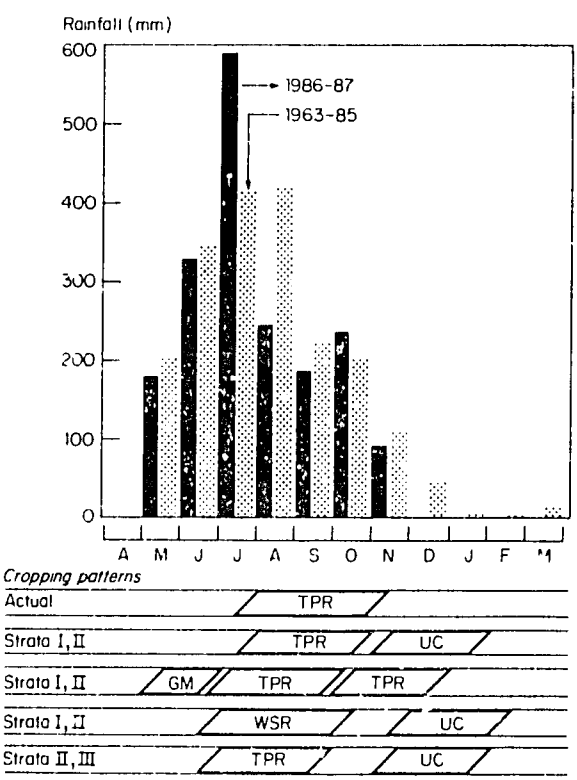
Table 8. Effect of transplanting distance on the yield and agronomic characteristics of IR64. Guimba, Nueva Ecija, Philippines, 1987 WS.

Planting distance (cm)	Grain yield (t/ha)	Productive tillers (no./m²)	Total dry matter yield (t/ha)
20 X 20	5.0	350	8.9
20 X 15	5.2	427	8.9
15 X 15	5.4	512	9.4
10 X 10	5.6	716	9.5
LSD (0.05)	0.4	73	ns
CV (%)	9.2	17.6	13.2

farmers in rainfed lowland areas; 2) develop management techniques for improved cropping patterns; 3) obtain estimates of labor and power profiles for the alternative patterns; and 4) determine farmers' present resource use, and the costs and returns of existing patterns.

Agronomic performance in 1986 wet season. The cropping patterns designed for the favorable rainfed environment for CY 1986-87 are presented in Figure 5. A total of 24 farmer-cooperators were selected, 8 from each stratum.

Farmers started preparing the seedbeds in mid-June after a 115-mm rainfall from 14 to 19 Jun. However, the cumulative rainfall from July to October in CY 1986-87 was less by 400 mm than that in CY 1985-86. Because of this deficit, water was not able to accumulate in the fields to permit puddling, a necessary operation for transplanting, until very late. The average age of seedlings that were transplanted in 12 fields was 50 d. Four fields in stratum I were wet seeded rather than transplanted because the seedlings were too old. As a consequence, only 12 fields were harvested. Five of these received supplemental irrigation from shallow well pumps. Eleven fields, including the 4 wet seeded ricefields, ended in complete crop failure because of WS drought. In the other fields, crop establishment was far behind the designated period.



5. Rainfall and existing and designed cropping patterns at a rainfed lowland site in Guimba, Nueva Ecija, Philippines, 1987. TPR = transplanted rice, UC = upland crop, GM = green manure, WSR = wet seeded rice.

The mean grain yield of IR64 at the rainfed site was 3.0 t/ha across strata. There was no significant difference in yield among strata or between rainfed fields and those with supplemental irrigation. Old seedlings and the long drought were the main reasons for the low yields.

Performance of *Sesbania rostrata* in farmers' fields. *Sesbania rostrata* was planted as green manure (GM) for the prerice crop in three fields in stratum II. Five N levels were superimposed in the main rice crop with GM and another in an adjacent field without GM. The results are summarized in Table 9. GM alone increased the yield of rice by 0.6 t/ha compared with the no-GM treatment. GM supplied between 30 and 60 kg N/ha. In general, the average yields of N + GM treatments were higher than with N alone. The low yields obtained in this study were due to drought and old seedlings.

In another study, *S. rostrata* was compared with 0, 20, 60, 80, and 100 kg N/ha as urea. The crop was given supplemental irrigation. *S. rostrata* seeded in April with a total fresh biomass of 12.8 t/ha at incorporation gave a 4.7 t grain yield/ha and could therefore substitute for up to 80 kg N/ha as urea (Table10). This study also demonstrates the feasibility of establishing *S. rostrata* in April with zero tillage. However,

Table 9. Effect of N levels on the yield of IR64 with and without *Sesbania rostrata*. Stratum II, rainfed environment, Guimba, Nueva Ecija, Philippines, 1987 WS.

N level	Grain yield[a] (t/ha)		
	With GM	Without GM	Average
0	2.5	1.9	2.2
30	2.9	2.3	2.6
60	2.8	2.8	2.8
90	2.7	2.2	2.5
120	3.0	2.2	2.6
Average	2.8	2.3	

[a]Av of 3 fields with green manure (GM) and 2 fields without GM.

Table 10. Comparative effect of GM and inorganic N on the yield and agronomic characteristics of IR64. Rainfed lowland environment, Guimba, Nueva Ecija, Philippines, 1987 WS.

Treatment	Grain yield (t/ha)	Productive tillers (no./m²)	Plant height (cm)
Control (0 N)	3.6	261	86.6
Urea[a]			
20 kg N/ha	3.6	267	88.0
40 kg N/ha	3.9	292	90.0
60 kg N/ha	4.2	295	93.7
80 kg N/ha	4.4	338	96.6
100 kg N/ha	4.8	363	97.2
Sesbania rostrata[b]	4.7	302	95.7
S. rostrata[c]	4.1	301	91.5
LSD (0.05)	1.1	46	10.6
CV (%)	17.6	14	7.7

[a]Urea applied split, ½ basal + ½ at panicle initiation. [b]Seeded 21 Apr, with an average fresh biomass of 12.8 t/ha. [c]Seeded 5 May, with an average fresh biomass of 10.0 t/ha.

farmers encountered incorporation problems due to delayed rains. In a few fields, *S. rostrata* grew tall, and traditional equipment could not be used for land preparation and GM incorporation. Thus, a GM chopper is needed for rainfed areas.

Dry seeded rice establishment. Because of uncertain rainfall, farmers often transplant old seedlings under rainfed lowland conditions, thus reducing yield potential. Dry seeding may allow a short-duration upland crop to be planted in late October to early November before rice. A field study was conducted to compare the inverted-T and the plow seeder developed at IRRI with the local lithao and traditional wooden plow. The seeding rate was 100 kg/ha using IR64. The yield and agronomic characteristic of rice in stratum I as affected by establishment method are presented in Table 11. The inverted-T seeder under full tillage gave the highest yield of 6.3 t/ha but was comparable to the plow seeder and the traditional drill-in-furrow method. The advantage of the inverted-T was the significantly greater number of emerged seedlings, resulting in more productive tillers. Treatments did not cause differences in panicle length and plant height.

Table 11. Yield and agronomic characteristics of IR64 as affected by dry seeding method. Stratum I, rainfed lowland environment, Guimba, Nueva Ecija, Philippines, 1987 WS.

Method of dry seeding	Grain yield (t/ha)	Productive tillers (no./m²)	Emergence (count/linear m)
Drill in furrow	5.5 ab	434	43.0 c
Lithao	5.4 b	485	35.8 c
Plow seeder	5.7 ab	470	36.9 c
Inverted-T, full tillage	6.3 a	561	90.3 a
Inverted-T, zero tillage	4.2 c	447	63.0 b
CV (%)	9.8	16	22.44

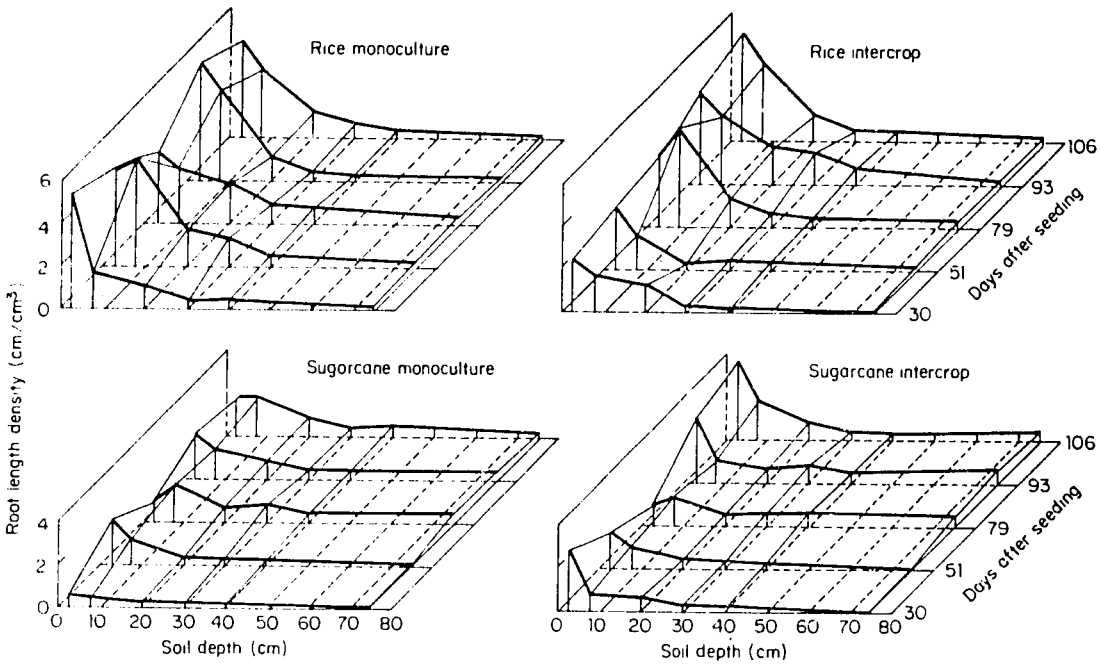
UPLAND RICE ENVIRONMENT

Agronomy Department

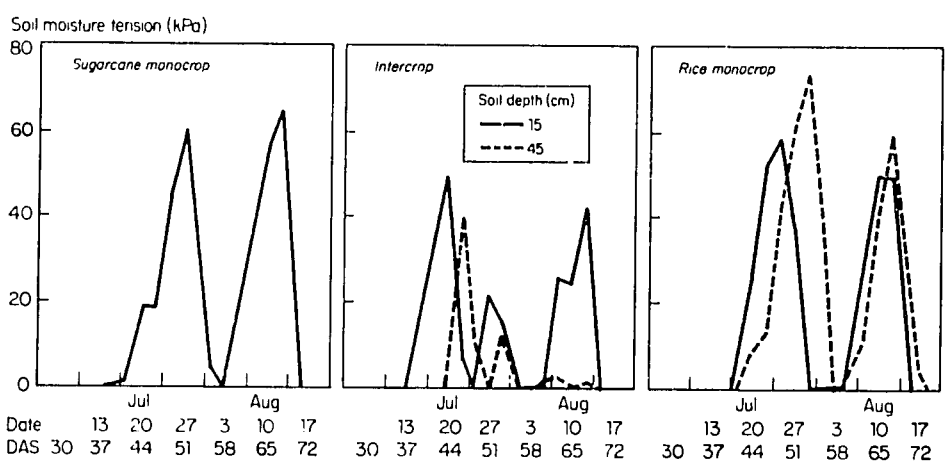
Root distribution and soil moisture of rice - sugarcane intercrop. Because little is known about how intercropped species share water resources when subjected to a water deficit, we studied root and soil moisture distribution in a rice + sugarcane intercropping system.

Field trials were established in cooperation with the University of the Philippines at Los Baños. Sugarcane was planted at the Central Experiment Station in a double-row pattern in July 1987 (WS). Distances between alternate rows were 0.75 and 2.25 m to give the average row spacing of 1.5 m used by most sugarcane growers. A rice + sugarcane intercrop was established by planting 8 rows of Mansanaya upland rice about 25 cm apart in the 2.25 m sugarcane interrow. An upland rice monoculture was also planted with a 25-cm row spacing.

At most soil depths, the root length density (RLD) of rice was greater than that of sugarcane (Fig. 6). For both crops, RLD was nearly fully established by 30 d after seeding (DAS). During a period of relatively dry weather in early July, from 40 to 70 DAS, the rice monoculture and rice + sugarcane used more soil moisture, and had greater soil moisture tension (SMT) than the sugarcane monoculture (Fig. 7). Rice + sugarcane had higher SMT because it fully utilized the area in the 2.25-m sugarcane interrow, whereas there were no sugar-



6. Root length density versus soil depth and days after seeding for rice and sugarcane monocultures and intercrops. Central Experiment Station, University of the Philippines at Los Baños, 1987 WS.



7. Soil moisture tension at 15 and 45 cm soil depth in the middle of 2.25-m interrow for sugarcane monocrop and rice + sugarcane intercrop and in between 25-cm interrow for rice monocrop. Central Experiment Station, University of the Philippines at Los Baños, 1987 WS. DAS = days after seeding.

cane roots in the center of the large interrow. On the other hand, SMT was lower in the intercrop than in the rice monocrop. Although this result may be interpreted to indicate that the rice monocrop was a better extractor of soil moisture, an alternative interpretation is that the rice was less stressed in the intercrop than in the monocrop, perhaps because of a windbreak or shading effect of the sugarcane. Rice yields were low in this experiment because of the variety's long duration

and susceptibility to blast (Bl). Future research will emphasize Bl-resistant varieties with duration of less than 100 d.

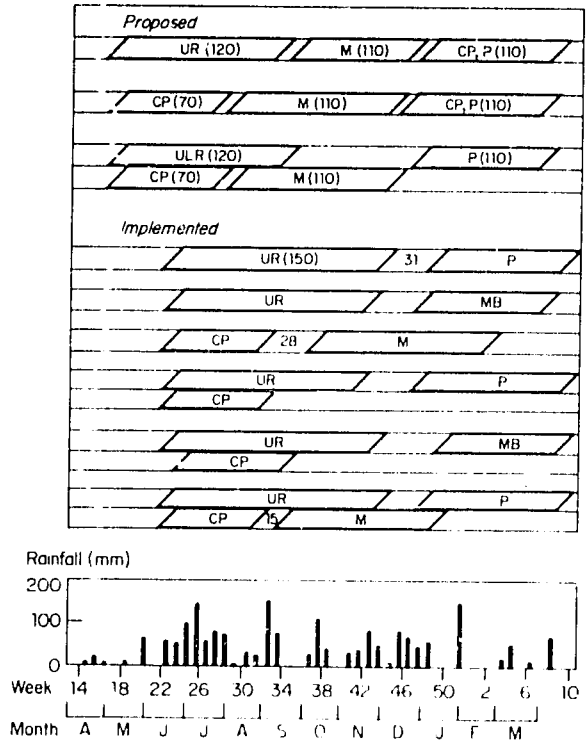
ACID UPLAND ENVIRONMENT

Multiple Cropping and Agricultural Economics Departments

Agronomic evaluation. The dominant field crop patterns at the acid upland research site in Claveria, Misamis Oriental, Mindanao, Philippines, (Oxic Dystropept, pH 4-5) are maize - maize and upland rice - fallow. A major research objective is to develop crop sequences and management practices to raise and sustain yields and economic productivity, that is, to reverse the steady declines in these factors presently being observed. The inclusion of legume crops in the sequence is a major research issue to diversify the cereal-based system and increase the levels of biologically fixed N in the cropping system.

Three cropping patterns containing upland rice (UR), maize (M), cowpea (CP), peanut (P), and mungbean (MB) were proposed for CY 1986-87 based on the results of CY 1985-86 (Annual report for 1986). During the design phase, two of the patterns were deleted because of poor performance. The alternative cropping patterns are graphed against the weekly rainfall distribution for 1986-87 in Figure 8.

The establishment dates for all the implemented patterns were about 3-4 wk later than the proposed patterns because of delay in the onset of rainfall. A midseason drought also occurred. Due to these factors, the farmers revised the cropping patterns in consultation with the research staff to produce six variations of the original three patterns (Table 12). The variations involved the deletion and substitution of component crops to improve the agronomic adaptation of the cropping pattern. In the UR - M - CP, P pattern, M was deleted because of the extended maturity of the preceding UR crop. In the CP - M - CP, P pattern, the last crop (CP or P) was either changed to MB or left unplanted. P was not planted because M harvest was late. In the UR + CP/M/P pattern, one variation was the deletion of M.



8. Proposed and implemented cropping patterns graphed against weekly rainfall distribution. Claveria, Misamis Oriental, Philippines, 1986-87. UR = upland rice, M = maize, CP = cowpea, P = peanut, MB = mungbean. Numbers in bars indicate crop duration (d), those between bars, turnaround time (d).

Table 12. Frequency of proposed and implemented cropping patterns. Claveria, Misamis Oriental, Philippines, 1986-87.[a]

Proposed pattern	Frequency	Implemented pattern	Frequency
UR - M - CP, P	15	UR - P	13
		UR - MB	2
CP - M - CP, P	11	CP - M	11
UR+CP/M/P	15	UR+CP - P	1
		UR+CP - MB	1
		UR+CP/M/P	13

[a]UR = upland rice, CP = cowpea, M = maize, P = peanut, MB = mungbean, - = sequential planting, + = intercropping, / = relay cropping.

Mean yields of the crops during 1986-87 were low because severe drought from the third week of August to the second week of September seriously affected the UR cultivar UPLRi-5 during its

reproductive phase (Fig. 8). Other crops such as CP and M were not in the critical reproductive phase when the drought occurred.

Crop yields in the executed cropping patterns are presented in Table 13. UR yields were 1.9 and 1.7 t/ha for the UR - P and UR - MB patterns. These yields were about 50% of the UR yields in CY 1985-86. Although CP was affected by pod borers, yields averaged 0.94 t/ha in the CP - M pattern. The UR + CP intercrop was also seriously affected by the drought. The yield of UR in this pattern barely exceeded 1.0 t/ha except in a field planted to UR + CP - P, which yielded 2.2 t/ha. CP yields were reduced by as much as 75% of the monoculture yield. The relay establishment of M into the rows vacated by CP was not successful, and M yields were low.

The yields of M following CP in the CP - M pattern were moderate, averaging 2.42 t/ha. MB, which substituted for CP or P, failed because it was sensitive to acidity-induced nutrient imbalances. The yields of P planted after UR or UR + CP intercrop were low, averaging only 0.27 t/ha, because of low rainfall after planting.

Table 14 shows turnaround time between crops in the implemented cropping patterns. The shortest turnaround time of 11 d was in UR + CP/M/P, in which M was relayed into UR following CP. The longest turnaround time (58 d) was in the UR - MB pattern because, shortly after UR harvest, the soil was too dry for MB establishment. Sufficient rainfall had to be accumulated before planting the crop. The long turnaround time in these patterns made it difficult to complete the whole cropping sequence.

The late maturity of the recommended UR cultivar was a major constraint to the establishment and productivity of any following crop. The most common local cultivar (Speaker) has similar maturity, and it is observed that no crop follows UR. Maize, however, matures much earlier (100-110 d), and double cropping is feasible, as shown by farmers' current double-cropped maize system. These observations suggest that a major requirement is UR cultivars with a maturity range of 110-115 d. Such cultivars would enable system productivity to increase through the addition of a second crop, even if rice yields with the earlier cultivars were similar to those of the medium cultivars. Several outstanding early lines have been developed and are under advanced testing at the site.

Table 13. Summary of crop yields in the executed cropping patterns. Claveria, Misamis Oriental, Philippines, 1986-87.

Executed cropping pattern	Observations (no.)	Yield[a] (t/ha)		
		Crop 1	Crop 2[b]	Crop 3
UR - P	13	1.9	0.33 (1)	–
UR - MB	2	1.7	0.00	–
CP - M	11	0.94	2.42	–
UR+CP - P	1	2.20 + 0.71	0.22	–
UR+CP - MB	1	0.87 + 0.66	0.00	–
UR+CP/M/P	13	1.25 + 0.31	0.25 (9)	0.27

[a]The yields of the farmers' traditional systems are as follows: maize - maize, 1.5 and 1.2 t/ha. [b]Numbers in the parentheses represent the frequency of failures.

Table 14. Turnaround time between crops in the implemented cropping patterns. Claveria, Misamis Oriental, Philippines, 1986-87.

Cropping pattern	Farms (no.)	Turnaround time (d)	
		Crop 1 - Crop 2	Crop 2 - Crop 3
UR - P	13	26	–
UR - MB	2	58	–
CP - M	11	28	–
UR+CP - P	1	35	–
UR+CP - MB	25	25	–
UR+CP/M/P	13	11	25

Assessing economic viability. The profitability of the tested cropping patterns and the farmers' patterns was evaluated using enterprise budgeting, given farmer-effective prices that prevailed in the area (Table 15). Except for UR - MB(E), all tested patterns yielded higher returns above variable costs (RAVC) than the farmers' M - M(F) pattern. Three patterns – UR + CP/M/P(E), CP - M(E), and UR + CP - M(E) – had higher returns to labor and power than the traditional pattern. However, the rate of return to material costs was lower because of the increased expenditures on cash inputs with the tested patterns.

UR + CP - M(E) and CP - M(E) dominated the rest of the tested patterns (Fig. 9). UR + CP - M(E)

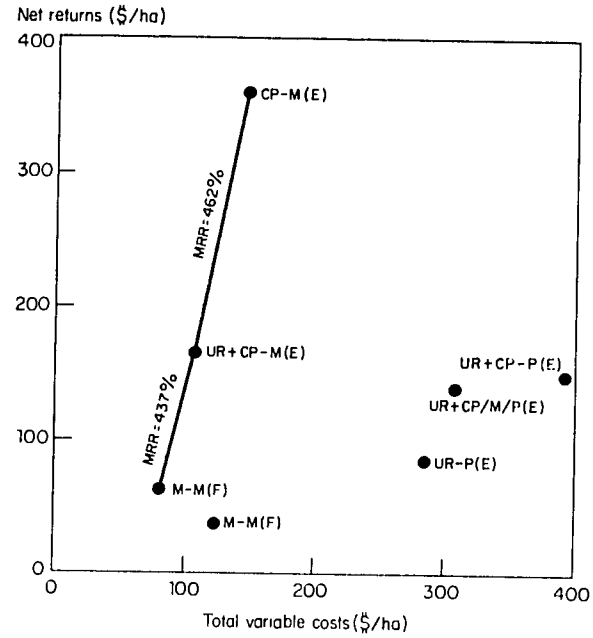
Table 15. Costs and returns of various farmer-managed cropping patterns on experimental (E) and farmers' (F) plots.[a] Claveria, Misamis Oriental, Philippines, 1986-87.

Cropping pattern[b]	Fields (no.)	Yield[c] (t/ha)			Cost ($/ha)			Gross[d] return ($/ha)	Return[e] above variable costs ($/ha)	Rates of return ($/$)		MBCR to replace M-M (F)[h]
		Crop 1	Crop 2	Crop 3	Labor and power	Material	Total variable costs (TVC)			Labor and power[f]	Material[g]	
UR - P (E)	13	1.89	0.33 (1)	–	112	170	282	365	83	1.74	1.49	1.11
UR - MB (E)	2	1.67	0	–	90	129	219	165	–54	0.40	0.58	0.18
CP - M (E)	11	0.94	2.42	–	74	71	145	505	360	5.85	6.09	5.56
UR+CP - P (E)	1	2.20 + 0.71	0.22	–	235	157	392	543	151	1.64	1.96	1.29
UR+CP - M (E)	1	0.87 + 0.66	0	–	49	54	103	269	166	4.40	4.07	5.47
UR+CP/M/P (E)	13	1.25 + 0.51	0.25 (9)	0.27	134	176	310	450	140	2.05	1.80	1.35
M - M (F)[i]	7	0.84	0.83	–	94	32	126	161	35	1.37	2.10	0.45
M - M (F)[j]	34	1.01	0.41	–	76	4	80	140	60	1.81	17.88	–

[a]$1 = ₱20.50. [b]Cultivars: CP, IT82D-889; UR, UPLRi-5; M, IPB Var. 1. E indicates proposed patterns with researcher consultation on management practices, F indicates a prevalently grown pattern with no researcher involvement (i.e., control). [c]Numbers in the parentheses indicate the number of trials that failed. [d]Based on yield, i.e., corrected for 17% harvester/thresher share + 3% losses. [e]Gross return – total variable cost. [f](Gross return – material)/labor and power cost. [g](Gross return – labor and power cost)/material cost.

[h]Marginal benefit-cost ratio (MBCR) = $\frac{\text{(gross return of potential pattern – gross return of prevalent pattern)}}{\text{(TVC of potential pattern – TVC of potential pattern)}}$

[i]Based on improved (hybrid) variety. [j]Based on farmers' variety.



9. Net benefit curve for 5 experimental cropping patterns and 1 farmer's cropping pattern, Claveria cropping systems site, Misamis Oriental, Philippines, 1986-87. M - M(F) used a hybrid maize variety. MRR = marginal rate of return.

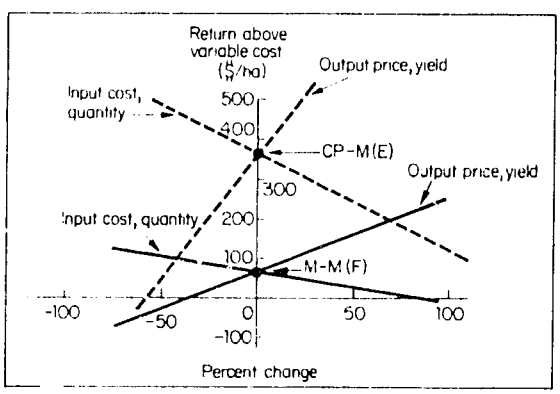
increased net gain by $105/ha (172%) while increasing investment by only $24/ha (30%). In contrast, CP - M(E) increased costs by 138% and net gain by $300/ha (490%). The marginal rates of return of both patterns were over 400%.

Minimum returns analysis was applied to evaluate whether the tested patterns are more or less risky than the traditional M - M(F) technology (Table 16). Only CP - M(E) appeared better than the farmer's pattern, implying that it is less risky than the traditional technology.

The most profitable pattern, CP - M(E), increased total investments from $79 to $145/ha (83%). Parametric budgeting was used to assess the degree to which the farmer is exposed to economic losses arising from increases in input costs or decreases in output price and yield. The result is shown in Figure 10 for CP - M(E) and the farmers' M - M(F) pattern. The improved CP - M(E) pattern required a larger percentage increase in costs (148%) or a reduction in yields and output prices (56%) to bring RAVC to zero. In contrast, the traditional M - M(F) technology would require a 77% increase in variable costs or a 33% reduction in yields and output prices to do so.

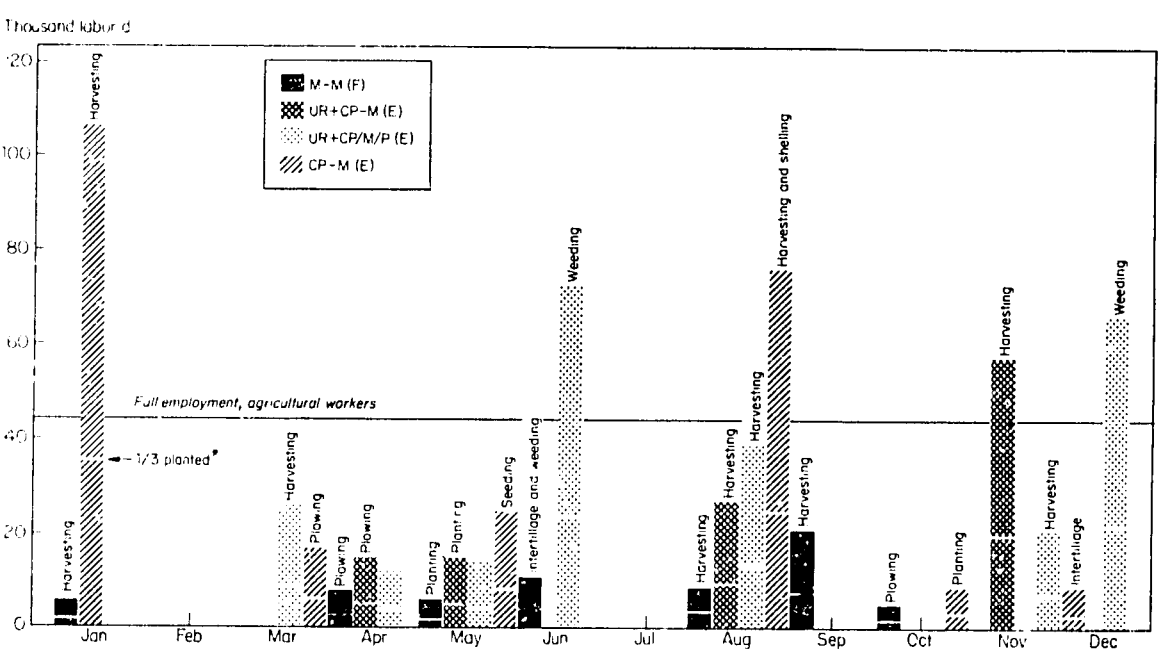
Table 16. Minimum returns analysis of cropping pattern trials. Claveria, Misamis Oriental, Philippines, 1986-87.

Cropping pattern	Wor t net return ($/ha)	Average of 20% of worst net return ($/ha)	Average of all net returns ($/ha)	Marginal rate of return ($)
CP - M (E)	2	157	300	456
UR - P (E)	-212	-125	83	11
UR+CP/M/P	-107	- 81	141	35
M - M (F)	-132	- 50	61	--



10. Sensitivity analysis of experimental cropping pattern CP - M(E) and farmers' dominant cropping pattern M - M(F). Claveria, Misamis Oriental, Philippines, 1986-87.

The labor profiles of the farmers' traditional pattern and those of the tested patterns are shown in Figure 11. Total labor use under the farmers' M - M(F) pattern was generally low during the year owing to the decreased activity as a consequence of the drought. Weeding labor could potentially cause a labor bottleneck in June and December for UR + CP/M/P(E) if all farmers adopted the pattern. Adoption of CP - M(E) on large areas of farmland would not be possible, since the total labor requirement for harvesting and shelling would exceed the existing labor supply (Fig. 11). The largest increase in labor requirement was with UR + CP/M/P(E), from 77 to 200 labor-d/ha (159%). CP - M(E) increased the total labor requirement by 57%. Assuming that all farmers adopt the combination of the three cropping patterns that gave high net benefits (Fig. 9) and allocate one-third of their total area to each of these patterns, the labor requirements could be met. The optimal combination of cropping patterns for Claveria is being examined using whole-farm planning techniques.



11. Monthly labor use at Claveria cropping systems site if all field crop area were planted to one of the experimental cropping patterns, 1986-87. * = labor use if 1/3 of the field crop area were planted to each of the cropping patterns showing high net benefit in Figure 9, i.e., M - M(F), UR + CP - M(E), and CP - M(E).

Cropping systems program

Selecting and testing varieties for rice-based cropping systems

Rice Farming Systems Program and Multiple Cropping and Plant Physiology Departments

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VARIETAL SCREENING FOR DROUGHT TOLERANCE

Multiple Cropping Department

In 1987 dry season (DS), 2 experiments were conducted on the IRRI farm to evaluate and compare the response of 22 soybean and 16 peanut cultivars to water stress imposed during the reproductive phase. The two crops were treated as separate experimental units and were planted in adjacent plots. A strip-plot design was used, with four replications for soybean and three for peanut. Moisture regimes were used as main plot treatments and cultivars as subplots. The plot (2 × 15 m) for each cultivar was subdivided into 3 strips (2 × 5 m) to represent 3 moisture regimes: 1 (closest to the line source = wet), 2 (intermediate), and 3 (farthest from the line source = dry). The experimental areas were irrigated uniformly until flowering. A line source sprinkler irrigation system was then used until crop maturity. The amount of water applied each time was recorded using catch cans strategically placed at canopy height within each of the water regime plots.

The cumulative amounts of water applied for soybean cultivars in the 3 water regimes were 413 mm in regime 1, 288 mm in regime 2, and 112 mm in regime 3; corresponding amounts for peanut were 316, 233, and 106 mm.

Tables 1 and 2 show the bean yield and other agronomic characters of soybean and peanut cultivars in regimes 1 and 3. In both crops, bean yield and yield components were significantly reduced by water stress during the reproductive phase. Soybean had a 45% reduction in grain yield and peanut, 61%.

In regime 3, the top soybean grain yielders were GC50218-6-6 (1.30 t/ha), Improved Pelican (1.25 t/ha), and SJ-2 (1.19 t/ha); for peanut the top grain yielders were F334-33 (1.21 t/ha), IPB PN42-14 (1.19 t/ha), and #234 (1.14 t/ha).

In both crops, number of pods per square meter was more sensitive to drought than seed weight. The reduction in number of pods when regimes 1

Table 1. Bean yield and yield components of 22 soybean cultivars evaluated under moisture regimes 1 and 3.[a] IRRI, 1987 dry season (DS).

Cultivar	Bean yield (t/ha)		Days to maturity		Plant height (cm)		Pods (no./m²)		100-seed weight (g)	
	1	3	1	3	1	3	1	3	1	3
PM 76-6-6-4	2.51	0.95	92	84	60	50	1327	887	10	8
GC60068-9	2.41	1.08	93	83	57	55	972	715	12	9
GC50218-6-6	2.39	1.30	94	86	64	57	1142	904	11	9
7207-1	2.27	0.99	89	82	49	49	884	656	14	11
SJ-2	2.26	1.19	92	83	46	44	964	825	13	10
Duo crop	2.14	1.14	90	83	35	29	778	680	17	12
GC60115-8	2.14	0.86	92	82	56	50	720	587	20	15
Improved Pelican	2.02	1.25	89	81	41	42	1027	823	13	10
Manchuria	1.97	1.03	90	81	46	41	893	674	17	13
TGX536-02D	1.88	0.90	92	84	45	43	1249	805	10	8
Line 1682/1334-1-10	1.84	0.99	89	80	49	44	990	704	11	10
EGSY 73	1.84	1.08	85	77	33	38	774	615	17	13
AGS 229	1.77	1.12	85	76	33	40	936	717	13	10
Willis	1.73	1.03	88	81	49	48	801	691	11	9
Bossier	1.66	1.01	87	79	27	25	679	593	15	12
UPLSY-2	1.66	1.16	85	76	39	43	818	616	16	13
S76-2109	1.53	0.93	85	76	23	24	638	515	16	11
AGS-129	1.52	0.93	85	77	28	29	656	570	16	13
F75-9207	1.44	0.69	91	83	23	23	719	496	13	9
Elgin	1.28	0.89	80	74	24	27	649	573	15	13
Williams	1.07	0.92	79	74	25	32	585	523	15	13
E dou No. 2	0.96	0.64	77	71	21	24	550	487	14	11
Mean	1.83	1.00	88	80	40	39	852	666	14	11
Reduction (%)	45		9		2.5		2.2		21	

[a]Moisture regimes: 1 = wet, 3 = dry.

Table 2. Bean yield and yield components of 16 peanut cultivars evaluated under moisture regimes 1 and 3. IRRI, 1987 DS.

Cultivar	Bean yield (t/ha)		Dry fodder yield (t/ha)		Days to maturity		Plant height (cm)		Pods (no./m²)		100-seed weight (g)	
	1	3	1	3	1	3	1	3	1	3	1	3
IPB PN 48-90	3.60	1.05	7.65	3.01	105	83	56	41	282	262	40	40
IPB PN 46-12	3.28	1.13	6.10	3.49	105	86	58	37	366	270	51	43
IPB PN 42-14	3.27	1.19	5.39	3.07	104	83	54	32	326	274	43	43
UPL PN-4	3.22	1.08	6.27	2.40	105	83	55	37	305	286	42	38
#234	3.21	1.14	6.73	3.13	100	83	56	36	292	222	47	46
#258	3.05	1.09	6.94	3.57	102	87	59	38	326	318	43	42
IPB PN 2-25	2.86	1.12	4.72	2.71	100	86	57	35	354	300	48	45
F334-33	2.77	1.24	5.32	3.25	100	88	58	34	328	212	50	45
EGPN-11	2.71	1.02	5.92	2.70	105	83	55	37	314	287	42	43
Kidang	2.71	0.95	5.88	2.86	100	83	53	36	254	194	49	45
JL 24	2.65	0.98	4.94	2.71	100	86	55	30	372	242	50	46
IPB PN 30-29	2.32	1.10	6.24	3.57	105	90	58	38	302	233	48	47
PL 118200	2.08	1.10	6.00	3.20	100	81	63	41	258	241	46	41
CES 102	2.00	0.87	5.97	3.16	101	86	58	38	326	237	45	43
#758	1.88	1.03	4.85	3.17	100	86	60	34	316	201	46	44
#268	1.76	1.03	4.25	2.97	99	84	53	35	322	320	46	43
Mean	2.71	1.07	5.82	3.07	102	85	57	36	315	256	46	43
Reduction (%)	61		47		17		39		19		7	

and 3 were compared was 22% for soybean and 19% for peanut. Seed weight reduction was 21% for soybean and 91% for peanut.

VARIETAL TESTING

Rice Farming Systems Program and Multiple Cropping Department

Mungbean. Varietal screening and selection of mungbean for rice-based farming systems was done in collaboration with the Institute of Plant Breeding (IPB) of the University of the Philippines at Los Baños (UPLB). In 1987, IPB collected 3,414 lines and varieties and screened them before and after wetland rice at UPLB and in Pangasinan, Philippines. Preliminary yield trials composed of 100 selected lines from the 1986 screening were also conducted after rice at UPLB and in Pangasinan. Yields ranged from 319 to 2,059 kg/ha at UPLB and from 373 to 1,175 kg/ha in Pangasinan. Twenty lines were then selected and entered into an advanced trial at both locations. Five selections—IPB M82-44-11, IPB M82-45-7, IPB M82-45-8, VC 2991-112B-1B, and VC 3749-2B-1-1-1B—were found outstanding at both locations, giving grain yields of 1.3-1.7 t/ha. Check variety Pag-asa 3 yielded 1.1 t/ha. In the prerice planting, five varieties—EGM 2764, IPB M82-57-7, VC 3741-2-1-1-B, VC 3520-B-2-1-2-B, and VC 3742-3B-2B—were also selected for inclusion in the Asian Rice Farming Systems Network (ARFSN) testing. Their yield ranged from 1.14 to 1.30 t/ha, EGM 2764 being the top yielder.

At IRRI, 12 varieties selected from IPB's advanced trial and from national programs were also evaluated before and after rice. The outstanding entries in the prerice test were IPB M79-13-29 (1.48 t/ha), Pag-asa 2 (1.37 t/ha), and IPB M79-9-82 (1.37 t/ha). IPB M79-13-29 gave the highest dry fodder yield of 2.81 t/ha, followed by VC 1973A with 2.55 t/ha. In the postrice test, IPB M79-13-60 (Pag-asa 5) and IPB M79-13-29 were the top grain yielders, with 1.26 and 1.10 t/ha. Dry fodder yield was highest in VC 2762-13-45-2B (2.33 t/ha) and IPB M79-13-29 (1.71 t/ha).

Cowpea. Ten promising cowpea varieties from the International Institute of Tropical Agriculture (IITA) and national programs were evaluated at IRRI before and after wetland rice. Before rice, IT82D-889, IT82D-755, and IT82D-892 were the outstanding entries, giving green pod yields >4 t/ha. The highest fodder yields after 3-4 primings were obtained from IT82E-16 (8.10 t/ha)

and TVx 1850-01E (7.51 t/ha). The trial after rice was discarded because of very poor stand due to waterlogging and seedling damping off.

Ninety-nine lines and varieties from IITA were also evaluated after upland rice during DS. Grain yield ranged from 147 to 1,999 kg/ha, with IT82-D-699 the top yielder. Other promising entries were IT835-728-3, IT835-774-1, and IT835-687-15, with grain yields of 1.5-1.8 t/ha. These varieties mature in 70-75 d.

Soybean. An observational nursery composed of 1,003 soybean lines and varieties from the Asian Vegetable Research and Development Center (AVRDC), IITA, and national programs was planted by IPB after wetland rice and under upland conditions at UPLB and in Pangasinan. Preliminary yield trials with 81 entries were also conducted after rice at UPLB and in Pangasinan. Twenty lines were selected and then entered into advanced yield trials at both locations. Yields ranged from 171 to 572 kg/ha at UPLB and from 169 to 1,749 kg/ha in Pangasinan. The low yields at UPLB were due to waterlogging from the early vegetative phase to flowering. Five lines (IPB SY-178-8, IPB SY-178-18, TGx 888-46, TGx 849-260E, and GC 00002-31) were selected for testing in the ARFSN.

Forty-two promising varieties classified as early (80-85 d)-, medium (86-90 d)-, and late (≥90 d)-maturing were evaluated after upland rice at IRRI during DS. The top grain yielders in the early group were UPLB SY-2 (1.74 t/ha), AGS 124 (1.80 t/ha), and EG SY 73 (1.88 t/ha). Among the medium-maturing varieties, the highest yields were from Improved Pelican (2.27 t/ha), GC 60115-8 (2.01 t/ha), and Willis (1.93 t/ha). The outstanding entries in the late-maturing group were GC 50218-6-6 (2.4 t/ha), GC 60068-9 (2.3 t/ha), and IAC 6 (2.2 t/ha).

Peanut. IPB evaluated 1,197 peanut lines in an observation nursery at UPLB during DS. A preliminary yield trial consisting of 104 IPB lines and foreign accessions was also planted in Pangasinan. Twenty-one entries were selected and entered into an advanced yield trial at UPLB and in Pangasinan. However, yields were very low, ranging from 2 to 600 kg/ha, with FDRS 20 the top yielder. Because yields were abnormally low during 1987, the trials will be repeated.

At IRRI, we evaluated 12 varieties from IPB and national programs after wetland rice and under upland conditions. In an international trial, 25 early-maturing peanut varieties from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) were also tested after rice. Among the IPB lines, EG PN-18, Tainan, and UPL PN4 were the most promising under lowland conditions, with shelled bean yields of 0.90, 0.68, and 0.62 t/ha, respectively. Fodder yield was highest in EG PN-11 (7.4 t/ha) and UPL PN-4 (6.6 t/ha). Under upland conditions, the top bean yielders were IPB PN-42-14 (2.0 t/ha), EG PN-11 (1.6 t/ha), and Tainan (1.6 t/ha). The top yielder of fodder was IPB PN-46-12 (6.12 t/ha). Among ICRISAT lines, ICGSE 11, ICGSE 25, and ICGSE 119 gave the highest bean yields of 1.83, 1.33, and 1.32 t/ha, respectively; the top yielders of fodder were ICGSE 174 (8.6 t/ha) and Robut (8.0 t/ha).

Wheat. Forty wheat entries from India, the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), and the Philippines were evaluated under irrigated and rainfed environments in an upland field. The trials were sown in Los Baños on 29 Dec 1986 (irrigated) and 30 Dec 1986 (rainfed). The seed rate was 120 kg/ha, sown in 20-cm rows. Fertilizer at 50-50-50 kg NPK/ha was applied as basal, and 50 kg N/ha was applied at 25 d after seeding (DAS). For the rainfed crop, the 100-50-50 kg NPK/ha was given as a single basal dose. Pests, diseases, and weeds were controlled.

In the irrigated trial, the grain yield ranged from 0.9 to 3.3 t/ha. Maturity ranged from 74 to 100 d. UPLW-1, Swati, UPLW-2, C213-15, BW-11, and DWR-39 were promising. The highest yield of 3.4 t/ha was obtained from UPLW-1. Late-maturing wheat had no significant advantage over the early-maturing.

In the rainfed trial, the grain yield ranged from 0.6 to 1.4 t/ha. Maturity ranged from 71 to 83 d. DWR-39, 5405, Swati, and UPLW-1 were promising. DWR-39 gave the highest yield of 1.4 t/ha. Late-maturing wheat had no significant advantage over the early-maturing.

Black gram. Twelve black gram selections from AVRDC were evaluated after wetland rice with zero tillage at IRRI. BC 48, BC 104, and BC 66 were most promising, giving dry bean yields of

1.33, 1.20, and 1.15 t/ha and 3.34, 5.46, and 4.51 t dry fodder/ha, respectively. They mature in 95 d.

Chickpea. An international trial of 16 semishort-duration chickpea varieties from ICRISAT was conducted at IRRI under upland conditions during DS. The top yielding entries were ICCL 11141 (0.97 t/ha), BDN 95 (0.96 t/ha), and ICCL 83419 (0.93 t/ha). They mature in 93-95 d.

Sesame. Seven sesame varieties from Thailand were tested at IRRI after wetland rice and under upland conditions during DS. The trial after rice was discarded because plant stand was very poor. Under upland conditions, Nakornsawan and Phitsanulok gave the highest seed yield (0.44 t/ha). These varieties mature in 95-98 d.

Maize. Twelve field maize varieties from IPB, CIMMYT, and national programs were tested after rice with zero tillage. Four varieties (Early DMR Group 1, Muneng 8331, Suwan 2, and XC #1) yielded more than 2 t/ha. Fodder yield was highest at 6-7 t/ha in IPB VAR 2, IPB VAR 1, and Comayugua 8130, which mature in 93-95 d.

Ten glutinous and sweet maize varieties and hybrids from IPB and Australia were also tested before rice. Hybrid 502 gave the highest yields of green ears (4.59 t/ha) and fresh fodder (21.13 t/ha). Check variety Los Baños Lagkitan gave per hectare yields of 2.52 t of green ears and 15.28 t of fresh fodder. The crop was harvested in 72 d.

In the upland, 11 early-maturing normal and 12 high quality protein maize varieties from CIMMYT were tested during the wet season. Among the normal grain types, the top grain yielders were Suwan 8331 (5.76 t/ha), PR 8349 (5.34 t/ha), and PR 8326 (5.31 t/ha). On the other hand, LA (1) 8363, Across 7940, Across 7726, Across 8363, and PR 8362 were the outstanding entries among the high quality protein varieties, with yields >5 t/ha. LA (1) 8363 was the top grain yielder (5.78 t/ha). Most of these varieties mature in 95 d.

Sorghum. Nine hybrids and nine varieties of sorghum found promising in ICRISAT's 1986 adaptation trial were further tested after rice with zero tillage. Twelve varieties from IPB and national programs and 24 introductions from ICRISAT were also evaluated under the same field conditions. Among the hybrids, ICSH 132 gave the highest grain yield (3.01 t/ha). The top yielders of fodder were ICSH 162 (3.67 t/ha) and ICSH 145 (3.12 t/ha). ICSV 126 and ICSV 186 were the outstanding entries, both with grain yields of 3.10 t/ha and with fodder yields of 3.6 and 3.8 t/ha, respectively. In the other trials, CS 116 and CS 137 gave the highest grain yield of 3.0 t/ha among the IPB materials. Among the ICRISAT introductions, ICSV 241 and ICSV 110 were the top grain yielders, both with 3.10 t/ha. The highest dry fodder yield was obtained, however, from ICSV 111, with 3.8 t/ha. These varieties mature in 105-110 d.

Sweet potato. Twelve sweet potato varieties from IPB were evaluated under both lowland and upland conditions during DS. The lowland trial had zero tillage, and the upland trial high tillage. In the lowland trial, G50-10A and G454-23A gave the highest root yields (14.58 and 11.36 t/ha). Dry fodder yield was highest in G525-R-2 (2.68 t/ha), followed by G207-3A (2.37 t/ha). In the upland trial, G454-23A was also the top root yielder, with 21.18 t/ha. As in the lowland trial, G207-3A and G525-R-2 were the highest yielders of dry fodder, with 5.06 and 4.59 t/ha, respectively. The trial was harvested in 105 d.

GROWTH CHARACTERISTICS OF JOB'S TEARS

Plant Physiology Department

Job's tears *Crix lacryma-jobi* L. is widely grown in China because of its grain's medicinal value. Reports indicate that it cures chronic rheumatism, cramps, beri-beri, appendicitis, hepatitis, and nephritis. Recent findings show effects as an anticancer drug.

Job's tears grain has 13.7% protein, 5.4% fat, and 65% carbohydrate. It also contains substantial Ca, P, Fe, and amino acids.

Job's tears is a C_4 plant and highly adaptable to various environments. While it grows best in fertile, moderately moist soil, it can thrive in irrigated, saline, and drought-prone areas.

The traditional Job's tears grows 1.5 m to 2.0 m high, has 10-12 culms, and matures very late. Because of its potential as a medicinal plant, new Job's tears were developed as semidwarf, few-tillering, short-duration crops.

In 1986 DS, the Plant Physiology Department

Table 3. Morphological characteristics and growth habits of 5 Job's tears varieties. IRRI, 1986 DS.

Variety	Seeding to heading (d)	Heading to harvest (d)	Growth duration (d)	Plant height (cm)	Culms (no./plant)	Grain yield (g/m^2)	Stem dry weight (g/m^2)	Total dry weight (g/m^2)	Harvest index
Nakasato	46	53	99	68	10.6	306	338	644	0.47
Okayama	59	61	120	84	7.6	268	454	722	0.37
Rio del Sol	59	61	120	76	6.8	232	352	584	0.39
Thailand	59	51	110	78	7.2	306	365	671	0.45
Indonesia	95	92	187	122	3.6	0[a]	775	775	0

[a]Flowers all sterile.

introduced Job's tears to a tropical environment to observe its physiological characteristics and evaluate it as an alternate crop to rice. Five Job's tears varieties were seeded in 5 20-m rows on 2 Feb 1986 in a well-drained, newly puddled ricefield soil fertilized basally with 100 kg N/ha. The plants were spaced at 20 cm between hills and 30 cm between rows, and were topdressed with 50 kg N/ha at 40 and 70 DAS.

Maturities ranged from 99 to 187 d (Table 3). Two very promising cultivars, Nakasato and Thailand, yielded 306 g/m^2 (equivalent to 3.0 t/ha). They produced dry weight comparable to that of late-maturing Indonesia but had better harvest indices, indicating good grain production efficiency. Both cultivars are semidwarf and early maturing.

Nakasato was bred and is grown in Japan, while Thailand is of tropical origin. Their comparable growth performance suggests that Job's tears can adapt to wide temperature regimes. Okayama deserves further testing because of its vigorous growth and promising yield.

Cropping systems program

Agronomic management in rice-based cropping systems

Multiple Cropping Department

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LOWLAND SYSTEMS

Performance of sesbania as biofertilizer in farmers' fields. A study in farmers' fields in Carosucan, Pangasinan, Philippines, in 1987 compared the agronomic responses of transplanted rice (TPR) to sesbania green manure (GM) and moderate fertilizer N applications or combinations of both at different times. Four farms served as replications. Five treatments were compared: no N (control), 60 kg N/ha, *Sesbania rostrata* at 60 d after emergence (DE), *S. rostrata* at 60 DE + 30 kg N/ha at transplanting, and the same combination topdressed at panicle initiation (PI).

Dry matter of sesbania GM varied from 5.5 to 6.6 t/ha, with N yield of 76 to 91 kg/ha (Table 1). All sesbania plots registered significant increases in rice dry matter and grain yield. Sesbania without N supplementation increased yield by 0.9 t/ha.

Table 1. Response of rice to *Sesbania rostrata* in farmers' fields in Pangasinan, Philippines, 1987.

Treatment[a]	*Sesbania rostrata* dry matter (t/ha)	N yield (kg/ha)	Rice (t/ha)	
			Dry matter	Grain yield
No N	–	–	5.1	2.5
60 kg N/ha	–	–	6.1	3.0
S. rostrata at 60 DE	5.5	76	7.2	3.4
S. rostrata at 60 DE + 30 kg N/ha at transplanting	6.4	88	7.4	3.6
S. rostrata at 60 DE + 30 kg N/ha at PI	6.6	91	7.2	3.7
LSD (0.05)	–	–	1.4	0.7

[a]DE = days after emergence, PI = panicle initiation.

Rice response to intersown and prerice sesbania green manure and to nitrogen rate and method. A study examined the effect of 45-d-old prerice and 20- and 30-d-old intersown sesbania GM on TPR. N at 60 kg/ha was added to GM-N by splitting the amount equally at transplanting and at PI. Another method was topdressing the whole amount at PI. Three N rates—0, 60, and 120 kg/ha, 1/2 basal and 1/2 at PI—without GM were included in the treatments to examine N substitution with GM treatments. Twenty-six-day-old seedlings of IR64 were used. Data from this trial were analyzed in a [(C3X2)+3] factorial in a randomized complete block design (RCBD) with 4 replications.

GM attributes are summarized in Table 2. Total dry matter yield (TDMY) and N yield were significantly affected by establishment method and GM age at incorporation. Prerice sesbania markedly increased in TDMY by 4182 kg/ha over 30-d-old and by 4973 kg/ha over 20-d-old GM intersown with rice, regardless of N application. Although the dry biomass yield responded to split application over topdressed N, the difference (222 kg/ha) was not statistically significant. A similar pattern was exhibited with N accumulation. Prerice GM significantly outyielded 30-d-old intersown GM by 91 kg/ha and 20-d-old GM by 115 kg N/ha, irrespective of N application method.

Rice grain yield and its yield components are shown in Table 3. Grain yield increased significantly with higher N accumulation from GM and with inorganic N rate. Forty-five-day-old GM

Table 2. Total dry matter yield (TDMY) and N yield of *S. rostrata* green manure at different establishment times and with N applied split or all at PI. IRRI, 1986 WS.

Green manure establishment and incorporation[a]	Green manure TDMY (kg/ha)			N accumulation (kg/ha)		
	N split	All at PI	Mean	N split	All at PI	Mean
Prerice, incorporated at 45 DAS	5265			128		
Intersown with rice, incorporated at 30 DAS	1226	940	1083	40	34	37
Intersown with rice, incorporated at 20 DAS	369	214	292	16	10	13
Mean	798	577	688	28	22	25
CV (%)	19.5			20.5		

[a]DAS = days after seeding.

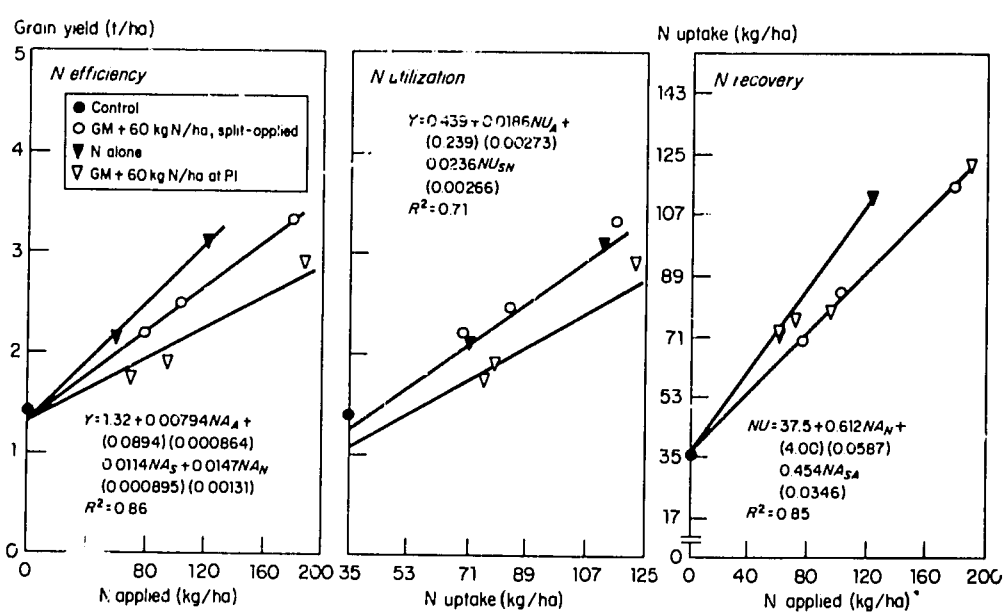
Table 3. Grain yield, N uptake, and TDMY response to N accumulation from sesbania green manure and N applied split or all at PI. IRRI, 1986 WS.

N rate and green manure treatment[a]	Grain yield (t/ha)			N uptake (kg/ha)			TDMY (t/ha)		
	Split	All at PI	Mean	Split	All at PI	Mean	Split	All at PI	Mean
No N	1.4			35			3.8		
60 kg N/ha	2.1			81			6.2		
120 kg N/ha	3.1			112			10.0		
20 DAS, intercropped, no N	1.7			57			6.3		
30 DAS, intercropped, no N	1.8			52			5.5		
45 DAS, in situ, no N	2.8			85			9.1		
20 DAS, intercropped + 60 kg N	2.2	1.8	2.0	68	77	73	7.2	6.7	6.2
30 DAS, intercropped + 60 kg N	2.5	1.9	2.2	84	79	82	7.3	6.5	6.9
45 DAS, in situ, + 60 kg N	3.3	2.9	3.1	117	123	120	9.8	8.5	9.2
Mean	2.7	2.2	2.4	90	93	92	8.1	7.1	7.6
CV (%)	9.1			16.3			14.0		

[a]DAS = days after seeding.

increased grain yield by 51%, while 120 kg N/ha increased yield by 55% over the control. Split application of 60 kg N/ha increased yield significantly by 0.5 t/ha over topdressed N on GM treatments, which conforms well with the pattern and extent of N uptake and TDMY.

The responses of the main rice crop in terms of N recovery, utilization, and efficiency are illustrated in Figure 1. Apparent recovery was 61.2% for split-applied N without GM, and 45.4% for GM with 60 kg N/ha split-applied or topdressed at PI, with the soil supplying 37.5 kg N/ha. N utilization response, however, showed that split N application with or without sesbania was superior to N topdressed at PI with GM treatments. N efficiency differed among all treatment sets, but N applied basal and incorporated in the soil was more efficient than topdressed N, regardless of GM treatment. The



1. N efficiency, utilization, and recovery responses of rice to N and green manure (GM), IRRI, 1986 WS. PI = panicle initiation.

grain-to-N ratio was 7.9:1 for GM with 60 kg N/ha topdressed, 11.4:1 for GM with 60 kg N/ha split-applied, and 14.7:1 for N alone.

After the main crop, another rice crop was transplanted to pick up possible residual N unrecovered by the first rice crop as indicated in Table 2. Grain yield, TDMY, and N uptake were significantly associated with N accumulation from GM plots and with timing of N application to the main crop. These attributes increased markedly with 45-d-old GM, which accumulated 128 kg N/ha. Topdressed and split-applied N were significantly at variance with respect to yield effect, with the former outyielding the latter by 0.3 t/ha.

These findings give optimum combinations of inorganic and organic N sources, N rates, and application methods to optimize grain yield in a GM - rice - rice cropping pattern.

Effect of green manure, nitrogen fertilizer, and spacing on transplanted rice. This experiment during the wet (WS) to dry (DS) season period (November 1986 to April 1987) evaluated the effects of plant density, N rate, and N source and their interaction on TPR. During the GM duration of 52 d, it accumulated 76 kg N/ha.

Grain yield, TDMY, productive tillers, and N uptake of 60 kg N/ha and sesbania treatments were significantly higher than those of the control plots (LSD 0.05) (Table 4). GM increased yield, TDMY, and N uptake significantly by 0.8 t/ha, 1.3 t/ha, and 10.6 kg N/ha, respectively, over the inorganic N treatment. However, productive tiller number was unaffected by GM. The significant yield responses to N source treatments are well supported by the pattern and extent of N uptake at different rice growth stages, as illustrated in Figure 2.

Mean values of grain yield, TDMY, productive tillers, and N uptake were generally inversely related to plant spacing. All these attributes except grain yield were significantly influenced by planting geometry. N uptake was higher at closer than at wider spacing across crop duration.

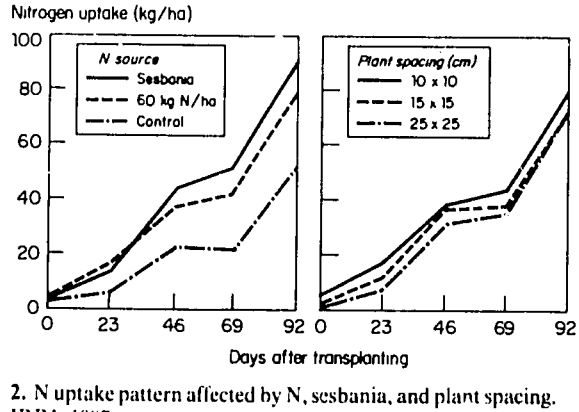
N efficiency, utilization, and recovery were examined using regression analysis as shown in Figure 3. Grain yield increased linearly with applied N regardless of source, with a grain-to-N ratio of 26.3:1. Since yield response to N rate is linear, timely topdressing of inorganic N could further increase N efficiency. N utilization and recovery responses were quadratic, with computed optimum grain yield of 4.6 t/ha when uptake was 103 kg N/ha. N recovery was over 75%, with the soil supplying 50.6 kg N/ha.

These responses suggest the need to optimize N applied, N combinations from organic and inorganic sources, and applications with respect to critical crop growth duration.

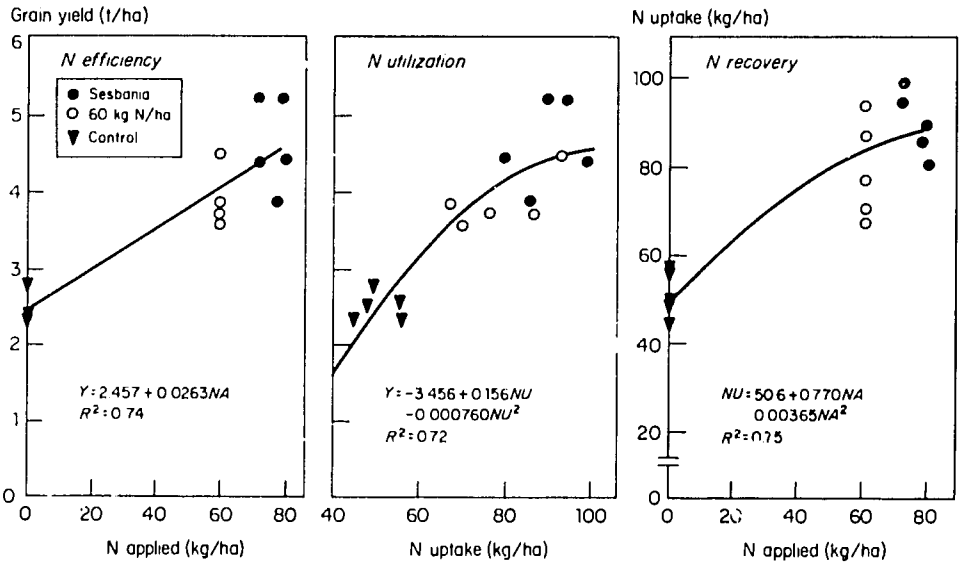
Effect of sesbania and crotalaria green manure and nitrogen supplement on transplanted rice. A field experiment examined the agronomic response of TPR to sesbania and crotalaria GMs at different incorporation ages with or without supplemental

Table 4. Grain yield, TDMY, productive tillers, and N uptake as influenced by green manuring and inorganic fertilization of transplanted rice at different plant spacings. IRRI, 1987 DS.

Parameter	Grain yield (t/ha)	TDMY (t/ha)	Productive tillers (no./m²)	N uptake (kg/ha)
N source				
Control	2.5	4.8	276	50.8
60 kg N/ha	3.8	6.6	334	78.6
Sesbania	4.6	7.9	366	89.2
Plant spacing				
10 X 10 cm	4.1	7.3	419	79.1
12.5 X 12.5 cm	3.7	6.8	367	75.4
15 X 15 cm	3.6	6.1	345	71.6
20 X 20 cm	3.4	5.7	265	66.7
25 X 25 cm	3.5	6.2	231	73.4
Grand mean	3.6	6.4	326	73.3
CV (%)	10.0	4.0	7	9.6
LSD (0.05)	0.7	0.4	34	10.0



2. N uptake pattern affected by N, sesbania, and plant spacing. IRRI, 1987.



3. N efficiency, utilization, and recovery by rice from organic and inorganic N sources. IRRI, 1987 DS.

30 kg N/ha. To determine N substitution expressed as yield response, 6 levels of inorganic N without GM were included in the treatments: 0, 30, 60, 90, 120, and 150 kg N/ha. Treatments were laid out in RCBD with 3 replications in plots measuring 3 × 10 m. Following the main crop, a second crop was transplanted without any fertilizer to evaluate responses to residual N unrecovered by the first crop.

Table 5 shows TDMY and N yields of sesbania and crotalaria at 25, 35, and 45 DE, at which point the GMs were incorporated into the soil. In both species, N accumulation and TDMY increased significantly with age; however, they did not differ between the species. Although crotalaria had slightly higher TDMY than sesbania across growth duration, the latter had slightly higher N accumulation because of its higher biomass N content.

Table 5. N accumulation and TDMY of 2 green manure species at different growth stages before soil incorporation. IRRI, 1986 WS.

Green manure age[a]	N accumulation (kg/ha)		TDMY (t/ha)	
	Crotalaria	Sesbania	Crotalaria	Sesbania
25 DE	49	52	1.5	1.4
35 DE	71	68	2.7	2.5
45 DE	89	95	3.8	3.6

[a]DE = days after emergence.

The grain yield, N uptake, and TDMY of the WS rice crop are summarized in Table 6. These agronomic attributes increased significantly with N accumulation (e.g., GM age). Although supplemental N of 30 kg/ha significantly increased N uptake, it did not improve yield. GM plots yielded significantly higher than either weedy or weed-free fallow treatments. Sesbania and crotalaria supply about 120 and 90 kg N/ha, respectively, at 45 DE.

The N efficiency, utilization, and recovery responses of the main rice crop are illustrated in Figure 4. The effect of supplemental N is not significant in the classification model or analysis of variance; hence, the yield and N uptake response functions to N applied were not significantly partitioned in the regression model.

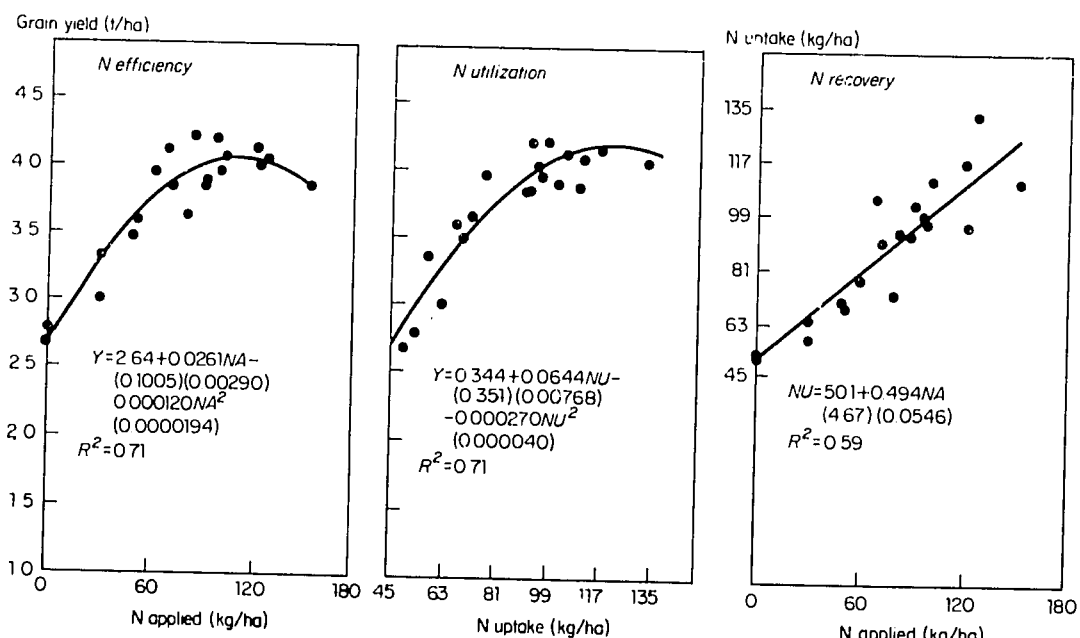
The apparent N recovery was about 49%, with the soil supplying approximately 51 kg N/ha. Grain yield was estimated as optimal when N uptake was 119.3 kg/ha and N applied, regardless of source, was 108.8 kg/ha.

Effect of crop residue, nitrogen, and phosphorus in double and single rice-based cropping sequences. This 1986-87 experiment at IRRI measured productivity changes in two fields with contrasting natural hydrologies and soils. It was difficult to maintain standing water in the upper field because

Table 6. Grain yield, N uptake, and TDMY of rice as influenced by inorganic (0 or 30 kg N/ha) and green manure N fertilization. IRRI, 1986 WS.

N rate (kg/ha) and green manure crop and age[a]	Grain yield (t/ha)		N uptake (kg/ha)		TDMY (t/ha)	
	0 N	30 N	0 N	30 N	0 N	30 N
0 N	2.8		53		6.7	
30 N	3.0		62		7.5	
60 N	4.0		77		8.5	
90 N	3.9		102		9.7	
120 N	4.0		101		10.1	
150 N	3.7		110		11.8	
Crotalaria at 25 DE	3.5	3.6	70	72	8.7	9.2
Crotalaria at 35 DE	3.8	4.1	90	110	10.9	11.9
Crotalaria at 45 DE	3.8	4.1	94	89	11.1	12.6
Sesbania at 25 DE	3.5	4.2	61	92	8.1	10.1
Sesbania at 35 DE	4.1	3.9	104	96	12.0	10.7
Sesbania at 45 DE	4.2	4.1	102	131	11.6	11.7
Weed free	2.7	3.3	49	58	6.1	7.6

[a]DE = days after emergence.



4. N efficiency, utilization, and recovery responses of rice to GM and inorganic N. IRRI, 1986 WS.

of high percolation, but the lower field maintained standing water. The N rate was 60 kg/ha for rice and 100 kg/ha for maize. P was applied at 13.2 kg/ha. All eight factorial combinations were tested in three replications of a RCBD.

Rice in both fields responded significantly to fertilizer. Residue increased yield by 0.4 t/ha in the upper field and by 1.0 t/ha in the lower field, while fertilizer N increased yield by 1.3 t/ha in the upper field and by 1.4 t/ha in the lower field (Table 7).

In 1986, the second rice crop in the lower field responded to fertilizer N and residue from the preceding rice crop. Fertilizer N increased rice yield by 1.0 t/ha, whereas rice residue increased rice yield by 0.2 t/ha. In the upper field, maize responded strongly to applied N, at 2.5 t/ha.

Table 7. Grain yields in 2 experiments[a] with sequences of 4 crops receiving 8 treatments (factorial combinations of with and without inorganic N and P fertilizers and return of crop residue). IRRI, 1986-87.

Treatment	Grain yield (t/ha)							
	Upper field				Lower field			
	1986		1987		1986		1987	
	Rice (IR58)	Maize (SM305)	Mungbean (M350)	Rice (IR62)	Rice (IR58)	Rice (IR58)	Mungbean (M350)	Rice (IR62)
Control (no N, P, or residue [R])	1.1	1.0	1.1	2.0	2.1	1.9	1.8	3.2
N	2.4	3.5	1.2	3.5	3.8	2.9	1.6	4.2
P	1.0	0.9	1.1	2.1	2.5	1.9	1.7	3.2
NP	2.5	3.0	1.2	3.3	4.0	3.0	1.9	4.4
R	1.7	1.3	1.2	2.3	3.2	2.1	1.7	3.5
NR	3.1	3.1	1.2	3.5	4.6	3.2	1.8	4.9
PR	1.4	1.2	1.0	2.4	3.7	2.2	1.5	3.6
NPR	2.5	3.4	1.1	3.6	4.9	3.2	1.6	4.8
LSD (0.05)	0.6	0.5	0.2	0.3	0.4	0.3	0.3	0.6

[a]In adjacent fields that differed in elevation.

In 1987, rice responded significantly to applied N in both fields. However, the response to fertilizer N was higher in the upper field (1.5 t/ha) than in the lower (1.0 t/ha).

Mungbean did not respond to N consistently in either the upper or lower field.

Influence of seeding rate and method and of simulated rainfall after seeding on wet seeded rice. This study evaluated the effect of seeding method, seeding rate, and simulated rainfall on crop stand, yield, and yield components of wet seeded rice. A strip-plot design in RCBD used moisture regimes as main plots and seeding rates and methods as subplots. An 8-row drum seeder was compared with broadcasting of seed at 50, 75, and 100 kg/ha. After sowing, a moisture gradient was imposed using the line source sprinkler system to simulate rainfall on the scattered rice seeds. Regime 1 received 45 mm; regime 2, 26 mm; and regime 3, 6 mm. Uniform flood irrigation was given from 7 d after seeding (DAS) until crop maturity.

Panicle number/m^2 at maturity was highest at 100 kg seed/ha, regardless of seeding method. Seeding at 100 kg/ha was superior to 50 and 75 kg/ha in panicle number, but made no significant difference in grain yield.

Neither seeding method nor water application affected rice yield.

Effect of sowing method and seeding depth on yield of wet seeded rice in the rainfed lowlands. This study evaluated seeding methods (broadcasting and drum seeding) at different depths (surface and 2 cm deep) on preconditioned IR58 and IR64 seed in RCBD. An 8-row drum seeder delivered seed in rows 25 cm apart. A furrow opener attached to the drum seeder drilled seed 2 cm deep. Seeding rate was maintained at 80 kg/ha.

Seeding method did not significantly influence grain yield, nor did sowing depth. This result indicates the potential of drum seeding, which allows mechanical weed control. IR64 was generally better than IR58 in grain yield and TDMY.

Effect of seeding method on establishment of mungbean and cowpea after lowland rice. This experiment determined the stand and yield of cowpea IT82D-889 and mungbean Pagasa I using a mechanical seeder with several furrow openers as compared with hand seeding (Table 8), without tillage and following lowland rice. The experimental design was split-plot in RCBD with the crops as main plots and with seeding methods as subplots. The mechanical seeder was attached to an Iseki hand tractor. For the hand seeded plots, a U-groove opener (dragstick) made shallow furrows. Row spacing was 50 cm, and seeding rate was 30 seeds/linear meter. No fertilizer was applied. Irrigation was provided during the vegetative phase and the flowering and pod-filling stages.

Cowpea grain yields from the inverted-Y seeder and U-groove opener were statistically greater than those from hand seeding (Table 8). The inverted-Y

Table 8. Grain yields of cowpea and mungbean under zero tillage. IRRI, 1987 DS.

Crop	Seeding method	Grain yield (t/ha)	Emergence (%)
Cowpea	Inverted-T	1.0	81.3
	Inverted-Y	1.0	91.3
	U-groove	0.9	80.0
	Hand seeding	0.8	80.0
Mungbean	Inverted-T	2.0	94.4
	Inverted-Y	1.7	95.0
	U-groove	1.8	94.7
	Hand seeding	1.5	85.7
CV (a) %		4.7	
CV (b) %		11.6	
SE		0.04	

and inverted-T seeders gave comparable seed yield, but the inverted-Y gave a higher yield than did the U-groove opener.

The grain yield of mungbean sown using the inverted-T furrow opener was significantly greater than that with other seeding methods. The inverted-Y seeder and the U-groove opener had similar seed yields, both statistically greater than that of hand seeding.

The results indicate that the inverted-T seeder is superior to hand seeding in percentage of seed emergence, thus contributing to better yields, especially with mungbean.

Effects of water stress and tillage on soybean performance. The effects of water stress and tillage on soybean yield were studied under upland and lowland conditions in 1987 DS (January-April). The experimental design was split-split plot with soybean varieties SJ2 and Elgin as main plots and two tillage treatments (conventional and none) as subplots. Irrigation was applied weekly during the reproductive phase, using the line source sprinkler system based on about 0.8 class A pan evaporation replacement 1 d before each irrigation.

Irrigation significantly improved yields of both varieties at both sites (Table 9, 10). SJ2 produced higher grain yields in all irrigation treatments than did Elgin, averaging 22% better in upland and 42% better in lowland. Tillage treatments affected seed yield at both sites. The percent increase in grain yield due to irrigation was higher in Elgin than in SJ2. Yield response to water applied was higher in upland than in lowland.

Effect of soil moisture on emergence of cowpea and mungbean using the inverted-T seeder after lowland rice. This study examined the emergence of cowpea IT82D-889 and mungbean Pagasa 1 using the inverted-T seeder under varying soil moisture levels. The area was flood-irrigated to simulate the saturated condition prevailing after rice harvest.

Both crops emerged best when seeded at 7 d after flooding (DAF) (Table 11). Seeding emergence was drastically reduced with seeding at 11 DAF because of declining soil moisture. At 3 DAF, emergence of both crops was lower than at 5 and 7 DAF because of high soil moisture. For mungbean, seedling emergence was comparable with seeding at 5 and 7 DAF. Cowpea emerged better than mungbean.

Performance of maize and sorghum at different nitrogen levels. We examined maize and sorghum performance at four N rates in 1987 DS after lowland rice with full tillage. N was applied half basal and half at 40 DAS. Maize IPB-1 and sorghum Cosor 5 were irrigated and received full plant protection.

Sorghum yielded higher than maize at low N input (0-40 kg N/ha). Beyond 80 kg N/ha, maize produced higher grain yield than sorghum.

The results show sorghum's potential with low N input.

Peanut establishment using the inverted-T seeder in postlowland rice environment. This experiment evaluated peanut (variety Kidang) performance after lowland rice using three seeding methods in RCBD. The inverted-T seeder and its modification, the T-groove, were compared with hand seeding. Row spacing was 50 cm, and seeding rate was 10 seeds/linear meter. Under high tillage, three passes of the upland power tiller (10 hp) prepared the land. For hand seeding, the rows were constructed with a dragstick attached to an Iseki hand tractor.

Under both zero and high tillage, the mechanical seedings proved better than hand seeding (Table 12).

Better emergence produced greater seed yields at zero tillage. However, the yield of hand seeded peanut was close to that of inverted-T-seeded peanut because the former had more filled pods.

At high tillage, the T-groove produced greater crop stand and seed yield. The inverted-T and hand

Table 9. Effect of water stress and tillage on grain yield of soybean genotypes in an upland experiment. IRRI, 1987 DS.

Variety	Tillage[a]	Grain yield[b] (t/ha)						
		I_1 (321)	I_2 (256)	I_3 (186)	I_4 (126)	I_5 (58)	Mean	
							Tillage	Variety
SJ2	CT	2.09	1.96	1.58	1.31	1.14	1.01	
SJ2	NT	2.07	1.79	1.52	1.34	0.99	1.54	1.58
Elgin	CT	2.02	1.85	1.18	0.95	0.75	1.35	
Elgin	NT	1.75	1.43	0.85	0.78	0.66	1.09	1.22
Mean SJ2		2.08	1.88	1.55	1.33	1.07		
Elgin		1.89	1.64	1.02	0.87	0.71		

[a]CT = conventional tillage, NT = no tillage. [b]I_1-I_5 = irrigation regimes. Numbers in parentheses indicate the irrigation water received, in mm.

Table 10. Effect of water stress and tillage on grain yield of soybean genotypes in a lowland experiment. IRRI, 1987 DS.

Variety	Tillage	Grain yield (t/ha)						
		I1 (294)	I2 (232)	I3 (178)	I4 (192)	I5 (76)	Mean	
							Tillage	Variety
SJ2	CT	3.16	2.36	2.33	1.78	1.59	2.24	
SJ2	NT	2.43	2.20	1.97	1.85	1.56	2.00	2.12
Elgin	CT	1.80	1.48	1.54	1.23	0.89	1.39	
Elgin	NT	1.39	1.18	1.04	0.95	0.75	1.06	1.23
Mean SJ2		2.80	2.28	2.15	1.82	1.58		
Elgin		1.60	1.33	1.29	1.09	0.82		

Table 11. Emergence of cowpea and mungbean at different dates after flooding. IRRI, 1987 DS.

Seeding date (DAF)[a]	Soil moisture content (%)	Emergence[b] (%)	
		Cowpea	Mungbean
3	36.5	67.6	55.2
5	34.4	76.5	70.6
7	31.0	86.5	71.3
11	26.0	30.4	28.4

[a]Days after flooding. [b]Data taken at 10 DAS for each planting date.

seeding were comparable. However, the three seeding methods gave comparable numbers of filled pods.

The results indicate that the T-groove opener is an improvement over the inverted-T opener. The former produces a deeper furrow, suitable for peanut root growth.

Agronomic management of wheat in tropical environments. During 1987 DS, we continued to study cultural practices for wheat to maximize its productivity in a postrice environment.

Table 12. Crop stand, seed yield, and filled pods of peanut under different seeding methods and tillage conditions. IRRI, 1987 DS.

Tillage condition	Seeding method	Seed yield (t/ha)	Crop stand (plants/m²)	Filled pods (no./plant)
Zero	Inverted-T	1.16	7.6	14
	T-groove	1.32	6.9	18
	Hand seeding	1.10	5.8	21
High	Inverted-T	1.82	6.1	24
	T-groove	2.00	7.3	23
	Hand seeding	1.81	6.4	22

Intercropping wheat and maize. An experiment in an upland field in Los Baños evaluated intercropping wheat with maize. We tested 6 intercrop combinations of 2 wheat varieties and maize at 2 N fertilizer levels (80 and 160 kg N/ha). Wheat varieties UPLW-3 and Ciete Cerros were sown on 12 Jan 1987 in rows 15 cm apart at 120 kg seed/ha. Maize was planted at 40,000 plants/ha (PPH) at 150-cm spacing (planting every 10th row). A maize

monoculture (60,000 PPH at 60-cm row spacing) and a wheat monoculture were included. Fertilizers were 80-40-20 kg NPK/ha and 160-60-40 kg NPK/ha. One-half of the N plus the P and K were applied at sowing, with the remaining N applied at 25 DAS. The crop was irrigated and protected from pests.

The grain yields of intercropped wheat and maize were lower than those of the monocrops (Table 13), especially with maize. Increasing the N level from 80 to 160 kg/ha increased the grain yields of both wheat and maize in monoculture and in the intercrop. UPLW-3 appeared to be better adapted than Ciete Cerros in both intercropping and N fertilizer treatments. Maize yield increased at the expense of Ciete Cerros yield. Total productivity (expressed as land equivalent ratio [LER]) was highest with UPLW-3 + maize intercropping at 160 kg N/ha (LER = 1.21). Significant increases in wheat and maize grain yields came primarily from better management.

Effect on wheat of simulated defoliation and awn removal. High humidity and temperature encourage leaf spot caused by *Helminthosporium* sp., reducing the effective leaf area of wheat, especially in the humid tropics. In 1987 DS, we studied the effect of reduced leaf area on wheat grain yield and the sensitivity of wheat to change in source- and sink-proportion in the cultivars Sonalika and UPLW-3.

The crop was sown in 20-cm rows using 120 kg seed/ha in a well-tilled, silty clay field. NP at 50-50 kg/ha was given basally at sowing, with 50 kg N/ha via irrigation. Pests and diseases were adequately controlled.

Wheat was clipped at anthesis (45 DAS) in 3 central rows of each plot. Leaves or awns were reduced by clipping with scissors (Table 14).

Clipping significantly reduced the mean dry matter where all leaves were clipped except flag leaves (T3), all leaves were clipped (T4), and all leaves were clipped and the stem wrapped with aluminum foil (T5).

Grain weight also significantly declined in these treatments. Grain size was smallest when all leaves were clipped and the stem wrapped with aluminum foil. Clipping of all awns, one-half of the awns, and half of the lamina of the flag leaves did not significantly reduce dry matter, seed yield, or seed weight.

Grain number was reduced when all leaves except the flag leaves were clipped or when the stem was wrapped with aluminum foil. On the other hand, clipping awns alone or lamina of the flag leaves to reduce leaf area did not affect grain setting.

Table 13. Grain yields and land equivalent ratio for wheat and maize intercrop. IRRI, 1987 DS.

Treatment	Grain yield (t/ha)		Land equivalent ratio		
	Wheat	Maize	Wheat	Maize	Total
UPLW-3 + maize					
80 kg N/ha	1.63	3.12	41.4	56.6	1.18
160 kg N/ha	1.77	3.99	38.8	47.5	1.21
Ciete Cerros + maize					
160 kg N/ha	1.29	4.12	23.9	50.5	1.18
Maize					
80 kg N/ha	–	6.81	–	1.0	1.0
160 kg N/ha	–	7.81	–	1.0	1.0
UPLW-3					
80 kg N/ha	2.33	–	1.0	–	1.0
160 kg N/ha	2.54	–	1.0	–	1.0
Ciete Cerros					
160 kg N/ha	1.29	–	1.0	–	1.0
ANOVA	**	**			
SE	114	289			

Table 14. Effect of awn removal and defoliation on mean yield and yield components of wheat. IRRI, 1987 DS.

	Treatment	Grain yield (t/ha)	Dry matter (t/ha)	1000-grain weight (kg)	Grains (no./m²)
T1	All awns clipped	2.52	7.36	36.7	9446
T2	All flag leaves clipped	2.33	6.54	34.4	6767
T3	All leaves except flag leaves clipped	2.21	5.81	35.5	6278
T4	All leaves clipped	1.57	4.63	28.4	5577
T5	All leaves clipped and stem wrapped with aluminum foil	0.67	3.77	17.8	3826
T6	All flag leaves + awns clipped	2.38	6.84	33.3	7174
T7	Control	2.68	7.05	38.0	7170
T8	1/2 awns clipped	2.61	7.11	37.7	6927
T9	1/2 lamina of the flag leaves clipped	2.62	7.06	36.4	7252
	ANOVA	**	**	**	**
	SE	141	520	1.22	427

The results indicate that leaf area loss from diseases such as *Helminthosporium* leaf spot can be tolerated as long as the disease does not occur early in crop growth.

Effects of shading. A simulated shading study measured wheat's sensitivity to shading duration. The experiment was sown on 27 Dec 1986 in 20-cm rows at 120 kg seed/ha in a well-tilled, silty clay field. Fertilizer NPK at 50-50-50 kg/ha was applied as basal, and 50 kg N/ha was sidedressed at 25 DAS. The crop was irrigated, and pests and diseases were adequately controlled. At anthesis (45 DAS), leaf area index varied from 1.88 to 3.88 among cultivars, but dry matter was similar (340 g m^2).

The shading treatments were applied to four wheat varieties at four growth stages. Radiation was reduced to 50% by stretching layers of nylon net over the canopy.

Dry matter and grain number declined significantly with shading from 30 DAS to maturity (Table 15), but not with shading from 30 to 45 DAS or from 45 DAS to maturity.

Table 15. Effect of shading on yield and yield components of wheat. IRRI, 1987 DS.

Treatment	Grain yield (t/ha)	Dry matter (t/ha)	1000-grain weight (g)	Grains (no./m^2)
Wheat variety				
UPLW-2	1.91	5.78	29.5	6434
C213-15	2.15	5.59	32.4	6881
DWR-39	2.02	5.41	27.5	7414
Sonora 64	1.87	4.74	29.4	6418
Shading duration				
Control	2.14	5.41	30.5	7036
30-45 DAS	1.95	5.20	31.6	6190
45 DAS-maturity	2.26	6.41	27.0	8498
30 DAS-maturity	1.61	4.50	29.8	5425
ANOVA: variety	ns	ns	**	ns
Shading	**	**	**	**
SE	330.1	751	1.68	1209

Table 16. Grain yield of UPLRi-5 as affected by P, lime, and residues. Claveria, Misamis Oriental, Philippines, crop years 1985-86 and 1986-87.

Treatment[a]	Grain yield (t/ha)	
	1985-86	1986-87
Control	5.9	1.7
With residue (R)[b]	6.3	1.6
P (26 kg P/ha)	7.1	2.2
P + R	6.9	1.7
L (3 t lime/ha)	6.6	2.1
L + R	5.8	1.6
L + P	7.4	2.1
L + P + R	6.9	2.0
CV (%)	11	16
R^2	0.5	0.7

[a]N was applied at 50 kg/ha. [b]Residue was incorporated for the successive crop.

UPLAND SYSTEMS

Crop residue management in an upland rice - maize sequence. Upland farmers usually burn or remove rice residue before preparing land for the next crop. A long-term study on crop residue incorporation and P and lime rates was begun in 1985 to evaluate their immediate and long-term effects in a rice - maize cropping sequence. In 1985-86, the first crop rice yields were influenced mainly by P application (Table 16).

The succeeding maize crop yields were significantly improved by lime or by P, but residue incorporation did not add to these increases. However, residue with both lime and P increased maize yield, though not statistically significantly.

Maize residues reduced yields of subsequent upland rice, contrary to expectations. A drought during the rice reproductive phase may have influenced this response. P continued to improve rice grain yield except when combined with maize crop residues. Yields during the 1986-87 season were low, ranging from 1.6 to 2.2 t/ha (Table 16).

The growth-depressing effects of maize residues on rice are presumed to be due to N immobilization during residue breakdown. Research is needed on methods of handling residues to maximize their nutrient benefits, while avoiding growth depression.

Intercropping of rice, cowpea, and mungbean in low-input upland rice-based cropping systems. Cereals or root crops dominate legumes in upland rice-based cropping systems. Yet N seriously limits biomass production and grain yield in all cereal-based sequences. In soils of low fertility and without fertilizer, growing legumes with cereals often increases N availability and stabilizes production. This research examined the effects of

intercropping grain or forage legumes with upland rice.

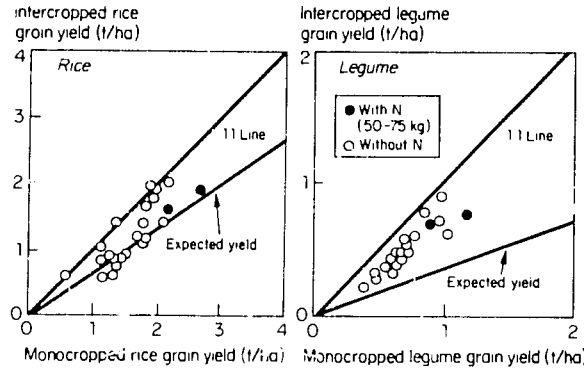
Experiments were conducted from 1983 to 1986 in several fields on the upland farm at IRRI, and on a farm in Claveria, Misamis Oriental, Philippines. Soils at IRRI were Typic Tropudalfs of clay to clay loam texture, acidic (pH 5.3-5.6), with low inherent N fertility (0.10-0.14%) but abundant P (18-50 ppm) and K (1.12-1.34 meq/100 g). Soils at the rolling upland Claveria site were Oxic Dystropepts of 70% clay, strongly acidic (pH 4.0-4.5), and of low available P (7-14 ppm) and K (0.12 meq/100 g).

To identify cultivars of cowpea and mungbean compatible with rice, we tested materials ranging widely in maturity and growth habit. Early-maturing (60-65 d), determinate cultivars such as IT82D-889 yielded high with low rice yield reduction.

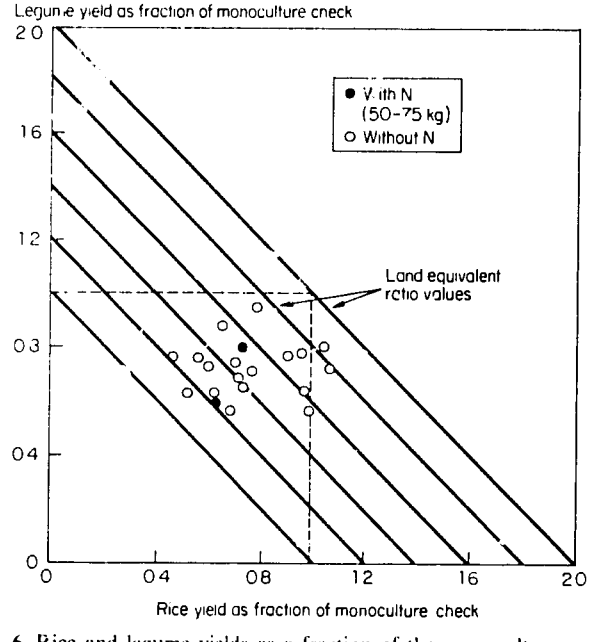
Early, determinate cultivars of cowpea and mungbean were combined with a modern upland rice variety (UPLRi-5 or UPLRi-7) of 125-d duration. Two or three rice rows were alternated with one row of legume. Crop ratios, applied N, and irrigation water availability varied. Results of the individual experiments are found in the Annual reports for 1984, 1985, and 1986.

In most experiments and treatments, yields of the rice monocrop ranged from 1.0 to 2.5 t/ha, indicating that the sites needed N application. In rice intercropped with mungbean or cowpea, rice and legume yields were reduced relative to the yield of monocrops (Fig. 5). Two-thirds of the land area was occupied by rice and one-third by the legume. Both crops yielded more than expected from the respective ground areas. In some cases, the grain yields of intercropped rice and monocropped rice were the same, indicating that the competitive effect of the legume was negligible.

Yields of the intercrop components are plotted as a function of their respective monoculture checks in Figure 6. The LERs were calculated as the land area required, using monoculture, to equal the total yield of a hectare of the intercrop. The diagonal lines in Figure 6 represent LER levels. The LER varied between 1.2 and 1.8, indicating increased intercrop efficiency. Figure 6 also shows that intercropped rice yields were generally between 70 and 100% of rice alone, and intercropped legume yields between 60 and 80% of their monocrop yields.



5. Intercropped rice and legume yields as a function of their monocropped yields, IRRI, 1984, 1985, 1986. The expected yield is based on the field area occupied in the intercrop.



6. Rice and legume yields as a fraction of the monoculture check yields, and land equivalent ratios. IRRI, 1984, 1985, 1985.

The total N uptake of rice alone (straw + grain) varied between 21.6 and 39.5 kg/ha among experiments and treatments (Table 17). The N uptake of intercropped rice ranged from 19.5 to 35.9 kg/ha. Mean N yields for rice intercropped and alone were similar. N uptake calculated per unit area of rice in the intercrop exceeded that for the rice monocrop in all experiments, indicating

Table 17. N yield of rice monocrop and intercrop. IRRI, 1984, 1985, and 1986.

Experiment or treatment	Rice monocrop (kg N/ha)	N yield: Intercropped rice[a] kg/ha	Intercropped rice[a] Percent[c]	Rice within intercrop[b] kg/ha	Rice within intercrop[b] Percent[c]
1	21.6	23.7	110	35.4	164
2	26.6	19.5	73	29.1	109
3	27.7	28.6	103	42.7	154
4	28.1	28.0	100	41.8	149
5	29.8	33.8	113	50.4	169
6	31.0	34.8	112	51.9	167
7	34.1	31.5	92	47.0	138
8	34.6	25.8	75	38.5	111
9	35.4	33.4	94	50.0	141
10	39.5	35.9	91	53.6	136
Mean	30.8	29.5	96	44.0	142

[a]N yield per unit area of the intercrop. [b]N yield per unit area of rice within the intercrop, i.e., sole rice equivalent. [c]Percent of rice monocrop N uptake.

that the per plant N nutrition of intercropped rice was superior to that in monoculture rice. The reduction in N yield in intercropped rice was much lower than the reduction in grain yield. N was more available to rice when rice was intercropped with a grain legume.

Contribution of intercropped indeterminate legumes to nitrogen in low-input upland rice-based cropping systems. Upland rice and determinate cowpea or mungbean are compatible crops—their intercropping at a 2:1 area ratio produces 80% of the rice monocrop yield, plus legume grain. Yet, lower rice yield may not be acceptable to subsistence farmers having small landholdings, large families, and rice as their staple food. Upland rice farmers would prefer rice yields at their monocrop level with legume yield as a bonus.

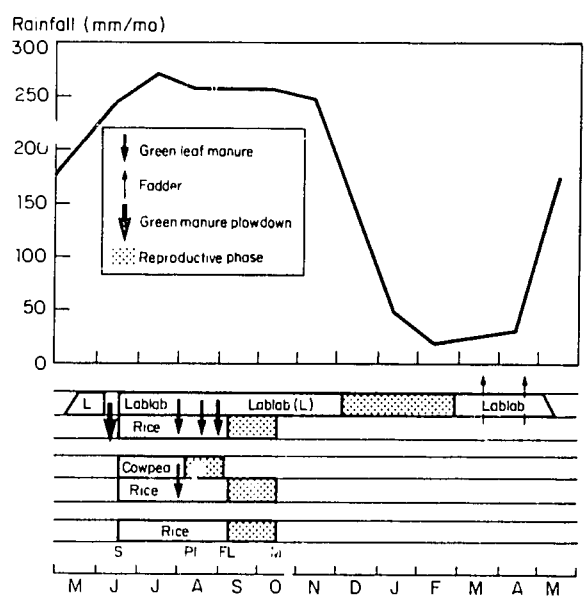
We studied the feasibility of using indeterminate cowpea cultivars and lablab (*Lablab purpureus*, formerly *Dolichos lablab* L.) as sources of GM for upland rice, with additional legume grain and fodder yield. Both crops have luxuriant vegetation and good N fixation. Cowpea will grow on the acid, infertile soils of most upland rice areas. Lablab tolerates drought, produces quality fodder, regrows after clipping, and produces edible pods and seeds.

Upland rice was grown between rows of the two legumes. The legumes were clipped several times during rice growth, and the tops were applied as a green leaf mulch. Cowpea grain was harvested after clipping ceased during the rice reproductive phase. Lablab continued to supply GM, fodder, and seed yield during DS (Fig. 7).

The experiment used five treatments (Table 18) under rainfed conditions. The rice monocrop was sown in 20-cm rows. In intercrops, three rice rows alternated with one legume row. Green leaf manure clipped from the legume monocrop was applied to the rice monocrop when the intercrop legumes were clipped. These treatments simulated the application of green leaf manure from equal-sized areas outside the rice area.

Both legumes had excellent vegetative growth (Fig. 8). Legumes were first clipped at 40 DAS. Cowpea could not be clipped subsequently because it soon flowered. Lablab was clipped again at 58 and 73 DAS. Clipped foliage was mulched between rice rows.

In intercrops, the total N of clippings applied to rice was 21 kg/ha from cowpea and 17, 28, and 48 kg/ha (92.5 kg N/ha total) from lablab. The cowpea monocrop supplied 24.3 kg N/ha in green leaf manure, and the lablab monocrop 109.2 kg N/ha. The grain yield and total N uptake (Table



7. Major treatments in an experiment on the intercropping of rice and indeterminate legumes for green leaf manure and plowdown GM, IRRI, 1986 WS. S = seedbed, PI = panicle initiation, FL = flowering, M = maturity.

Table 18. Grain and N yields of rice monocrop and rice intercropped with indeterminate cowpea and lablab. IRRI, 1986-87 WS.

Treatment	N added by clippings (kg/ha)	Yield per unit area of intercrop			Yield per unit area of rice		Legume grain yield (t/ha)
		Grain (t/ha)	N (kg/ha)	% N in grain	Grain (t/ha)	N (kg/ha)	
Rice monocrop	0	1.5	28.9	1.00	1.5	28.9	
Rice + cowpea intercrop	21.0	1.5	34.9	1.30	1.8	43.7	1.02
Rice monocrop with cowpea monocrop leaves	24.3	0.9[a]	*b*	*b*	1.9	*b*	1.32
Rice + lablab intercrop	92.5	1.9	48.0	1.37	2.3	60.0	0.50
Rice monocrop with lablab monocrop leaves	109.2	1.5[a]	*b*	*b*	2.9	*b*	
Cowpea monocrop	–	–	–	–	–	–	1.83
SE		0.2		0.04	–	–	–
ANOVA		**		**			

[a]Yields are expressed per unit of the total area occupied by monocrops. [b]Not sampled.

18) of rice intercropped with cowpea equaled that of the rice monocrop. A bonus cowpea yield of 1.02 t/ha was obtained without reducing rice productivity.

When the rice monocrop was mulched with green leaf manure from the cowpea monocrop, grain yields were substantially lower than those of intercropped rice. The N added by mulch did not compensate for the area taken up by the cowpea supplying the mulch. The N supply from cowpea clippings in the intercrop, together with the greater root exploration, enabled rice to compensate entirely for the 33% reduction in area occupied. The N uptake per unit area of rice increased from 28.9 to 43.7 kg/ha or 51%.

8. Views of the field experiment on intercropping indeterminate legumes with upland rice for green leaf manure: a) rice + cowpea, b) rice + lablab. IRRI, 1986 WS.

When intercropped with lablab, rice yields were significantly increased by 0.4 t/ha, and productivity per unit of actual rice area rose from 1.5 to 2.3 t/ha (Table 18). The increased rice yields in the intercrop were associated with a 66% increase in rice N uptake per unit area of intercrop, and a 104% increase in N uptake per unit area of rice within the intercrop. N uptake efficiency, estimated by increase in N yield per kilogram of N applied in clippings, was relatively low at 0.21. The ratio was 0.34 calculated by N yield per unit area of rice. Thus, uptake efficiency could be increased by better manipulation of the legume cutting regime and soil incorporation of the green leaf manure.

Intercropping improved rice grain quality (Table 19). The percent N in rice grains was 30% higher in the rice + cowpea intercrop and 37% higher in the rice + lablab intercrop.

The higher grain yield in the rice + lablab intercrop was a function of the higher harvest index (HI) (Table 19). The TDMY of rice did not differ between monocrop and intercrop, but the grain yield of the intercropped rice was higher.

Table 19. Grain yield and yield components of sole rice and rice intercropped with indeterminate cowpea and lablab. IRRI, 1986-87 WS.

Treatment	Grain yield (t/ha)	TDMY (t/ha)	Harvest index (%)	Panicles (no./m²)	Grains (no./m²)	Grains (no./panicle)	1000-grain wt (g)
Rice monocrop	1.5	4.49	0.35	214	5674	26.5	27.3
Rice + cowpea	1.5	3.56	0.41	149	5439	36.5	26.8
Rice monocrop with cowpea monocrop leaves	0.9	2.91	0.32	144	3418	23.7	27.5
Rice + lablab	1.9	4.51	0.42	169	6839	40.5	27.5
Rice monocrop with lablab leaves	1.5	3.57	0.41	145	5088	35.1	28.6
SE	0.2	0.44	0.03	14	700		0.4
ANOVA	**	**	*	**	**		**

Panicles per m² was less in the intercrop, but grains per panicle and grains per m² increased substantially. The HI of rice also increased in the rice + cowpea intercrop, with higher grains per m².

After rice harvest, lablab grew through the 5-mo DS, reaching 1 m height by 1987 WS. The 19.0 t/ha fresh biomass was incorporated into the soil just before rice seeding.

Nitrogen transfer and crop growth interactions of intercropped mungbean and rice. The increase in N availability in rice intercropped with a grain legume might be due to N transfer from the legume to rice, or to greater soil and aerial volume available to the rice, or to both. N could be transferred by direct excretion, nodule and root decay, leaching from leaves, or decomposition of fallen leaves.

In a cereal + legume intercrop, N uptake by the cereal may be influenced by the two crops' relative use of soil mineral N. Other factors are the greater root volume of the cereal crop because of differences in rooting, and the availability of vacant soil volume after harvest of the earlier maturing legume. The rice and legume in a 125-d rice intercropped with a 65-d mungbean or 65-d cowpea do not strongly compete for growth resources, including N.

Two experiments measured the contributions of different growth resources to intercropped rice grain and N yields, and partitioned these effects.

The first experiment used two monocrops of rice, one monocrop of mungbean, and four intercrop treatments (Table 20). Below-ground contact between the intercropped rice and mungbean roots was prevented (in T2) by placing vertical sheets of galvanized iron 50 cm deep between rows. A control (T3) used vertical openings 50 cm deep. T3 separated the effects on crop performance of soil disturbance during barrier insertion. The N transfer of abscissed mungbean leaves to intercropped rice was measured by removing all abscissed leaves from plots every second day, starting at 40 DAS (T4). To quantify any advantage to intercropped rice of an increase in soil volume available after mungbean harvest, every third row of rice in a rice monocrop was harvested (T6) when mungbean was harvested in the intercrops. An undisturbed

Table 20. Effect of plant interactions on grain yields of intercropped rice and mungbean and N yield of rice. IRRI, 1986 WS.

Treatment	Grain yield (t/ha)		Rice N uptake (kg/ha)	Percent N in rice grain
	Rice	Mungbean		
T1 Intercrop	1.4	0.81	33.4	1.23
T2 Intercrop with no belowground interaction[a]	1.0	0.82	24.9	1.20
T3 Intercrop with slots prepared (control for T2)[b]	1.3	0.74	33.1	1.19
T4 Intercrop with abscissed mungbean leaves removed	1.3	0.73	27.7	1.15
T5 Rice monocrop	1.8	–	35.4	1.02
T6 Rice monocrop – 3d row removed[c]	1.3	–	28.6	1.13
T7 Mungbean monocrop	–	0.84	–	–
ANOVA	**	**	**	**
SE	0.1	0.05	3.1	0.04

[a]Galvanized iron sheets placed in slots between rows to 50 cm depth. [b]Slots prepared for GI sheets as in T2, but sheets not inserted. [c]Plants removed at harvest of mungbean.

intercrop (T1), rice monocrop (T5), and mungbean monocrop (T7) were included.

The rice monocrop (UPLRi-7, 115-120 d duration) was drilled in 20-cm rows using 100 kg seed/ha. The mungbean monocrop (EG MG 174-3, 60-65 d duration) was seeded in 40-cm rows and then, after germination, thinned to 12-15 plants/linear meter. In intercrops sown in 20-cm rows, 2 rice rows alternated with 1 row of mungbean. The experiment was laid out in RCBD with four replications.

The grain yield of intercropped rice was 20% less than that of rice alone, but N yields were similar (Table 20). In the intercrop with barrier (T2), rice yield and N content were significantly reduced. Mungbean grain and N yields were unaffected by intercropping (T2). Mungbean and rice apparently did not compete because they differed in growth duration and rooting depth.

Abscissed mungbean leaves added 15.5 kg N/ha to the soil surface at 43-60 DAS. Although the N yield of rice was 5.7 kg/ha (17%) lower when abscissed mungbean leaves were removed, this was not statistically significant. Removing every third row of rice at mungbean harvest (T6) produced rice yields equal to those in the intercrop (T1) (Table 20). The N yield of rice was lower but not significantly so. The percent N in the rice grain was significantly reduced compared with that in the intercrop.

The results show that yield compensation was due mostly to the increased soil and aerial space available after mungbean harvest. Net direct N transfer was minor. Comparison of T2 and T6 suggests that the substantial drop in rice yield with restricted rice root growth (T2) was due primarily to less soil volume accessible to the rice roots for N extraction.

The second experiment (Table 21) added treatments to quantify the effect on intercropped rice of mungbean stover incorporated within the row after mungbean harvest (T7), and the effect on monocropped rice of a skip row—to represent the space mungbean would have occupied in the intercrop (T8).

The results were similar to those in the first experiment. Incorporation of mungbean stover at harvest (T7) did not increase rice yield and N uptake by rice compared with allowing the biomass to remain on the soil surface.

Table 21. Effect of belowground plant interaction on grain yield of intercropped rice and mungbean and N uptake by rice. IRRI, 1987 WS.

	Treatment	Grain yield (t/ha)		Rice N uptake (kg/ha)
		Rice	Mungbean	
T1	Intercrop	2.0	0.95	41.1
T2	Intercrop with no belowground interaction[a]	0.6	0.75	26.8
T3	Intercrop with slots prepared (control for T2)[b]	1.8	1.05	43.9
T4	Intercrop with abscissed mungbean leaves removed	1.9	1.15	40.8
T5	Rice alone	2.3	–	38.2
T6	Rice alone – 3d row removed[c]	1.7	–	31.9
T7	Intercrop – mungbean incorporated at harvest	1.7	1.18	40.5
T8	Rice alone – every 3d row vacant	2.6	–	43.5
T9	Mungbean alone	–	1.70	
	ANOVA	**	**	
	SE	0.3	0.13	

[a]Galvanized iron sheets placed in slots between rows to 50 cm depth. [b]Slots prepared for GI sheets as in T2, but sheets not inserted. [c]Plants removed at harvest of mungbean.

T8 results reinforce the main finding in the first experiment. By leaving the third row vacant throughout the growing season, the rice grain yield and N uptake were higher (although not significantly) than with the rice monocrop. They were significantly higher than in the intercropped treatments, even though the area of rice was the same. This further supports the hypothesis that rice yield with a mungbean intercrop benefits from increased soil and aerial space after mungbean harvest. Skip row planting yielded as well as uniform planting, suggesting better use of space and time in low-input upland rice systems by intercropping with a short-duration legume.

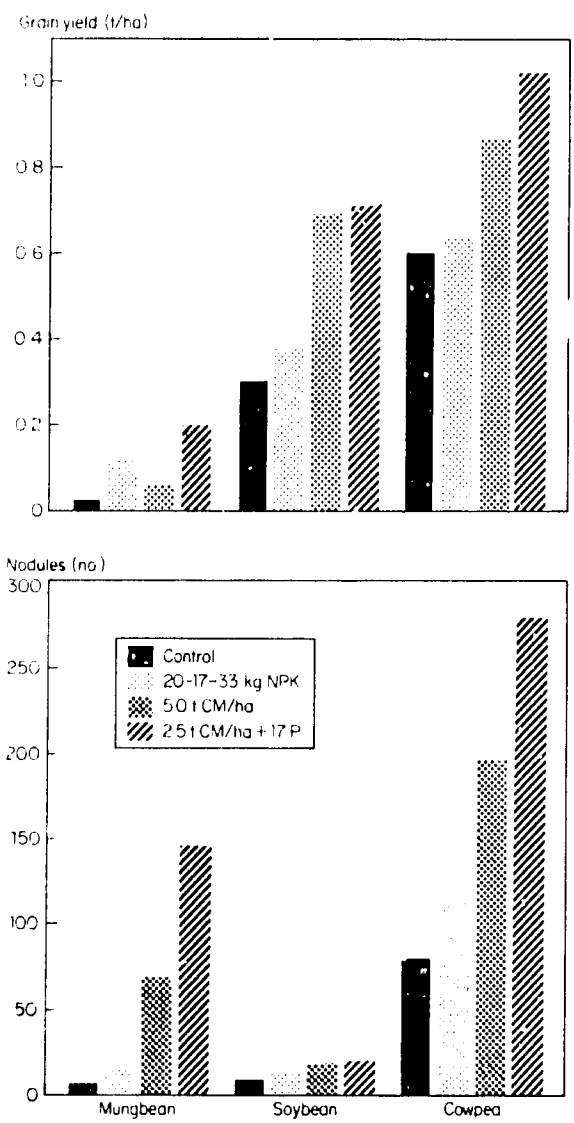
Effects of spacing between mungbean and rice. The compensatory benefit to adjacent rice rows in an intercrop was studied. Intimacy was varied by planting 10 rice rows alternating with 5 mungbean rows. At maturity, each rice row's grain and N yield were measured. Rice yield and N uptake increased when the rice rows were closer to the mungbean.

The rice row most intimately associated with mungbean had 26% higher grain yield and 52%

higher N yield than the fourth row away, which was essentially rice alone. The effects were significant to the second row, 50 cm from mungbean.

Grain legume nutrient management in acid upland soils. We compared the performance of mungbean, soybean, and cowpea with varying rates of chicken manure (CM) and inorganic fertilizer in Claveria, Misamis Oriental, Philippines, during 1985 WS.

Grain yield and nodule count (Fig. 9) varied significantly with crop species and fertilizer material. The grain yield performance across fertilizer material was cowpea > soybean > mungbean. For nodule count, the ranking was cowpea > mungbean > soybean. In general, the 3 legumes responded to fertilizer material following the order 2.5 t CM + 17 kg P > 5.0 t CM > 20 kg N + 17 kg P + 33 kg K > unfertilized control. Organic matter and P helped the legumes adapt to this acid upland environment.



9. Grain yield and nodules of 3 legume species as affected by chicken manure (CM) and inorganic fertilizer. Claveria, Misamis Oriental, Philippines, 1985 WS.

The experiment on lime and P application on mungbean (Annual report for 1986) was followed by an experiment on the following maize crop to evaluate the residual effects of 3 t lime/ha and varying levels of P applied to the mungbean. The maize crop was uniformly fertilized with 50 kg N/ha. Maize responded significantly to treatments applied to mungbean in the previous season.

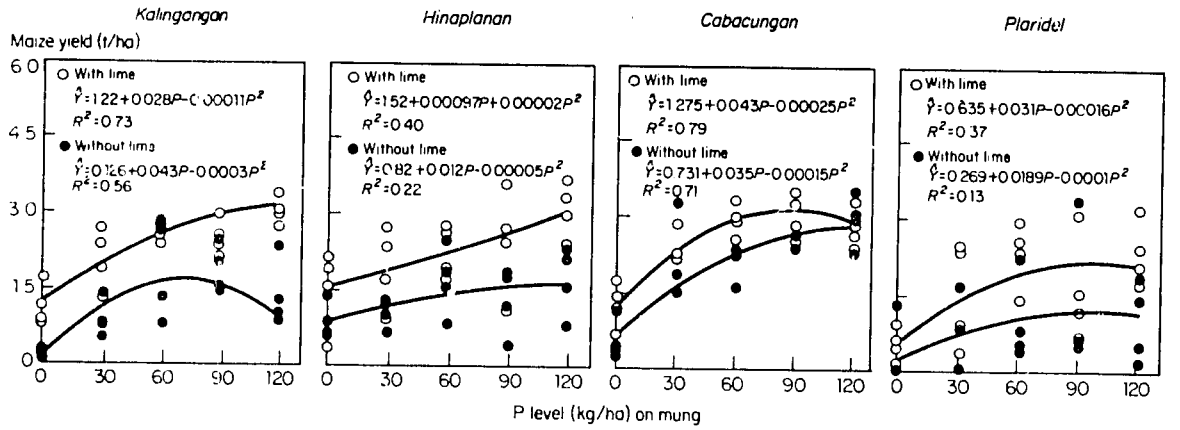
The responses varied significantly with the inherent fertility of the fields (Fig. 10, 11). Strong responses to residual P were observed at three of four low-fertility sites and one of two high-fertility sites. The results indicate that maize does not need lime and P application when the preceding mungbean crop is fertilized with high rates, especially in fields with high inherent fertility. Residual lime improved residual P use by maize.

Soil fertility management to sustain rice yields in acid upland environments. Experiments in farmers' fields in 1985 and 1986 WS determined the fertilizer response of upland rice on acid upland soils of Claveria, Misamis Oriental. Twelve treatments combined N, P, K, and lime applied to rice cultivar UPLRi-5, with untreated control.

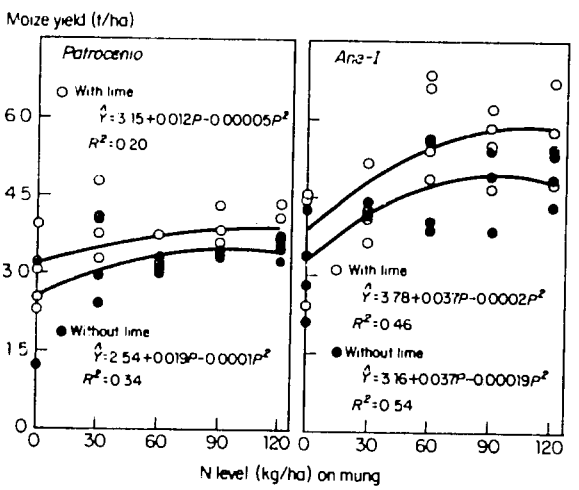
Mean grain yields are shown in Tables 22 and 23. Yields varied greatly across locations and treatments. In 1985, control yields ranged from 1.5 to 4.6 t/ha. Except in field 4, yield responses to fertilizer treatments were statistically significant. Lime did not significantly improve yield.

Response differences across fields suggest that fields differ in fertility. The yield response and location placed field 1 in the high-fertility stratum and fields 2, 3, and 4 in the low-fertility stratum. High-fertility stratum fields have slopes of 3-8% or less, organic C > 2.0%, Olsen P > 5.0 ppm, Bray P > 10.0 ppm, CEC > 14.0 meq/100 g, total N > 0.22%, exchangeable K > 0.2 meq/100 g, and pH > 5.0.

In 1986, severe drought reduced yields of UPLRi-5 to 40-50% of the 1985 levels. Fertilizer



10. Grain yield response of maize IPB Var 1 to residual effects of P and lime applied to the previous mungbean crop in the low soil fertility stratum, Claveria, Misamis Oriental, Philippines, 1986-87.



11. Grain yield response of maize IPB Var 1 to residual effects of P and lime applied to the previous mungbean crop in the high soil fertility stratum, Claveria, Misamis Oriental, Philippines, 1986-87.

Table 22. Grain yield of UPLRi-5 in 4 farmers' fields[a] as affected by NPK and lime. Claveria, Misamis Oriental, Philippines, 1985 WS.

Treatment	Grain yield (t/ha)			
	1	2	3	4
1 Control	4.6	2.6	1.5	1.8
2 Lime	5.2	4.5	2.1	1.9
3 25 N	5.2	3.5	2.6	1.9
4 25 N + lime	5.1	3.4	2.4	1.9
5 25 N + 9 P	5.6	4.7	2.7	2.1
6 25 N + 9 P + lime	5.8	3.7	2.3	2.1
7 50 N + 9 P	5.7	4.3	2.9	1.9
8 50 N + 9 P + lime	5.8	4.6	3.4	2.3
9 50 N + 18 P	6.2	4.3	3.0	2.3
10 50 N + 18 P + lime	5.9	4.0	3.5	2.3
11 50 N + 36 P	7.0	4.1	3.4	2.6
12 50 N + 18 P + 25 K + lime	5.7	4.2	3.1	2.6
LSD (0.05)	0.8	0.9	0.6	0.5
CV (%)	15	23	23	21
R^2	0.46	0.52	0.57	0.51

[a]Field 1 was in the high-fertility stratum; fields 2, 3, and 4 were in the low-fertility stratum.

effects were significant only in two fields. Lime was important in field 2.

Net benefit curves for each soil fertility stratum in 1985 WS are given in Figure 12a. In the high-fertility stratum, 4 treatments were considered not dominated, i.e., they had yields not exceeded by other treatments at comparable investment levels. These treatments were 25 kg N, 25 kg N + 9 kg P, 50 kg N + 18 kg P, and 50 kg N + 36 kg P. In the low-fertility stratum, only 2 treatments were not dominated (25 kg N and 25 kg N + 9 kg P). The values for the yield, gross returns, and variable costs from these nondominated treatments were used to compute the marginal benefit-cost ratio (MBCR) shown in Table 24. In the high-fertility stratum, application of 25 kg N gave the highest MBCR of 4.02. This treatment cost only $15.90/ha. The highest net benefit was obtained from 50 kg N + 36 kg P; however, its MBCR was lower at 2.81. In the low-fertility stratum, applying 25 kg N/ha gave MBCR of 3.77.

Although P is low in these soils, N remains the most limiting nutrient. However, as applied N

Table 23. Grain yield of UPLRi-5 in 4 farmers' fields[a] as affected by NPK and lime. Claveria, Misamis Oriental, Philippines, 1986-87.

	Treatment	Grain yield (t/ha)			
		1	2	3	4
1	Control	1.1	1.4	1.9	2.5
2	Lime (L)	0.8	1.8	1.8	2.7
3	25 N	1.2	1.4	1.5	2.3
4	25 N + L	1.1	1.6	2.2	2.4
5	25 N + 9 P	1.0	1.8	1.8	2.3
6	25 N + 9 P + L	1.1	2.0	2.0	2.4
7	50 N + 9 P	1.1	1.8	1.4	2.5
8	50 N + 9 P + L	0.8	1.9	2.0	2.2
9	50 N + 18 P	0.8	2.2	2.1	2.6
10	50 N + 18 P + L	0.7	1.9	1.9	2.3
11	50 N + 18 P + 30 K + L	0.6	2.2	2.2	2.5
12	50 N + 36 P	0.7	2.4	2.4	2.4
	CV (%)	29	17	24	12
	R^2	0.6	0.6	0.4	0.2

[a]Fields 1 and 2 were in the low-fertility stratum; fields 3 and 4 were in the high-fertility stratum.

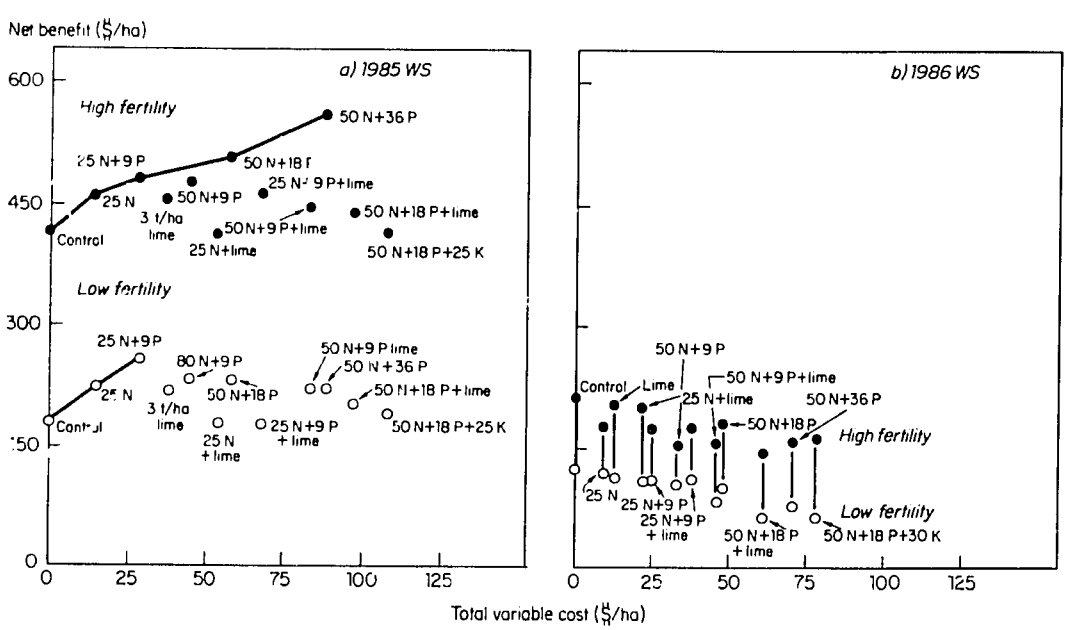
increases, the P requirement rises. Applying lime reduced the net benefit by as much as $34/ha, an uneconomical result if evaluated considering upland rice only.

Figure 12b shows the relationship between net benefit and total variable cost for two soil fertility strata during 1986 WS. Fertilizer treatments in the high-fertility stratum generally gave higher net benefits than those in the low-fertility stratum. Because of very low yield response even with high fertilizer rates, no fertilizer treatment was considered nondominated. Therefore, MBCRs could not be calculated.

Table 24. Computation of the marginal benefit-cost ratio (MBCR) for undominated NPK and lime treatments on upland rice UPLRi-5. Claveria, Misamis Oriental, Philippines, 1985 WS.

Treatment increment	Marginal cost ($/ha)	Marginal benefit ($/ha)	MBCR ($/$)
High-fertility stratum			
Control - 25 N	15.90	63.95	4.02
25 N - 25 N + 9 P	13.70	33.75	2.46
25 N + 9 P - 50 N + 18 P	29.45	53.45	1.81
50 N + 18 P - 50 N + 36 P	30.10	84.60	2.81
Low-fertility stratum			
Control - 25 N	15.90	64.00	3.77
25 N - 25 N + 9 P	13.70	47.20	3.44

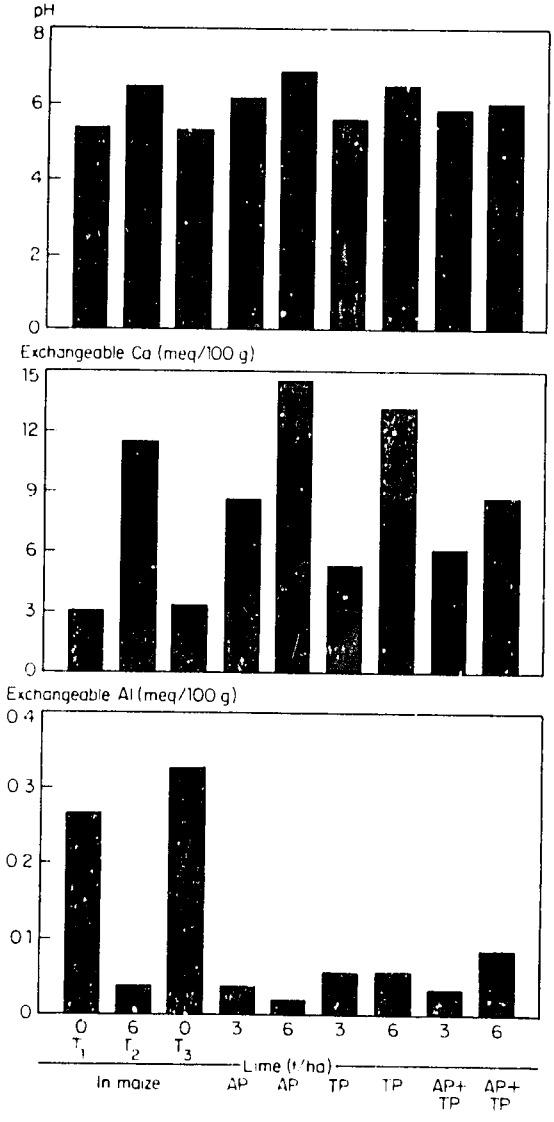
Lime rate and incorporation methods in rice-based cropping systems. Begun in 1985, this study uses three methods of lime incorporation and two lime rates to determine the long-term residual effects of lime. Results on upland rice UPLRi-5 in



12. (a) Net benefit curve for 12 fertilizer treatments in 1985, and (b) relationship between net benefit and total variable cost of the fertilizer treatments in 1986 on UPLRi-5 upland rice variety grown on 2 soil fertility strata in Claveria, Misamis Oriental, Philippines.

the rice - maize - cowpea cropping sequence were reported in the Annual report for 1986.

To determine chemical changes in soil, soil samples from the 0-15 cm depth were taken after maize harvest (Fig. 13). Lime reduced exchangeable Al but increased exchangeable Ca, especially at the 6 t/ha rate. Exchangeable Mg was not affected. The fresh application of lime in T2 (Fig. 13) increased the pH and exchangeable Ca, and decreased exchangeable Al concentration. The pH increase was more influenced by lime rate than by incorporation method.



13. Effect of lime rate and method of incorporation on pH, exchangeable Ca, and exchangeable Al in the soil at 0-15 cm depth after the maize crop. Claveria, Misamis Oriental, Philippines, 1985 DS. AP = animal plowing to incorporate the lime at a depth of 15 cm. TP = tractor plowing to incorporate the lime at 30-cm depth. AP+TP = half of the lime was broadcast, then plowed under by tractor plowing; the other half was incorporated by animal plowing

Plant height, dry matter yield, nodule count, and grain yield of cowpea IT82D-889 were all significantly affected by lime rate and incorporation method. The 6 t lime/ha applied before the previous maize crop in T2 had strong residual effects on cowpea (Fig. 14). Lime application increased nodules, dry matter yield, and grain yield of cowpea. The effect of rate was stronger than that of incorporation method.

Mean yields of UPLRi-5 by lime rates and incorporation methods for 1985 and 1986 WS appear in Table 25. The 1986 WS yields ranged from 2.4 to 3.1 t/ha, only half of 1985 yields. In 1986, treatment differences were not statistically significant.

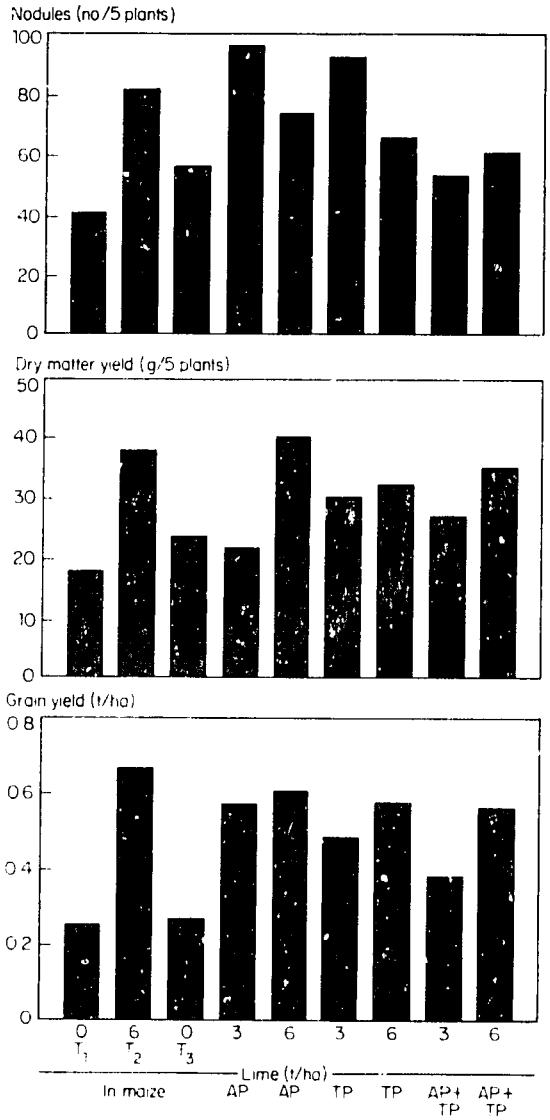
CROP SIMULATION MODELING

The Crop Simulation Modeling section of the Multiple Cropping Department was created in 1987 with funding by the Netherlands to develop crop growth modeling at IRRI and in national agricultural research systems. Cooperating Dutch institutes are the Centre for Agrobiological Research and the Department of Theoretical Production Ecology of the Agricultural University in Wageningen.

Dynamic modeling was supplied to ongoing research on several topics including growth and water use of rainfed rice and of crops after rice, water movement in lowland soils, and yield losses due to stem borer and leaffolder. Results are reported in those areas.

To stimulate crop modeling at IRRI and in national systems, we have produced these modules to run on personal computers:

1. Growth processes of crops unrestricted by water or nutrient shortage (integration time interval is 1 d);
2. The same, but with a 6-h time interval to simulate carbohydrate level fluctuations dynamically;



14. Effect of lime rate and method of incorporation on nodule count, dry matter, and grain yield of cowpea IT82D-889, Claveria, Misamis Oriental, Philippines, 1985 DS. AP = animal plowing to incorporate the lime at a depth of 15 cm. TP = tractor plowing to incorporate the lime at 30-cm depth. AP+TP = half of lime was broadcast, then plowed under by tractor plowing; the other half was incorporated by animal plowing.

3. Development of tillers, flowers, and grains in the crop;
4. Transpiration processes of crops without nutrient stress;
5. Water balance processes for soils with a deep groundwater table;

Table 25. Grain yield of UPLRi-5 as affected by lime rate and incorporation method. Claveria, Misamis Oriental, Philippines, 1985-86 and 1986-87.

Treatment[a]	Grain yield (t/ha)	
	1985-86	1986-87
1 Control	4.4	2.6
2 Control[b]	4.7	2.8
3 Control	4.6	2.6
4 3 t lime/ha, AP	4.6	2.5
5 6 t lime/ha, AP	5.4	2.4
6 3 t lime/ha, TP	5.2	3.1
7 6 t lime/ha, TP	6.0	2.5
8 3 t lime/ha, AP+TP	5.4	2.9
9 6 t lime/ha, AP+TP	6.1	2.4
CV (%)	9	21
R^2	0.8	0.2

[a]AP = animal plowing, TP = tractor plowing. [b]6 t lime/ha was applied before the maize crop.

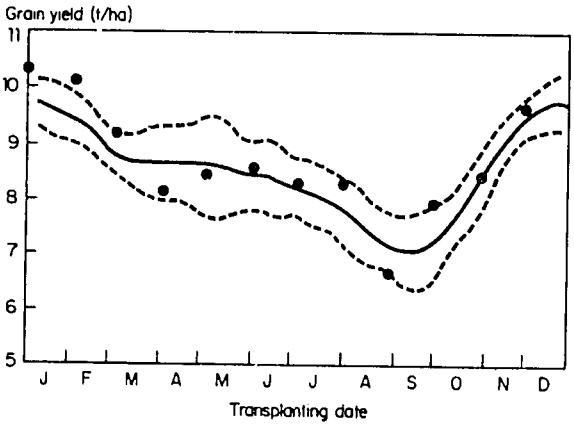
6. Water balance processes for layered soils with a shallow water table;
7. A service module of standard functions and subroutines.

These modules are extensively documented; a book will appear as a copublication of the Centre for Agricultural Publishing and Documentation and IRRI. Documentation includes physiological data for four rice varieties (IR36, IR54, IR64, and Kinandang Pula) and for several other annual crops (cereals, legumes, and tuber crops).

Two examples of the use of modeling follow. First, we examined the effects of current weather on potential and water-limited rice yields. Such yields are computed monthly and added to the summaries of weather data distributed by the Climate Unit. Figure 15 shows such values for 1987.

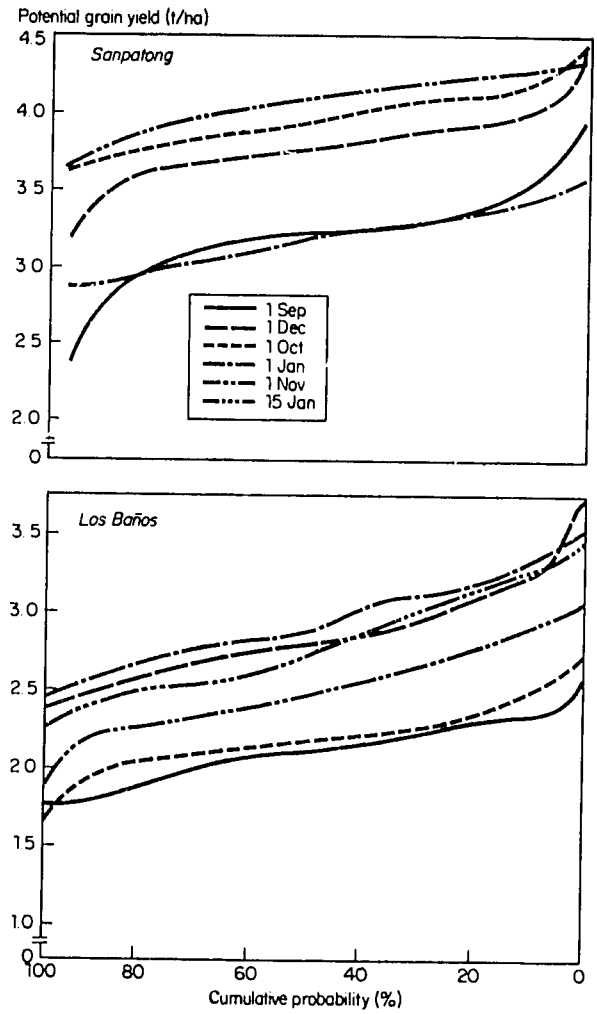
Low N concentrations in leaves occur often during the ripening phase, even at high fertilization levels. This lowers the growth rate in the ripening phase and reduces yield by 500-1000 kg/ha. Internal N redistribution after flowering plays a crucial role. The relevant processes were integrated in a model. Evaluation involved simulation of rice crops in Maligaya, Nueva Ecija, Philippines, where detailed canopy gas-exchange measurements had been made.

Second, we developed a crop growth model for wheat. The model (modules 1, 4, 5, 7) was used to



15. The potential grain yield (14% moisture) of IR64 in 1987 versus the date of transplanting, IRRI, 1987. The continuous line represents the 25-yr averages, the dotted lines the average plus or minus the standard error.

establish trends in potential and rainfed yields of wheat following rice. A comparison of measured and simulated yields validated the model's performance. The results show that the yield potential of irrigated DS wheat is 3.0-6.6 t/ha between 10°S and 25°N latitude and up to 500 m elevation. Such yields are stable and relatively insensitive to sowing date. At 1,000-m elevation, where it is cooler, the potential yields are about 2 t/ha higher. Yields under rainfed conditions are lower and have higher year-to-year variability. They are fairly sensitive to sowing date. The gap between potential and water-limited grain yield is small if wheat is sown toward the end of the rainy season on a deep, well-drained soil. Figure 16 illustrates this for Los Baños and Sanpatong (Thailand); larger rainfall in DS in Los Baños and the slightly higher temperatures produce the yield differences between locations.



16. Effect of date of sowing on cumulative yield probabilities of wheat grown in Los Baños, Philippines, and Sanpatong, Thailand. Curves are based on 25 yr of simulated yields.

Cropping systems program

Preproduction testing of improved cropping patterns

Agronomy Department

PROFITABLE CROPPING PATTERNS AND INTEGRATED NUTRIENT MANAGEMENT **502**
Irrigated lowland rice-based system **502**
Rainfed lowland rice-based system **504**

PROFITABLE CROPPING PATTERNS AND INTEGRATED NUTRIENT MANAGEMENT

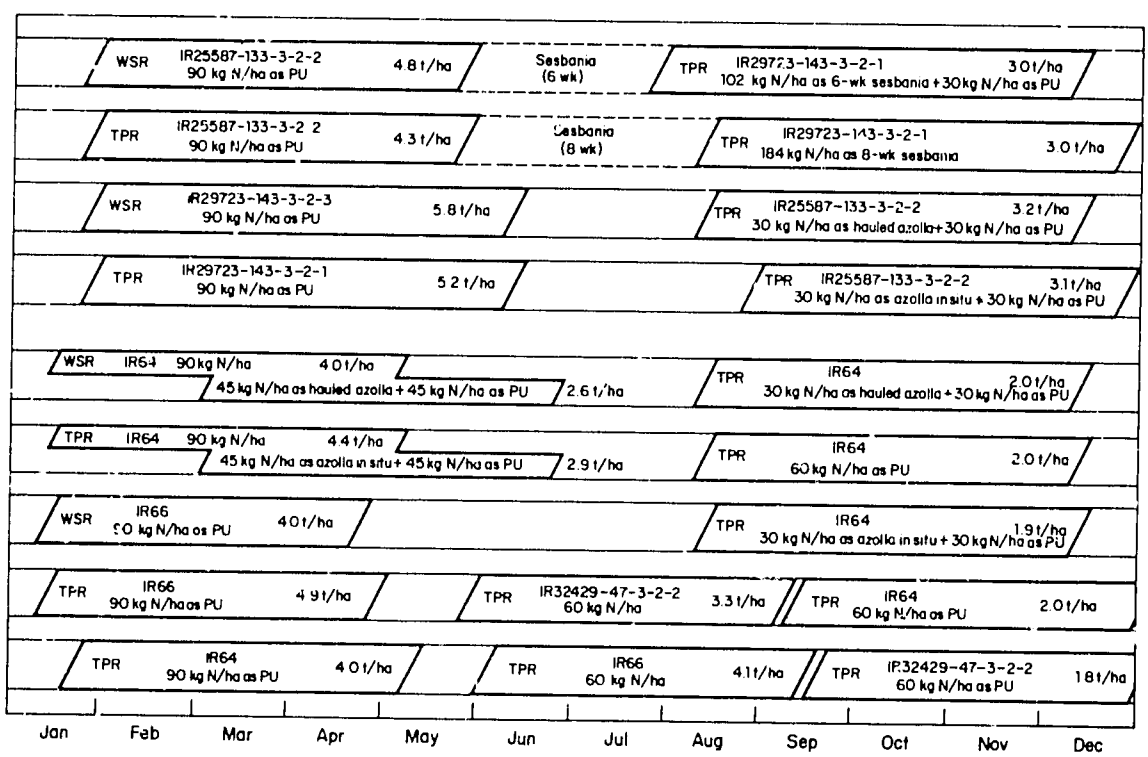
Irrigated lowland rice-based system. The profitability of using different cropping patterns, crop establishment methods, and integrated nutrient management techniques was evaluated at IRRI to identify production strategies that will increase farming profit at low production cost. The January-June cropping was fertilized with 90 kg N/ha, and the June-December cropping received 60 kg N/ha. Azolla green manure contributed 50% of the N requirement, while *Sesbania rostrata* supplied as high as 184 kg N/ha (Fig. 1). Rice grain yield was valued at $170.73/t. The cost of harvesting was 14.3% of the gross return, and irrigation expenses amounted to $22.68/ha per regular cropping. Labor services were valued at $1.46/labor day, $3.16/labor-animal day, and $11.22/labor-machine day. Rice seed cost $24.00/ha; sesbania seed, $37.00/ha; and prilled urea (PU), $129.46/t.

The most profitable cropping pattern was wet seeded rice (WSR) IR29723-143-3-2-1 - transplanted rice (TPR) IR25587-133-3-2-2, with the highest net margin of $981/ha (Table 1). The three-rice crop pattern TPR IR66 - TPR IR32429-47-3-2-2 - TPR IR64 followed closely.

Compared with TPR, WSR reduced by as much as $13/ha the variable cost for crop establishment (Table 2).

Use of azolla in situ delayed crop establishment of TPR IR64. This resulted in tungro disease and a 1.5 t yield decline/ha (Table 3). It thus reduced profit by $214/ha and gross revenue by $256/ha. With delayed incorporation of hauled azolla for WSR IR64, profit was reduced by $204/ha (Table 3).

Azolla manuring was excessively expensive in the IRRI lowland rice environment, needing a



1. Alternative integrated nutrient management in irrigated lowland rice-based systems, IRRI, 1987. WSR = wet seeded rice, TPR = transplanted rice, PU = prilled urea.

Table 1. Economic analysis of 11 cropping patterns and profitability of prilled urea (PU), *Sesbania rostrata*, and azolla manuring in an irrigated lowland rice-based system.[a] IRRI, 1987 DS and WS.

Cropping pattern[b]	Yield (t/ha)	Gross return ($)	Variable costs ($)							Net margin ($)
			Land preparation	Seed and crop establishment	Fertilization	Weed control	Insect control	Harvesting	Irrigation	
WSR IR25587-133-3-2-2 90 kg N/ha as PU	7.8	1332	142	65	78	40	9	190	45	763
TPR IR29723-143-3-2-1 102 kg N/ha as 6-wk-old sesbania + 30 kg N/ha as PU										
TPR IR25587-133-3-2-2 90 kg N/ha as PU	7.3	1246	145	79	67	56	11	178	45	665
TPR IR29723-143-3-2-1 184 kg N/ha as 8-wk-old sesbania										
WSR IR29723-143-3-2-1 90 kg N/ha as PU	9.0	1536	118	65	59	40	9	219	45	981
TPR IR25587-133-3-2-2 30 kg N/ha as hauled azolla + 30 kg N/ha as PU										
TPR IR29723-143-3-2-1 90 kg N/ha	8.5	1451	122	80	73	44	9	207	45	871
TPR IR25587-133-3-2-2 30 kg N/ha as azolla in situ + 30 kg N/ha as PU										
WSR IR64 90 kg N/ha as PU	6.0	1024	116	61	54	27	4	146	45	571
TPR IR64 30 kg N/ha as hauled azolla + 30 kg N/ha as PU										
WSR IR64 45 kg N/ha as hauled azolla + 45 kg N/ha as PU	4.6	785	112	60	51	38	4	112	45	363
TPR IR64 30 kg N/ha as hauled azolla + 30 kg N/ha as PU										
TPR IR64 90 kg N/ha as PU	6.4	1093	111	79	45	46	4	53	45	710
TPR IR64 60 kg N/ha as PU										
TPR IR64 45 kg N/ha as azolla in situ + 45 kg N/ha as PU	4.9	836	101	80	40	49	4	41	45	476
WSR IR64 60 kg N/ha as PU										
WSR IR66 90 kg N/ha as PU	5.9	1007	133	71	102	29	12	144	45	471

Continued on next page

Table 1 continued

Cropping pattern[b]	Yield (t/ha)	Gross return ($)	Variable costs ($)							Net margin ($)
			Land preparation	Seed and crop establishment	Fertilization	Weed control	Insect control	Harvesting	Irrigation	
TPR IR64 30 kg N/ha as azolla in situ + 30 kg N/ha as PU										
TPR IR66 90 kg N/ha as PU	10.2	1741	181	138	68	86	9	249	45	965
TPR IR32429-47-3-2-2 60 kg N/ha as PU										
TPR IR64 60 kg N/ha as PU										
TPR IR64 90 kg N/ha as PU	9.8	1673	140	141	68	176	4	239	45	860
TPR IR66 60 kg N/ha as PU										
TPR IR32429-47-3-2-2 60 kg N/ha as PU										

[a]$1.00 = ₱20.50. [b]TPR = transplanted rice, WSR = wet seeded rice, PU = prilled urea.

Table 2. Economic analysis of WSR and TPR and profitability of 3 rice cultivars in an irrigated lowland rice-based system.[a] IRRI, 1987 DS.

Cropping pattern	Yield (t/ha)	Gross return ($)	Variable costs ($)						Net margin ($)
			Land preparation	Seed and crop establishment	Fertilization	Weed control	Harvesting	Irrigation	
WSR IR25587-133-3-2-2	4.8	1034	70	31	26	15	148	23	721
TPR IR25587-133-3-2-2	4.3	734	74	44	25	23	105	23	440
Difference	0.5	300		-13					281
WSR IR29723-143-3-2-1	5.8	990	66	31	27	19	141	23	683
TPR IR29723-143-3-2-1	5.2	888	63	44	21	22	127	23	588
Difference	0.6	102		-13					95
WSR IR66	4.0	683	74	31	26	15	98	23	416
TPR IR66	4.9	836	76	44	27	21	119	23	526
Difference	-0.9	-153		-13					-110

[a]$1.00 = ₱20.50.

supplement of 13.2 kg P/ha and regular pesticide application. Hauled azolla combined with PU incurred a fertilization cost of $28-$32/ha, while PU application at 60 kg N/ha cost only $18/ha (Table 4). Use of azolla in situ was more costly at $47-$75/ha.

In sesbania manuring, the 6-wk biomass production and fixation of atmospheric N incorporated 102 kg N/ha; in 8 wk, it incorporated 184 kg N/ha (Table 4). Both treatments gave 3.0 t/ha and a net margin of $234/ha. If purchase of sesbania seed is considered part of the input, sesbania is more expensive than PU. Otherwise, it is three times cheaper than PU fertilizer.

Rainfed lowland rice-based system. Evaluation of TPR, WSR, and row seeded rice (RSR) using 2

Table 3. Economic analysis of WSR, TPR, and azolla manuring in an irrigated lowland rice-based system.[a] IRRI, 1987 DS.

Treatment	Yield (t/ha)	Gross return ($)	Variable costs ($)						Net margin ($)
			Land preparation	Seed and crop establishment	Fertilization	Weed control	Harvesting	Irrigation	
WSR IR64 90 kg N/ha as PU	4.0	683	71	31	26	24	98	23	410
WSR IR64 45 kg N/ha as hauled azolla + 45 kg N/ha as PU	2.6[b]	444	71	31	24	26	63	23	206
Difference	1.4	239							204
TPR IR64 90 kg N/ha as PU	4.4	751	65	44	26	24	107	23	462
TPR IR64 45 kg N/ha as azolla in situ + 45 kg N/ha as PU	2.9[b]	495	55	44	24	30	71	23	248
Difference	1.5	256							214

[a]$1.00 = ₱20.50. [b]Infected with rice tungro virus because of delayed crop establishment when azolla was propagated.

Table 4. Economic analysis of PU, *S. rostrata*, and azolla and profitability of 3 rice cultivars in an irrigated lowland rice-based system.[a] IRRI, 1987 WS.

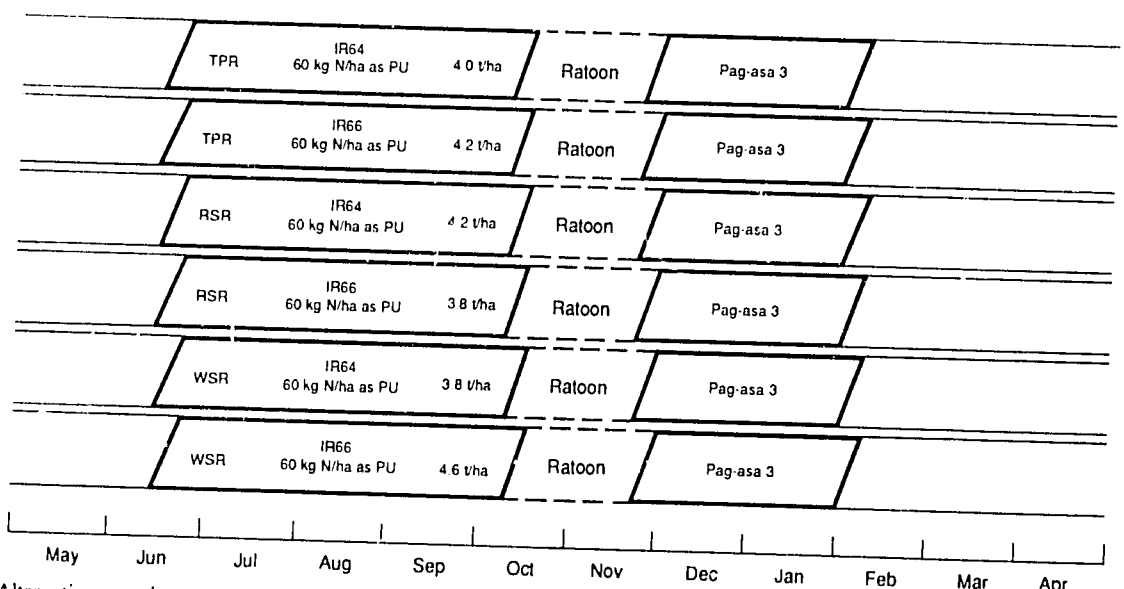
Cropping pattern	Yield (t/ha)	Gross return ($)	Variable costs ($)							Net margin ($)
			Land preparation	Seed and crop establishment	Fertilization	Weed control	Insect control	Harvesting	Irrigation	
TPR IR29723-143-3-2-1 102 kg N/ha as 6-wk-old sesbania + 30 kg N/ha as PU	3.0	512	72	34	52	25	9	73	23	234
TPR IR29723-143-3-2-1 184 kg N/ha as 8-2k-old sesbania	3.0	512	72	35	42	32	11	73	23	234
TPR IR25587-133-3-2-2 30 kg N/ha as hauled azolla + 30 kg N/ha as PU	3.2	546	53	34	32	21	9	78	23	296
TPR IR25587-133-3-2-2 30 kg N/ha as azolla in situ + 30 kg N/ha as PU	3.1	529	58	36	47	22	9	76	23	258
TPR IR64 30 kg N/ha as azolla in situ + 30 kg N/ha as PU	1.9	324	58	39	75	14	12	46	23	57
TPR IR64 30 kg N/ha as hauled azolla + 30 kg N/ha as PU	2.0	341	42	30	28	12	4	49	23	153
TPR IR64 60 kg N/ha as PU	2.0	341	36	36	18	19	4	49	23	156

[a]$1.00 = ₱20.50.

Table 5. Economic analysis of WSR, TPR, and row seeded rice (RSR) and profitability of 2 rice varieties in a rainfed lowland rice-based system.[a] IRRI, 1987 DS.

Treatment	Yield (t/ha)	Gross return ($)	Variable costs ($)					Net margin ($)
			Land preparation	Seed and crop establishment	Fertilization	Weed control[b]	Harvesting	
TPR IR64	4.0	683	57	43	15	82	88	398
TPR IR66	4.2	717	61	43	15	77	102	419
RSR IR64	4.2	717	59	25[c]	18	220	102	293
RSR IR66	3.8	649	58	25[c]	18	178	93	277
WSR IR64	3.8	649	58	24[d]	20	147	93	307
WSR IR66	4.6	785	58	28[d]	22	147	112	418

[a]$1.00 = ₱20.50. [b]For TPR, butachlor at 0.75 kg ai/ha + 2,4-D 0.5 kg ai/ha at 4-5 d after transplanting; for RSR, mechanical rotary weeder; for WSR, butachlor at 1.0 kg ai/ha at 3 d before seeding. [c]$1.3/ha for crop establishment. [d]$0.30/ha for crop establishment.



2. Alternative cropping patterns for a rainfed lowland rice-based system, IRRI, 1987-88. RSR = row-seeded rice.

rice varieties in the June-October cropping showed a profit as high as $418/ha from WSR IR66 at 4.6 t/ha grain yield (Table 5, Fig. 2). Inadequate rainfall influenced weed control cost in RSR and WSR. Profit was increased with the low cost of weed management and of seed and crop establishment. Weed control in TPR cost $71-$82/ha; that in WSR cost $147/ha. RSR incurred the highest cost for weed management at $178-$220/ha (Table 5).

Machinery development and testing

Agricultural Engineering, Multiple Cropping, and Agronomy Departments

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Hydrotiller **508**
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The principal projects undertaken during the year involved the development of machines and structures for improving farmers' traditional practices to enhance cropping intensity, increase income, and reduce the drudgery of farm work.

LAND PREPARATION

Agricultural Engineering Department

Pedestrian tractors. Machinery designs, like crop varieties, require "maintenance research" so as not to become obsolete and therefore be surpassed by other designs. The IRRI pedestrian tractors (power tillers) were modified to upgrade their performance.

IRRI's lightweight pedestrian tractor, the PT-5 powered by a 3.7-kW engine was developed primarily for land preparation and reaping. The design was released to manufacturers in 1981. Because some manufacturers use engines larger than 3.7 kW, the transmission bearing capacity was increased 40%; the transmission case was lengthened and inclined rearward 30° from the vertical; and the steering handle was placed farther from the driving axle, thus requiring less force for turning the tractor. Evaluation of the PT-5 is continuing.

The PT-3, IRRI's larger pedestrian tractor, is designed to be powered by a 7.5-kW engine and is steered with steering clutches. Field experience has revealed some failures of the sprockets and the final drive chain in the transmission. To reduce stress on these parts, the final drive chain was increased from RC50 to RC60, and the bars on the final drive sprockets were replaced with a pair of dog clutches on the input shaft to the final drive. The modification is being tested.

The power tiller converted for upland tillage was further tested and modified. The slasher-type blades were replaced by slitter-cutter blades, and a dashpot-type shock absorber was placed between the handle and a ground-engaging skid to lower the shock loads transmitted to the operator. As a result of the tests, we decided not to pursue the power tiller conversion for upland tillage, since performance and the estimated costs of conversion do not warrant it.

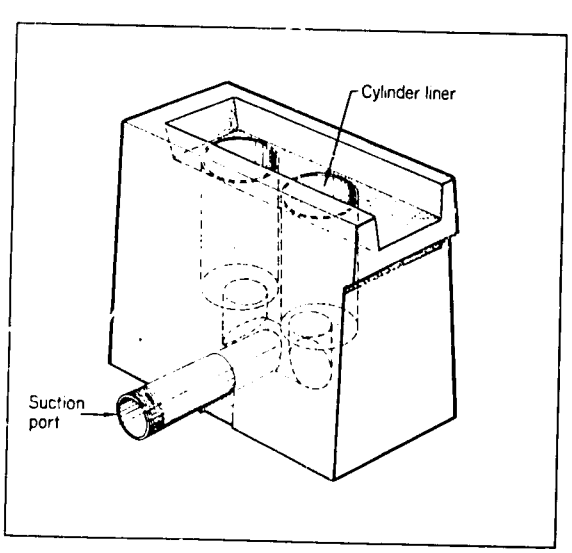
Hydrotiller. Instrumented float shapes were tested in laboratory soil bins to investigate the drag characteristics of the skid or float of the hydrotiller. The results of these studies should be useful in designing improved hulls or skids. Several full-size units of the Department of Agriculture (DA)-IRRI hydrotiller are being tested to determine why one manufacturer's unit is more maneuverable than another's, although both units are of the same basic design and weight.

IRRIGATION

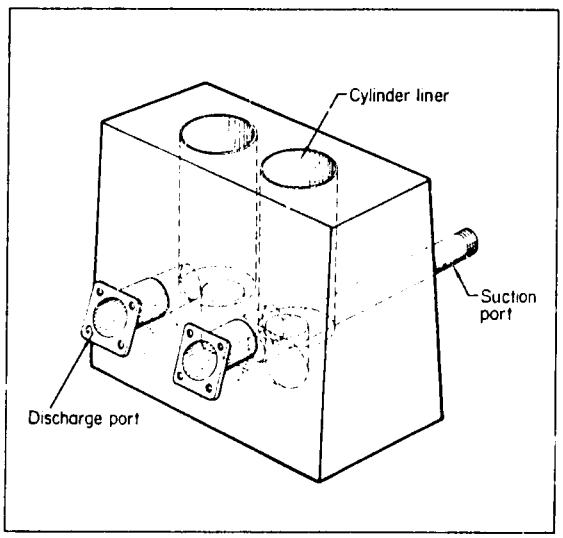
Agricultural Engineering Department

Treadle pump. The manually powered *tapak-tapak* treadle pump is fabricated from steel. To reduce the cost of the pump, IRRI engineers worked with counterparts at the Maros Research Institute for Food Crops, South Sulawesi, Indonesia, to develop designs with the housing cast from concrete for both nonpressurized (Fig. 1) and pressurized (Fig. 2) models. A reusable wooden mold holds the cylinder liners and intake part in proper position while the concrete is curing. The output characteristics of the concrete treadle pump are identical to those of the steel *tapak-tapak* pump.

Small electric pump. Engineers in the DA-IRRI program designed modifications of locally produced centrifugal pumps so that they can be powered by 0.37- to 1.1-kW electric motors. The electric motors last longer, require lower mainten-



1. Nonpressurized concrete treadle pump.



2. Pressurized concrete treadle pump.

ance, and are easier to operate than internal combustion engines. Because of the pump's low power requirement, single-phase motors can be used. This will contribute to its acceptance, since single phase is the common electric source in the Philippines. Demonstrations of the electric pump in northern and southern Philippines generated interest among rainfed farmers. Tests revealed that a 0.56-kW electric pumpset operating 24 h/d can provide supplemental irrigation to a maximum of 2.0 ha of rice. Table 1 shows the power required to provide various flow-rates for different lifts. In areas where the water level is beyond the suction lift capability of a centrifugal pump (approximately 7 m), a small electric pump can be suspended with ropes and, using a flexible discharge hose, can be easily placed close to the water level.

The DA-IRRI program disseminated to local manufacturers of centrifugal pumps information on the proper impeller diameter and width for different horsepower ratings.

Hydraulic ram. The hydraulic ram is one of the most satisfactory devices invented for pumping water from a flowing stream to a higher elevation. The ram utilizes the kinetic energy of flowing water to pump a small fraction of the water. The ram can be used only in streams where there is a steady and reliable supply of water and a fall of at least 1 m.

The hydraulic ram has advantages over hand-, animal-, and wind-powered pumps, for it has only two moving parts and requires no external power sources.

To irrigate 1-2 ha of riceland, an output of 100-200 liters/min is needed. A hydraulic ram prototype to fit this specification was designed, to be constructed and tested in 1988.

CROP ESTABLISHMENT

Agricultural Engineering, Multiple Cropping, and Agronomy Departments

The following seed metering devices used on various IRRI seeders were tested in the laboratory: drum, inclined plate, horizontal plate, foam roller, and foam pad for mungbean, soybean, cowpea, maize, peanut, wheat, and sorghum. The testing was done to establish the performance of the seed metering mechanisms under the best uniform conditions and to compare the devices. Analyses of the data will be completed in the first quarter of 1988.

Plow drum seeder (*Agricultural Engineering and Multiple Cropping*). Because, in the original

Table 1. Power requirement (motor size) of small centrifugal pumps at various outputs and heads.

	Pump discharge (liters/min)						
	75	115	150	190	225	265	305
Total head (m)							
4.6	0.19 kW		0.37 kW				
6.1	0.25 kW						
7.6 19.1		0.56 kW			0.75 kW		
10.7 12.2				1.13 kW			

design of the plow drum seeder (Annual report for 1986), the seeder drive wheel was fixed to the plow handle, the drive wheel clogged in cloddy fields and seed was missed in the row when the farmer lifted the plow handle to adjust plow penetration. We changed the drive wheel from a lugged wheel to a smooth wheel and placed it on the left side of the plow. A spring-loaded assembly was installed so that the ground wheel is kept in contact with the soil surface during normal plow handle movement. The Multiple Cropping Department compared the plow drum seeder with other seeding methods for planting IR64 in the 1987 wet season (WS). There was no significant difference in yield of the various seeding methods when seeding was done on a well-prepared seedbed (Table 2).

Manual upland drum seeder (*Agricultural Engineering*). Because operators prefer pushing a seeder under upland conditions, the upland drum seeder was modified from pull-type to push-type. Weed accumulations on the inverted-T furrow opener persisted despite various modifications. Efforts were thus extended to other furrower designs suitable for manual operation. A parabolic furrower using a flat bar surface, a triangular surface furrower (by shaping an angle bar), and the inverted-T furrower used in the previous unit were attached to a common toolbar for comparison tests. Initial tests on weedy fields and on uneven soil surfaces revealed that the parabolic furrow opener was able to cut through the soil surface irrespective of soil tilth. Soil and weeds moved along its surface so that accumulation was minimized. The triangular surface furrower suffered from weed accumulation, as did the front plate of the inverted-T furrower. These furrowers will be tested further.

Inverted-T seeder (*Agricultural Engineering and Multiple Cropping*). The inverted-T seeder was tested in WS for rice establishment under rainfed conditions. Results are shown in Table 2. The inverted-T seeder had higher plant emergence than the other establishment methods. The emergence of rice planted by the inverted-T under zero tillage in Stratum I was lower than with conventional tillage but significantly greater than with the other seeding methods. The plots planted by the inverted-T seeder had the earliest and most

Table 2. Effects of dry seeding methods on emergence, yield, and yield components of IR64 on 2 soil strata of rainfed environment.[a] Guimba, Nueva Ecija, 1987 WS.

Seeding method[b]	Emergence (no. of plants/m)	Plant height at maturity (cm)	Productive tillers (no./m)	Panicle length (cm)	Grain yield (t/ha)
		Stratum I[c]			
A	43 cde	103.05 a	435 b	23.10 a	5.49 ab
B	36 e	101.77 a	485 ab	22.35 a	5.40 b
C	37 de	101.77 a	471 ab	23.37 a	5.65 ab
D	90 a	100.07 a	561 a	22.15 a	6.29 a
E	63 b	90.30 b	447 ab	21.73 a	4.23 c
CV (%)	22.4	2.46	16.28	5.44	9.74
		Stratum III[d]			
A	25 cd	105.30 a	352 b	23.63 ab	4.75 a
B	20 d	105.03 a	428 ab	24.47 a	4.85 a
C	31 bc	107.53 a	415 ab	22.65 b	5.30 a
D	53 a	104.37 a	468 a	23.17 ab	5.28 a
CV (%)	18.55	2.81	14.23	4.35	9.05

[a]Av of 4 replications. Within a stratum, means in a column followed by a common letter are not significantly different at the 5% level by LSD. [b]A = drilled by hand on furrows, B = broadcast on furrows made by lithao, C = drum seeder attached to a native plow, D = inverted-T seeder, E = inverted-T seeder (zero tillage, plots sprayed with glyphosate 1 d before planting). Methods A, B, and C used a comb harrow to cover seeds. CV = coefficient of variance. [c]Highest elevation of the field. Land preparation for methods A-D = 2 plowings with native moldboard plow and 2 spiketooth harrowings. Seeding rate = 100 kg/ha except in method C, which was 80 kg/ha. [d]Lowest elevation of the field. Land preparation for all methods = 3 passes by a PT-5-type power tiller (Landmaster) equipped with rototiller tines. Seeding rate = 100 kg/ha except in method C, which was 80 kg/ha.

uniform plant emergence among the treatments. Although the zero-tillage plots obtained high emergence, residual effects of the herbicide used to control weeds caused yellowing and poor grain yield despite a comparable number of productive tillers. The lower emergence with the other planting methods was caused by poor seed soil covering and nonuniform seeding depth.

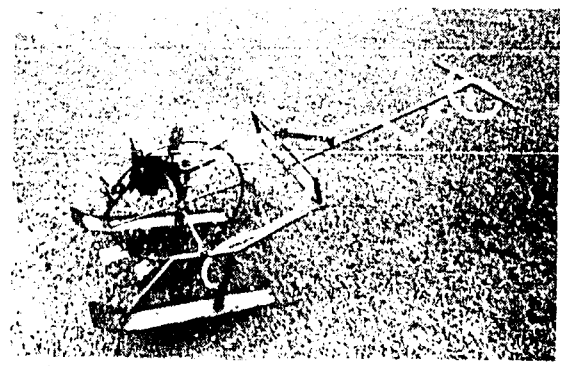
Cooperative work with the Multiple Cropping Department in testing two shapes of seed grooves for the inverted-T seeder revealed greater peanut establishment and seed yield in both tilled and untilled plots than with hand seeding (Table 3).

Liquid chemical injector (*Agricultural Engineering and Agronomy*). An improved liquid injector was designed for the 1987 dry season (DS). The two-row injector has a peristaltic pump operated by a central wheel (Fig. 3). The unit has furrow openers and closers similar to the patented IRRI granular fertilizer applicators. The operator pushes the machine and carries the solution in a backpack.

Table 3. Peanut establishment, seed yield, and filled pods with hand seeding and in tilled and untilled plots using the inverted-T seeder with 2 groove shapes. IRRI, 1987 DS.

Tillage method[a]	Seeding method		
	Inverted-T	T-groove	Hand seeding
	Rate (no. of seed dropped/m)[b]		
Untilled	5.1	5.7	5.8
Tilled	6.9	7.2	9.6
	Emergence (no. of seedlings/m)		
Untilled	4.6	5.2	7.5
Tilled	6.4	6.5	7.5
	Plant establishment (%)[c]		
Untilled	90.2	91.2	65.5
Tilled	92.8	90.3	78.1
	Crop stand (no. of plants/m²)[d]		
Untilled	7.6	6.9	5.8
Tilled	6.1	7.3	6.4
	Filled pods (no./plant)[e]		
Untilled	14	18	21
Tilled	24	23	22
	Seed yield (t/ha)		
Untilled	1.16	1.32	1.10
Tilled	1.82	2.00	1.81

[a]High tillage consists of tractor moldboard plowing + rotary tillage with tractor rototiller. [b]Av of 7 linear m/plot. [c]At 14 d after sowing. [d]At harvest, taken from 30 m². [e]Randomly taken from 10 plants.



3. Liquid chemical injector.

A flexible plastic tube transports the solution from the tank to the peristaltic pump. The pump meters the liquid and forces it under pressure from an orifice behind each furrow opener. The fins and the wedge on the bottom of each skid cover the furrow with mud and seal the solution from water or the atmosphere. Tests with this machine by the Agronomy Department for the deep placement of aqueous NH_3 showed that this method of applying N during wetland rice crop establishment leads to efficient N utilization. Results of the tests are shown in Table 4.

WEED CONTROL

Agricultural Engineering Department

Upland weeder. Field tests of push-type upland weeder prototypes showed the advantage of an arcuate spike roller with a straight sweep (Fig. 4). The roller is made from a steel pipe 10 cm in diameter; the spikes are formed of steel sheet metal. The roller disturbs the soil and helps uproot weeds. The disturbed soil is then swept by the blade at 3 cm depth to bring up the weeds. The machine is light to push, requiring a force of only 60-80 N. However, it cannot be worked very close to the plants, nor can it move the soil to cover the weeds along the rows. The arcuate spikes may also be more difficult to fabricat than the radial type roller.

A two-blade shovel-cultivator was designed (Fig. 5). The reversible blades are inclined to increase soil scouring, reduce draft, and shed weeds. Shovels set at 20° and 25° required the least draft—an average of 78 N for each pair of blades—

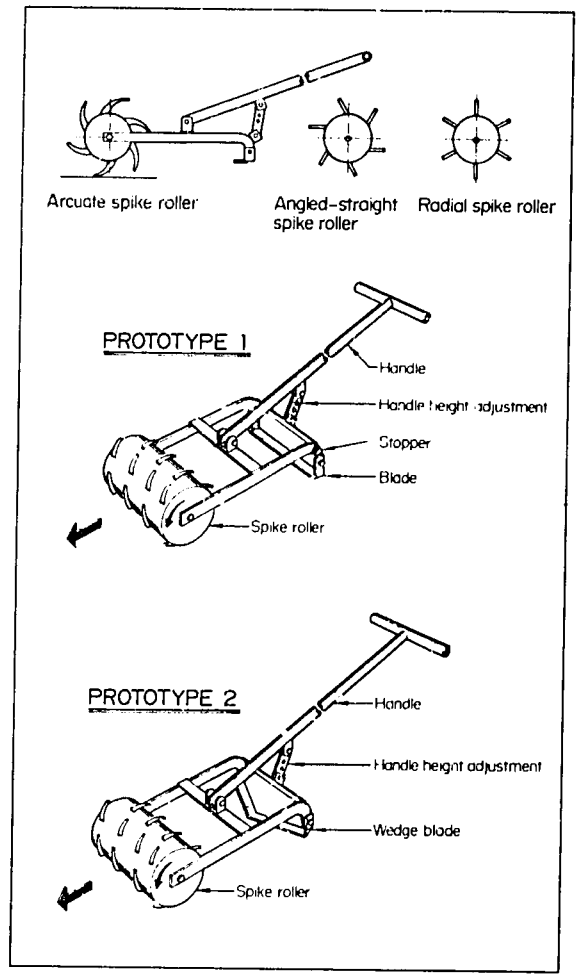
Table 4. Effects of N fertilizer application and crop establishment methods on IR64, Nueva Ecija, 1987 DS.[a]

Treatment[b]	Grain yield (t/ha)	Agronomic efficiency (Δ kg grain/kg N applied)
Transplanted (at 4 plants/hill, 20- X 20-cm spacing)		
No fertilizer N	3.3	–
2/3 BB&I + 1/3 broadcast at 5-7 DBPI	7.6	49
2/3 injected at 14 DT + 1/3 injected at 5-7 DBPI	8.0	54
1/3 injected at 14 DT + 2/3 injected at 5-7 DBPI	8.2	56
1/3 injected at 14 DT + 1/3 injected at 5-7 DBPI + 1/3 broadcast at 10 DBPI	7.8	52
USG point-placed at 1 DT	7.8	52
Direct seeded (hill-wise at 4 plants/hill, 20- X 20-cm spacing)		
No fertilizer N	3.3	–
2/3 BB&I + 1/3 broadcast at 5-7 DBPI	7.7	51
1/3 BB&I + 2/3 broadcast at 5-7 DBPI	7.2	45
1/3 injected at 20 DAS + 2/3 injected at 5-7 DBPI	8.5	60
1/3 injected at 20 DAS + 1/3 injected at 5-7 DBPI + 1/3 broadcast at 10 DAPI	7.5	48
USG point-placed at 20 DAS	8.3	57
Row seeded (using drum seeder at 60 kg/ha)		
No fertilizer N	3.3	–
1/3 BB&I + 2/3 broadcast at 5-7 DBPI	7.3	46
1/3 injected at 20 DAS + 2/3 injected at 5-7 DBPI	7.9	53
Broadcast seeded (at 90 kg/ha)		
No fertilizer N	3.6	–
1/3 BB&I + 2/3 broadcast at 5-7 DBPI	7.6	46

[a]Av of 4 replications. Total fertilizer rate was 87 kg N/ha.
[b]BB&I = basal, broadcast, and incorporated; DBPI = days before panicle initiation; DT = days after transplanting; USG = urea supergranules; DAS = days after seeding; DAPI = days after panicle initiation. "Injected" = aqueous NH_3 applied using the liquid chemical injector.

while angles of 15° and 30° needed average drafts of 138 and 135 N, respectively. As a result of this research, the cultivator blade was made at an angle of 20°. The machine has the following features:

Mode of operation	Push-type interrow
Purpose	Weeding and hilling
Power	One person
Draft requirement	60-80 N
Weight	6 kg
Adjustments	Handle height, width of cut
Crops	Rice, legumes, other crops in 25- X 25-cm rows



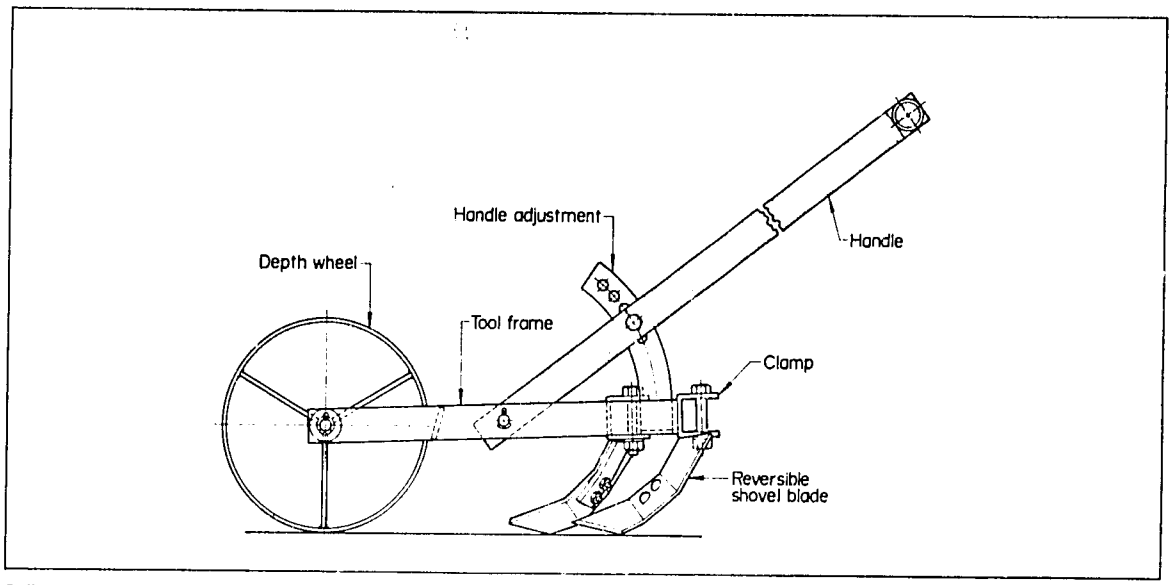
4. Push-type roller and wedge sweep upland weeder.

HARVESTING

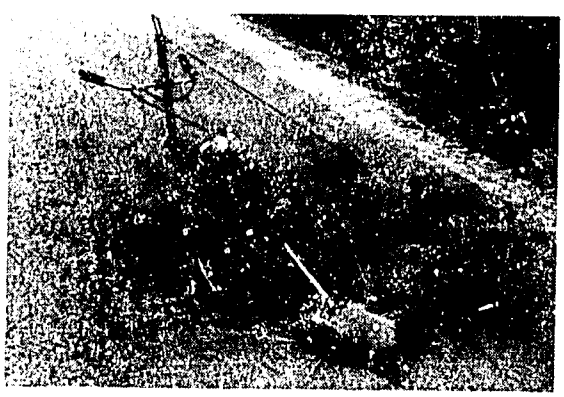
Agricultural Engineering Department

0.25-m reaper. A small reaper based on a commercially available brush cutter was designed to cut and windrow rice (Fig. 6). The reaper is pushed by hand, but the cutting blade is powered by a 1.5-kW 2-cycle gasoline engine. A pair of pneumatic bicycle wheels supports the frame. The cutting blade is driven directly by a shaft from the engine crankshaft. The reaper specifications are

Power	Human and 1.5-kW 2-cycle gasoline engine
Weight	18.5 kg
Estimated manufacturing cost (less engine and blade)	US$68.00
Engine and blade	US$225.00
Estimated selling price	US$350.00



5. Two-blade shovel cultivator weeder.



6. 0.25-m reaper.

Various designs of the cutting blade shield and plate were tested to secure a good windrow. However, tests of the 0.25-m reaper in transplanted rice revealed that the cut rice did not flow smoothly into a swath, and there was some wrapping of straw around the cutting blade.

Axial-flow minithresher. A portable axial-flow minithresher was designed and fabricated for small farmers with 2 ha of ricefield. The thresher has a cylinder length of 46 cm, cylinder ring diameter of 30.5 cm, and a 5-cm distance between adjacent peg teeth. The first section of the concave was made adjustable to vary the clearance between concave bars and cylinder teeth at the feeding end.

Tests of the prototype (Table 5) revealed that 1) reduced peg teeth in the threshing cylinder decreased separation loss; 2) as straw length decreased, separation loss decreased; 3) losses

Table 5. Test results of axial-flow minithresher, IRRI, 1987.

Parameter	Test[a]			
	I	II	III	IV
Date of test	8 Jul	9 Jul	13 Jul	14 Jul
Duration (s)	30	30	30	30
Cylinder RPM[b]	650	650	550	550
No. of cylinder pegteeth, feedside	22	16	16	16
No. of cylinder pegteeth, separation	22	12	12	12
No. of counter pegs, feedside	3	3	3	3
No. of counter pegs, separation	4	4	4	4
Pegtooth-concave bar clearance (mm)	16	12	12	12
Rice variety	IR64	IR64	IR64	IR64
Date harvested	9 Jul	8 Jul	13 Jul	14 Jul
Moisture content of grain (%)	30.6	24.5	20.4	22.1
Length of material threshed (cm)	72.8	70.1	74.37	54.35
Capacity (kg/h)	207.96	117.61	218.32	159.39
Separation loss (%)	6.42	3.07	6.45	4.83
Unthreshed loss (%)	Nil	Nil	Nil	Nil

[a]Av of 3 trials. [b]RPM = revolutions per minute.

due to unthreshed grains were negligible; and 4) reduced clearance between concave bars and cylinder teeth reduced separation loss.

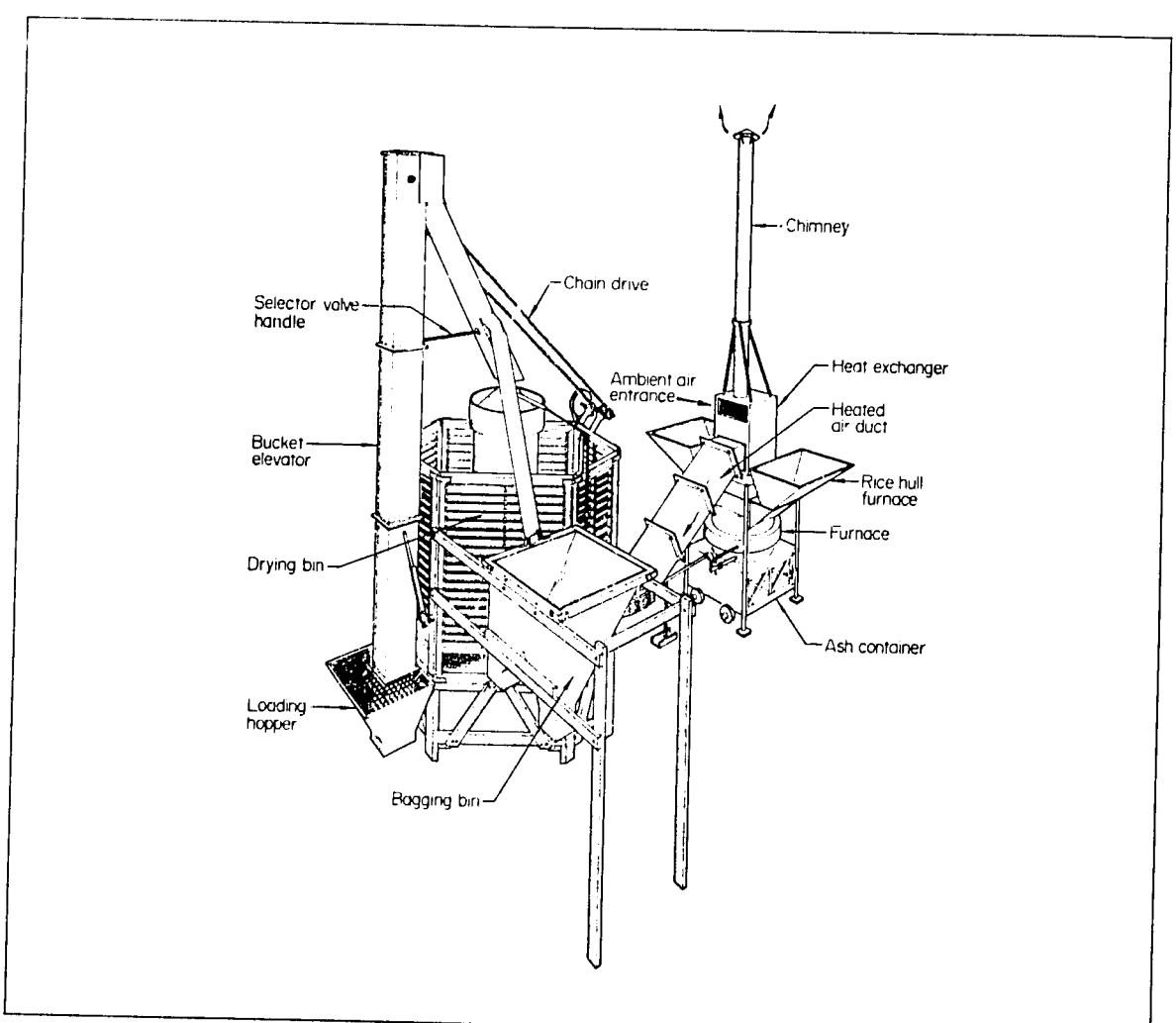
POSTHARVEST EQUIPMENT

Agricultural Engineering Department

Sun-drying research. The study of the effects of rice layer thickness and mixing-time interval on the physical qualities of sun-dried rice, conducted at IRRI and in three major rice-producing regions of Luzon, was first reported in the Annual report for 1983. IRRI engineers completed the study this year. A computer program—SRPROB—written in BASIC, was developed to calculate the probability of occurrence of daily solar radiation and to provide the probability of success of sun-drying rice. An adjustable mixing blade to fit on the IRRI PT-5 power tiller was developed for mechanizing sun-drying on drying floors. Analysis of the research reveals that the power tiller and blade are more cost-effective than manual turning, mixing, and piling of rice while sun-drying.

4-t recycling batch dryer. A 4-t dryer using rice hulls as fuel was designed for rice farmers who live near rice mills where rice hulls are easily obtained, farmers' cooperatives, and small and medium rice mills.

The dryer (Fig. 7) has a bucket elevator to facilitate grain handling, and a holding bin to enhance grain mixing. Heated air from a heat



7. 4-t recycling batch dryer.

exchanger is forced by a blower through a perforated vertical plenum at the center of the drying bin.

Initi. . ·ng revealed that 4 t of freshly harvested rice at about 25-30% moisture content (wet basis) can be dried to 14% moisture content (wet basis) in less than 10 h. Mixing the grain between drying periods reduced moisture content variation from 10% to 2% within the grain in the drying bin. The grain milling qualities (recovery and head rice) were not adversely affected.

Some difficulties were experienced with the bucket elevator and formation of clinkers in the rice hull furnace.

Modifications of the holding bin (bagging bin), blower, discharge system, elevator, and furnace will be made before further testing.

Multicrop rotary drum dryer. The manually powered rotary dryer (Annual report for 1986) was modified by mounting a cleaning fan at the discharge end to remove light debris from the material being dried. The drive train was redesigned so that the drum can be powered manually or by an engine.

INDUSTRIAL EXTENSION

Agricultural Engineering Department

When the United States Agency for International Development-funded DA-IRRI Program on Small Equipment ended on 30 Jun 1987, eight Philippine manufacturers were fabricating the hydrotiller. Work continues with the Agricultural Engineering Section of the Bureau of Plant Industry (BPI) of the DA, but at a much lower level. One IRRI engineer spends 2 d/wk working with BPI on their outreach program.

Training programs

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We continued our training and educational programs to strengthen our linkages with organizations supporting the international research networks and our global research programs. Our training and educational programs are classified into 1) research-oriented programs, 2) nondegree courses, and 3) special training programs.

RESEARCH-ORIENTED PROGRAMS

Postdoctoral and visiting scientist program. We offer postdoctoral and visiting scientist positions to senior scientists of national research organizations and universities to reorient their skills and expertise in their fields of research specialization. At IRRI, they conduct research projects on problems of mutual interest to IRRI and their national research programs. On completion of their fellowships, which are usually for a maximum of 2 yr, they return to their organizations to continue working on rice and rice-based cropping systems. The projects they pursue at IRRI provide valuable contributions to our research accomplishments, and they often become active collaborators in our research and training programs when they return to their organizations. Occasionally, we offer fellowships to new Ph D graduates who have special expertise needed to initiate new research projects.

Collaborative research scientists come to IRRI to conduct research programs under collaborative research programs we have with organizations and universities in developed countries. The research projects they pursue form part of the overall research program of the work plan included in the agreement. The fellowships of collaborative research scientists are funded by their organizations.

During 1987, we had 19 visiting scientists, 45 postdoctoral scientists, and 13 collaborative research scientists (Table 1, 2). Twelve completed their tenure during the year.

During the year, an agreement was signed with the International Centre of Insect Physiology and Ecology (ICIPE) for IRRI to assign one visiting scientist to work at the ICIPE Mbita Research Station on upland rice.

Degree program. We offer a graduate degree program for the completion of MS and Ph D degrees in collaboration with selected universities all over the world. The scholarship enables the candidate to pursue course work and do research in a selected university arranged by IRRI, or to conduct research at IRRI after completing the course requirements at his or her university. The first program is intended for candidates of collaborating organizations from developing countries, especially from countries that have inadequate facilities for graduate education. The second program enables graduate students from developing countries to use IRRI's facilities for their research; like the participants in the first program, they benefit from the guidance of IRRI scientists and from access to IRRI's facilities, including the library and computer center.

During the year, 89 Ph D and 81 MS scholars were in residence at IRRI (Table 1, 2). Thirty completed their training during the year. The committee on degree and research-related nondegree programs accepted 46 new candidates during the year. These scholars were enrolled at 34 universities in 14 countries. Among the degree candidates, 53 were accepted to conduct their thesis or dissertation research at IRRI, having earlier completed their course requirements at their universities. Table 3 presents the distribution of the candidates by university.

Collaboration with agricultural universities. Collaboration with selected agricultural universities all over the world is a vital component of IRRI's graduate training program. Through this collaboration, IRRI is able to respond to the needs of national programs to generate a pool of scientists trained at the MS and Ph D levels who, in addition to completing academic course preparation offered by their universities, are trained in scientific research while conducting their research at IRRI.

IRRI now has formal collaborative graduate programs with 29 universities, and informal arrangements with more than 20 additional universities.

During 1987, IRRI signed agreements with two universities: the University of Agriculture and Forestry of Vietnam (November) and McGill University of Canada (December). The latter agreement will enable Canadian Ph D students to conduct their dissertation research at IRRI under the sponsorship of Canadian funding institutions.

Nondegree research-oriented programs. Nondegree research-oriented programs enable scientists

Table 1. Visiting scientists (VS), postdoctoral scientists (PDS), collaborative research fellows and scientists (CRF/CRS), research fellows, and research scholars by region and country. IRRI, 1987.

Country	VS	PDS	CRF/CRS	Ph D	MS	Nondegree	Total
Asia							
Bangladesh	0	2	0	12	13	1	28
Bhutan	0	0	0	0	0	1	1
Burma	1	0	0	2	10	0	13
China	0	5	0	11	17	10	43
India	11	17	2	10	0	0	40
Indonesia	0	1	0	2	0	5	8
Iran	0	0	0	0	1	3	4
Japan	0	1	1	4	0	0	6
Korea	0	3	2	10	2	1	18
Laos	0	0	0	0	0	5	5
Malaysia	0	0	0	0	0	1	1
Nepal	0	0	0	6	3	0	9
Pakistan	0	0	0	5	2	0	7
Philippines	2	10	0	9	6	2	29
Sri Lanka	2	0	0	1	2	1	6
Thailand	1	0	0	3	13	4	21
Vietnam	0	0	0	1	2	12	15
Subtotal	17	39	5	76	71	46	254
Africa							
Egypt	0	1	0	1	0	1	3
Ghana	1	1	0	0	2	0	4
Guyana	0	0	0	0	1	0	1
Kenya	0	0	0	0	1	0	1
Madagascar	0	0	0	0	1	0	1
Nigeria	1	1	0	0	0	0	2
Sierra Leone	0	1	0	1	1	1	4
Tanzania	0	0	0	1	0	0	1
Zaire	0	1	0	0	0	0	1
Subtotal	2	5	0	3	6	2	18
North America							
Canada	0	0	0	1	1	0	2
United States	0	0	0	2	0	0	2
Subtotal	0	0	0	3	1	0	4
Latin America							
Brazil	0	0	0	0	1	0	1
Cuba	0	0	0	0	0	2	2
Mexico	0	1	0	0	1	0	2
Subtotal	0	1	0	0	2	2	5
Europe							
Belgium	0	0	0	2	0	0	2
Bulgaria	0	0	0	0	0	1	1
France	0	0	0	1	0	0	1
Germany	0	0	4	3	1	0	8
Netherlands	0	0	1	1	0	2	4
Switzerland	0	0	1	0	0	0	1
United Kingdom	0	0	2	0	0	2	4
Subtotal	0	0	8	7	1	5	21
Total	19	45	13	89	81	55	302

to undertake on-the-job, apprenticeship-type training in IRRI's experimental farm and laboratories. The programs are designed to impart job-related research skills while the trainees work on specific research projects under the supervision of IRRI scientists. They may last from 3 mo to 1 yr.

In 1987, 55 scientists from 18 countries participated in nondegree research-oriented programs

Table 2. Visiting scientists, postdoctoral scientists, collaborative research fellows and scientists, research fellows, and research scholars by department. IRRI, 1987.

Department	VS	PDS	CRF/CRS	Ph D	MS	Nondegree	Total
Agricultural Economics	1	1	0	8	11	3	24
Agricultural Engineering	1	1	0	0	5	1	8
Agronomy	0	5	2	11	9	0	27
Cereal Chemistry	0	1	0	0	1	2	4
Communication and Publications	0	0	0	1	1	2	4
Entomology	1	3	1	9	11	5	30
International Rice Germplasm Center	0	0	0	0	2	2	4
International Rice Testing Program	2	3	0	1	0	0	6
Library and Documentation Center	0	0	0	0	0	1	1
Multiple Cropping	0	2	1	4	4	1	12
Plant Breeding	3	9	2	14	13	18	59
Plant Pathology	6	7	4	12	8	8	45
Plant Physiology	0	3	1	6	0	2	12
Rice Farming Systems Program	1	2	0	7	2	1	13
Soil Microbiology	3	2	1	4	4	2	16
Soils	1	2	1	4	3	2	13
Statistics	0	2	0	1	2	3	8
Training and Technology Transfer	0	1	0	1	1	1	4
Water Management	0	1	0	2	2	1	6
Overseas[a]	0	0	0	4	2	0	6
Total	19	45	13	89	81	55	302

[a]Candidates completed their degree programs entirely at overseas universities.

to upgrade their research skills. The majority of them worked in plant breeding.

NONDEGREE COURSES

In 1987, IRRI offered 11 regular and 9 special short-term courses. The numbers of participants by region and country are given in Tables 4 and 5.

Regular courses. *Agricultural Engineering Course (AEC).* This 3-wk course, initiated in 1975, complements IRRI's on-farm machinery development program. It is offered to cooperators of IRRI's farm machinery program and includes all aspects of design, manufacture, and field testing of IRRI-designed machines. The two 1987 sessions were attended by 27 trainees from 13 countries.

Cropping Systems Training Program (CSTP). This 21-wk course is intended to develop human resources proficient in establishing an intensified, diversified multiple cropping program that circumvents the single-crop risk factor and generates additional commodity markets. The course includes topics on new rice-based cropping patterns and component technologies. A 2-wk component on research management, in collaboration with the Research Management Center of the University of the Philippines at Los Baños (UPLB), is included. The 1987 session was attended by 21 trainees from 9 countries.

Table 3. Distribution of MS and Ph D degree candidates by university of enrollment, 1987.

Institution	MS	Ph D	Total
University of the Philippines at Los Baños, Philippines	58	51	109
Kasetsart University, Thailand	10	0	10
Central Luzon State University, Philippines	7	1	8
Indian Agricultural Research Institute, India	0	7	7
Cornell University, United States	0	3	3
University of the Philippines, Diliman, Philippines	0	3	3
Justus Liebig University, Federal Republic of Germany	0	2	2
Post-Graduate Institute of Agriculture, Sri Lanka	2	0	2
University of Manitoba, Canada	2	0	2
University of Wageningen, Netherlands	1	1	2
Others[a]	1	21	22
Total	81	89	170

[a]Candidates were from 22 universities in 14 countries.

Table 4. Participants in regular nondegree training courses[a] by region and country. IRRI, 1987.

Country	AEC I	AEC II	CSTP	EDPUB I	EDPUB II	FSSR	GEU	IPM	INSFFER	IWM	SPCAAR	T3C I	T3C II	URTC	Total
Africa															
Botswana				1											1
Cameroon								1							1
Egypt		1													1
Guinea														1	1
Ivory Coast														1	1
Kenya					1										1
Liberia														2	2
Madagascar		2				2	1		1						6
Malawi					1										1
Mali	1														1
Nigeria	1	1		1	1			1	1					1	7
Sudan								1							1
Tanzania	1		1	1			1								4
Asia															
Bangladesh		1	2	2						2	2		3	1	13
Bhutan						1				1					2
Burma														1	1
China	1		2	1	1	4	3	4	3		1	6			26
India	2	2	3	2			4	3	2	3	1			4	26
Indonesia						2		1		4			4	1	12
Laos											2				2
Malaysia		1			1	1					1				4
Nepal						2	1	1	1	2					7
Pakistan			1								1				2
Philippines	4		4	1	1	3	1	1	2	5	1				23
Sri Lanka	3	3	3		1	2		2	1	3			6		24
Thailand	1	1	4	1		3	1	2	3	4	1	4			25
Vietnam		1	1			1	2	2	2	2	1				12
Latin America/Caribbean															
Brazil					1	1	1							1	4
Colombia						1									1
Costa Rica														1	1
Ecuador					1										1
Mexico							1			1				1	3
Total	14	13	21	10	9	23	16	19	16	27	11	10	13	15	217

[a]AEC = Agricultural Engineering Course, CSTP = Cropping Systems Training Program, EDPUB = Editing and Publication, FSSR = Farming Systems Socioeconomic Research, GEU = Genetic Evaluation and Utilization, IPM = Integrated Pest Management, INSFFER = International Network on Soil Fertility and Fertilizer Evaluation for Rice, IWM = Irrigation Water Management, SPCAAR = Statistical Procedures and Computer Applications in Agricultural Research, T3C = Training and Technology Transfer Course, URTC = Upland Rice Training Course.

Editing and Publication (EDPUB). This 14-wk course emphasized problem-solving and practical projects in editing, design, illustration, and production of scientific reports and general publications for disseminating research results. An alumni newsletter was started as a classroom exercise and to encourage an international alumni network. The course began in mid-1985 in conjunction with a 3-yr project funded by the International Development Research Centre (IDRC) of Canada in collaboration with the University of Toronto Press. The two 1987 sessions, which were the last, were attended by 19 trainees from 14 countries.

Farming Systems Socioeconomic Research (FSSR). This 9-wk course integrates economic and sociological aspects with the technical components of small-scale rice farming involving technology design and on-farm research, together with methodologies for economic evaluation of research station experiments and assessing the broader impact of

Table 5. Participants in special short-term nondegree training courses[a] by region and country. IRRI, 1987.

Country	CS/OJT		PDWR	GDWR	HRSP	AZOLLA	DDCM	PTR2	RP/KM	Total
	VT	LVI								
Africa										
Madagascar						2				2
Asia										
Bangladesh	1	1	2	1				5		10
Burma				1						1
China	2			1		9	3			15
India			8	5	4	3				20
Indonesia	2	1	2	1	3		4	5		18
Kampuchea									13	13
Korea					2			2		4
Malaysia					1	1				2
Nepal		1								1
Pakistan						1				1
Philippines	2		1		2	4	7	1		17
Sri Lanka		1				1	1	5		8
Thailand	2	1	2	3	2	2	2	6		20
Vietnam			2	1	1					4
Latin America										
Brazil					1	1				2
Total	9	5	17	13	16	24	17	24	13	138

[a]CS/OJT = Cropping Systems On-the-Job Training; VT = Varietal Testing for Intensive Rice Farming Systems; LVI = Legume Varietal Improvement for Rice-Based Cropping Systems; PDWR = Field Methods for Pest Management Research for Deepwater Rice; GDWR = Genetic Evaluation and Utilization for Deepwater Rice; HRSP = Hybrid Rice Seed Production; AZOLLA = International Azolla Training Course, Fuzhou, China; DDCM = Multipurpose Dryer Design, Construction, and Maintenance; PTR2 = Prosperity Through Rice – Phase 2; RP/KM = Rice Production Course for Kampucheans.

increased agricultural productivity. The 1987 session was attended by 23 trainees from 12 countries.

Genetic Evaluation and Utilization (GEU). This 16-wk course is intended for agricultural scientists engaged or expected to become actively involved in rice germplasm improvement and management in their countries. The training course complements IRRI's GEU research program. The 1987 session was attended by 16 trainees from 10 countries.

Integrated Pest Management (IPM). This 18 wk course integrates pest control strategies that consider the interaction of crop management, ecological factors, and the environment to effect crop protection. The course emphasizes cost-efficient management strategies that rely on natural biological and environmental occurrences. The 1987 session was attended by 19 trainees from 11 countries.

International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER). This 16-wk course encompasses the concepts in related sciences that explain crop responses to soil fertility and fertilizer. It also emphasizes integrated nutrient management through the proper combination of organic and inorganic fertilizers, and takes cropping systems into account. The 1987 session was attended by 16 trainees from 9 countries.

Irrigation Water Management (IWM). This 6-wk course enhances the engineering, agronomic, economic, socio-institutional, and communication knowledge and skills associated with sound irrigation water management principles and practices, proper identification of field-level water problems, and development of approaches to solve them. The 1987 session was attended by 27 trainees from 10 countries.

Statistical Procedures and Computer Applications in Agricultural Research (SPCAAR). This 10-wk course familiarizes participants with the use of the microcomputer and appropriate software for conducting statistical analyses and managing agricultural research data. The experimental version of IRRISTAT, a microbased statistical

package being developed at IRRI for use by agricultural researchers, was introduced to, and tested by, the trainees. The course also updates the trainees on new statistical procedures and techniques, with emphasis on their application to agricultural research. The 1987 session was attended by 11 trainees from 9 countries. The course will not be offered in 1988 and will undergo a review of content and format reflecting the current needs of national programs.

Training and Technology Transfer Course (T3C). This 12-wk course is designed for professionals involved in training or technology transfer programs and addresses the latest concepts and skills utilized in developing human resources and disseminating technology. It emphasizes components of needs assessment and curriculum development, training media, methodologies, and the evaluation of training programs. It is experiential, with more than 50% of the time being spent on a practicum. It implements a team concept in training and culminates in a training program that is designed by a team. The two 1987 sessions were attended by 23 trainees from 5 countries.

Upland Rice Training Course (URTC). This 16-wk course covers the principles of upland rice production. It emphasizes varietal improvement for resistance to or tolerance for rice blast disease, drought, and problem soils; crop management; and knowledge of specific soil and water management problems. The 1987 session was attended by 15 trainees from 11 countries.

Special short-term courses. *Cropping Systems On-the-Job Training (CS/OJT).* Two courses associated with the cropping systems program were offered. The 4-wk Varietal Testing for Intensive Rice Farming Systems (VT) provided the 9 participants from 5 countries with actual experience in the different field techniques of testing upland crop cultivars for rice-based farming systems. The 18-wk Legume Varietal Improvement for Rice-Based Cropping Systems (LVI), conducted in cooperation with the Institute of Plant Breeding at UPLB, focused on techniques in varietal improvement for upland crops. The course was attended by 5 trainees from 5 countries, and culminated in a 1-wk observational tour in Indonesia.

Field Methods for Pest Management Research for Deepwater Rice (PDWR). This 3-wk course was jointly organized by IRRI and the Governments of India and West Bengal. The first week was held at the Ramakrishna Mission Institute, Calcutta, India; the second and third were at the Bangladesh Rice Research Institute (BRRI), Joydebpur. The course, the second since 1984, was attended by 17 entomologists, plant breeders, plant pathologists, and agronomists from 6 countries. It focused on methods of pest management in deeply flooded ricefields.

Genetic Evaluation and Utilization for Deepwater Rice (GDWR). This session of the Genetic Evaluation and Utilization course focused on deepwater rice for the first time. The 15-wk course was attended by 13 trainees from 7 countries. Its theoretical component was taught at IRRI, and the last 3 wk were spent on field visits and a workshop in Thailand.

Hybrid Rice Seed Production (HRSP). Studies at IRRI and in other countries show the potential of hybrid rice in further increasing rice yields in the tropics. Adoption of hybrid rice technology depends largely on an efficient seed production, certification, and distribution program; hence, a 3-wk course to transfer this technology was conducted at IRRI. The course, attended by 16 trainees from 8 countries, was funded by the Italian Government through its Seed Technology and Tissue Culture Research for Economic Production of Hybrid Rice Project.

International Azolla Training Course (AZOLLA). This 2-wk course was conducted in Fuzhou, China, in collaboration with the Fujian Academy of Agricultural Sciences. The course was attended by 24 trainees from 9 countries and had topics on new approaches in azolla research and utilization.

Multipurpose Dryer Design, Construction, and Maintenance (DDCM). This 2-wk course, attended by 17 engineers and economists from 5 countries, was conducted in conjunction with a grant from IDRC to disseminate and assess the impact of the multipurpose drying technology.

Prosperity Through Rice — Phase 2 (PTR2). This 3-wk course was conducted for 24 trainees from 6 countries as a component of the Asian Development Bank-funded project on Research,

Demonstration, and Training on Rice Production Postharvest Technology and Biomass Utilization, Phase 2. The course consisted of 3 parts: a 1-wk orientation program at IRRI on project concept, design, and implementation of village-level projects and on postharvest and biomass technologies currently demonstrated in Los Baños; a 1-wk study tour in South Korea to observe its rural and agricultural development, including the Saemul Undong Movement; and a 1-wk project design workshop at IRRI.

Rice Production Course for Kampucheans (RP/KM). This special 19-wk rice course was organized to assist Kampuchea in its agricultural development program. Thirteen Kampuchean agricultural personnel attended the course. An English-for-special-purposes (ESP) component was incorporated in the course because the trainees had little facility with the English language. The course taught cultural practices in rice production side-by-side with basic English for rice production.

SPECIAL TRAINING PROGRAMS

On a need basis, national organizations, especially those collaborating with the Institute on research programs, request IRRI to allow their research personnel who are assigned to new jobs to undergo training in special research methodologies and technical skills in areas such as techniques of plant-soil analyses using sophisticated instrument, computer management, statistical analysis, library and documentation processing, and farm management. As much as space and resources permit, IRRI accepts these requests for special training, which range in duration from 1 to 3 mo.

On-the-job training. An individual or a small group of participants are accepted to apprentice in IRRI fields and laboratories to learn special skills under IRRI scientists' supervision. They conduct experiments and go through the various processes of analyzing research data they collect and verifying a scientific report on the research methodology they employed and the results they obtained. During the year, IRRI accepted 56 participants from 19 countries for special on-the-job training in its various departments. These participants returned to their organizations better able to perform the duties required of their new positions.

Course transfer to national programs. IRRI assists national client systems in their human resource development efforts. One approach is developing their in-country training capabilities at strategic in-country locations. This approach involved an eight-step shuttle training model to transfer courses. The preliminary step was making contact with training institutes that had the physical resources to transfer and implement training programs. Personnel dedicated to training from these institutes were trained in the regular Training and Technology Transfer course to carry on the training transfer process in their respective countries. The teams came from the China National Rice Research Institute, BRRI, Departments of Agriculture of Sri Lanka and Thailand, and Directorate of Food Crops Production of Indonesia.

Another approach is providing subject matter specialists to conduct training courses in-country, in response to requests from national client systems. During 1987, IRRI sent a research assistant from the Department of Statistics to Nepal and Madagascar to conduct the following courses:

- Use of Microcomputers in Agricultural Research: IRRI-Agricultural Research and Production Project of the Department of Agriculture of Nepal joint training program. This 2-wk course was held in Kathmandu 22 Jun-3 Jul and was attended by 24 research personnel from various agencies of the Department of Agriculture.
- Statistical Procedures in Agricultural Research and Computer Applications: IRRI-National Center of Applied Research in Rural Development (FOFIFA) of Madagascar joint training program. This 3-wk course was held in Antananarivo 21 Sep-9 Oct and was attended by 12 research personnel of FOFIFA.

INSTRUCTIONAL RESEARCH

To obtain feedback on training activities, to validate training practices, and to subsequently deliver a more effective, efficient, and economical training program, instructional research was initiated in 1987. During the year, 16 research projects in testing and evaluation, methodology, language and communication, impact of training, cross-

cultural psychology, and training management were conceived and implemented.

A study on test type preference and test performance of trainees in laboratory practicals was completed. Of the 83 trainee-respondents, 58% preferred the multiple choice type of test over completion or supply type questions. Age, civil status, and English language proficiency were found to be associated with test preference. Trainees who were older, married, and less proficient in English preferred multiple choice. Trainees who preferred completion questions or had no definite preference scored significantly higher in the completion type than in multiple choice tests. The performance of trainees who indicated preference for multiple choice questions did not differ significantly in both test types. Based on these results, the use of either pure multiple choice items or a combination of multiple choice and completion test types, with fewer completion items, is recommended for practical tests.

INSTRUCTIONAL RESOURCES

The generation of courseware that documents content information in the form of self-learning materials was intensified. The following courseware is either available or in various stages of production:

- Manuals of performance objectives for seven regular courses (CSTP, GEU, FSSR, IPM, INSFFER, T3C, and URTC)
- A series of illustrated booklets portraying field and laboratory skills—33 Rice Production (RPC) booklets in English and French; 16 CSTP; 6 GEU
- Slide-tape programs—65 RPC; 10 CSTP; 30 FSSR
- Computer-based instruction—6 RPC

A 2-yr IDRC-sponsored project and a donation by the Hewlett Packard Corporation provided resources to develop knowledge databases specifically for training and for using the computer as a storage and retrieval device.

A computer-based information management system for administering training programs is in the final phase of testing. It will assist in personnel administration, project information management, financial management, and correspondence inherent in administering training programs.

ACADEMIC COUNCIL

At the last Academic Council meeting held on 10 Mar 1987, the proposal to offer a course on research management for our current visiting scientists and postdoctoral scientists was strongly endorsed. The course will complement the research training of the scientists.

It was also agreed that IRRI would award plaques of merit and completion to visiting scientists and degree scholars who complete their academic requirements within the period of their MS and Ph D scholarships.

VISITING SCIENTISTS, POSTDOCTORAL SCIENTISTS, AND COLLABORATIVE RESEARCH FELLOWS AND SCIENTISTS

Those who completed their programs during 1987 are listed below.

Agronomy

A. N. Rao. Postdoctoral scientist. India. Farmers' weed control practices in Guimba, Nueva Ecija.

Banda Mambani. Postdoctoral scientist. Zaire. Physical edaphology of tropical lowland rice soils in rice-based systems.

Multiple Cropping

P. K. Aggarwal. Postdoctoral scientist. India. 1) Wheat production in Southeast Asia—potential and constraints. 2) Intercropping of legumes to contribute nitrogen in low input upland rice-based cropping systems.

Y. Shimizu. Collaborative research fellow. Japan. Maize establishment and management after lowland rice in partial irrigated environment at Guimba, Nueva Ecija.

Plant Pathology

Lina Ilag. Visiting scientist. Philippines. Mycorrhizae on rice-based cropping systems and their effect on disease.

Arcadio Quimio. Visiting scientist. Philippines. 1) Detection and identification of *Xanthomonas campestris* pv. *oryzae* by direct immunofluorescent procedure. 2) Serological relationships among Philippine strains of *Xanthomonas campestris* pv. *oryzae*.

Richard Plowright. Collaborative research scientist. United Kingdom. 1) An investigation of the influence of the root lesion nematode, *Pratylenchus zeae* on the growth and yield of rice. 2) Examination of the variation in host status of upland rice accessions to *Pratylenchus zeae*.

Soil Microbiology

R. Simanungkalit. Postdoctoral scientist. Indonesia. Growth and nutritional response to upland rice to visicular-arbuscular mycorrhizal inoculation.

M. G. Murthy. Postdoctoral scientist. India. Association of diazotrophs and growth-promoting rhizobacteria with rice.

Soils

D. K. Painuli. Postdoctoral fellow. India. Physical and micromorphological aspects of rice-soil puddling.

P. Olegario Muñíz Ugarte. Special research fellow. Cuba. Comparison of extractants to determine available zinc.

Statistics

Brigida Octavio. Postdoctoral scientist. Philippines. 1) Development and installation of a database management systems (DBMS) for GEU. 2) Development of training materials for the computer sessions in nondegree training programs.

RESEARCH FELLOWS

An asterisk (*) indicates completion of the MS degree and two asterisks (**) the Ph D degree during the year.

Agricultural Economics

Virginia Sandoval**. Philippines. Agricultural decision-making patterns and process in a rice-aquaculture based community.

Agronomy

Dong Hyun Shin**. Korea. Development of rice resistance to herbicide through tissue culture.

Sang Chul Lee**. Korea. Effect of planting method, fertilizer management, and plant growth regulator on lodging in lowland rice.

Valerio Tanguilig**. Philippines. Root growth, water potential, nutrient uptake, and grain yield of upland rice as affected by soil moisture deficit.

A. L. Shah*. Bangladesh. Sulfur and zinc interaction in lowland rice.

Cereal Chemistry

Sunil Kumer Biswas**. Bangladesh. Effect of starch properties on parboiling process and some physicochemical properties of parboiled rice.

International Rice Germplasm Center

Md. Kairul Bashar*. Bangladesh. Generic studies of rice root xylem vessels and related characters in relation to drought avoidance mechanism.

Multiple Cropping

Ruhul Amin*. Bangladesh. Studies on breaking seed dormancy in *Sesbania rostrata* (Brem. and Oberm.).

Plant Breeding

Ghulam Nabi Mir**. India. Inheritance of bacterial leaf blight resistance in rice cultivars.

Morton Poonyarit**. Thailand. Genetics of basic vegetative phase, photoperiod sensitivity, and critical daylength in rice *Oryza sativa* L.

Plant Physiology

Dilip Kundu**. India. Chemical kinetics of aerobic soils and rice growth.

P. K. Patra**. India. Influence of water regime on chemical kinetics of soils and rice growth.

M. A. M. Miah**. Bangladesh. Phosphorus nutrition of rice in saline soil.

Md. Kairul Bashar*. Bangladesh. Genetic studies of rice root xylem vessels and related characters in relation to drought avoidance mechanism.

Rice Farming Systems Program

Nizam Uddin Ahmed**. Bangladesh. Short-duration postrainy season pigeonpea (*Cajanus cajan* (L.) Millsp) as a dual purpose crop in farmers' lowland rice-based cropping systems.

Soil Microbiology

Lin Chang**. China. Study on the association between *Anabaena azollae* Strasburger and *Azolla microphylla* Kaulfuss during germination of megasporocarps.

Consolacion Castaneto**. Philippines. Some physiological changes in senescing Azolla *Anabaena azollae* complex as induced by crowding.

C. Y. Chiu**. China. Nitrogen transformation in soil-plant system by using ^{15}N technique.

Shahajahan Miyan*. Bangladesh. Rhizobium inoculation of *Sesbania rostrata* and the influence of its incorporation on plant-associated N_2-fixation and yield of wetland rice.

Training and Technology Transfer

Meer Md. Muniruzzaman*. Bangladesh. The effect of synthetic nitrogen fertilizer and green manure combinations on the yield of transplanted rice in farmer's field.

Water Management

Christopher Wensley**. USA. Rehabilitation of irrigation systems: a comparative analysis of the Philippines.

Md. Abdul Ghani**. Bangladesh. Improving water management in the G. K. irrigation system in Bangladesh.

RESEARCH SCHOLARS

The following completed the MS degree during 1987.

Agricultural Economics

Samuel Brempong*. Ghana. Comparative advantage and rice policy, Ghana.

Usman Mustafa*. Pakistan. A general equilibrium model of the effects of wheat/rice mechanization in Pakistan.

Entomology

Francis Onyango*. Kenya. Behavioral and physiological responses of green leafhopper *Nephotettix virescens* (Distant) to selected resistant rice varieties.

Plant Breeding

Wu Kunsheng*. China. Chromosomal location of isozyme loci with primary trisomics in rice.

Cyril Sebastian Roberts*. Guyana. Genetic analysis of response to butachlor in rice (*Oryza sativa* L.).

Tissue Culture Facility

Celsa Quimio*. Philippines. Diallel analysis of callus formation and green plant regeneration in anther culture of rice.

Soil Microbiology

Stella Asuming Brempong.* Ghana. Response of Anabaena: free and symbiotic azolla to temperature and phosphorus.

Soils

Do Thi Than Ren*. Vietnam. Chemical characteristics and nutrient kinetics of acid sulfate soils from the Mekong Delta in Vietnam.

Victor Asio*. Philippines. Biocalcification and siltation in paddy soils.

NONDEGREE SCHOLARS AND FELLOWS

Communication and Publications

U Kartasasmita. Indonesia. Training in graphics and audiovisual production.

Mohamad A. Sanoh. Sierra Leone. Training in graphics and audiovisual production.

International Rice Germplasm Center

Chen Shuping. China. Orientation and briefing of IRGC operations.

Nguyen Xuan Hien. China. Rice germplasm management.

K. Kanyavong. Laos. Rice germplasm management.

Plant Breeding

Lu Zitong. China. Shuttle breeding project.

Le Cam Loan. Vietnam. Analysis of rice grain quality.

Lai Van Nhu. Vietnam. Rice breeding.

Doan Van Tranh. Vietnam. Rice breeding.

Pham Dinh Phuc. Vietnam. Rice breeding.

Pham Cong Voc. Vietnam. Rice breeding.

S. Nugprachaya. Thailand. Hybrid rice.

K. K. Doungsila. Laos. Analysis of grain quality.
Phoumi Ithapanya. Laos. Rice breeding.
Huang Chi Lin. China. Analysis of rice grain quality.
He Rong. China. Analysis of rice grain quality.
Chen Yi. China. Analysis of rice grain quality.
Lui X. Ping. China. Analysis of rice grain quality.

Plant Physiology
Pham Van Cuong. Korea. Effect of ripening condition on yield.

Soil Microbiology
Nguyen Than Hien. Vietnam. Nitrogen fixation in the rhizosphere of rice.
M. Asfia. Iran. Training on azolla use.
H. P. Singh. India. Training on azolla use.

Statistics
B. Kanyavong. Laos. Application of statistical procedures in agricultural research.
Noukone. Laos. Application of statistical procedures in agricultural research.

PARTICIPANTS IN REGULAR COURSES

Agricultural Engineering Course I (AEC I)
25 May-12 Jun 1987

China
Dong Cuifang

India
Suvrat Kumar Singh
E. V. Thomas

Mali
Mody Sow

Nigeria
Ibiam Ogaluonye Oguejiofo

Philippines
Guillermo B. Baylas
Rosario Pacheco
Lacmodin Ubpon
Ernesto M. Velasco

Sri Lanka
Bandara Dhanapala Arampola
Muthukuda H. M. Abeysinghe Bandara
Peter Lengowski

Tanzania
Bunyinyiga Bituro Jackson

Thailand
Ravee Araveeporn

Agricultural Engineering Course II (AEC II)
16 Nov-4 Dec 1987

Bangladesh
Md. Aggar Hossain Khan

Egypt
Md. Moustafa El-Kholy

India
Inumella S. R. P. Sarma
Akhilendra Prakash Srivastava

Madagascar
Justin Henri Rakotonaivo
Romule Joseph Randrianaivo

Malaysia
Abu Hassan Bin Daud

Nigeria
Bashiru Akande Lawal

Sri Lanka
Abeysinghe M. P. Bandara
Cyril Jayasinghe Danthanarayanage
Volker Hell

Thailand
Hotrachitra Somsak

Vietnam
Dao Tue Vu

Cropping Systems Training Program (CSTP)
2 Feb-26 Jun 1987

Bangladesh
Md. Shafiul Alam
A. F. S. Shoriful Haque

China
Wang Liude
Ying Jifeng

India
Setty Ranganath Adeppa
Tiyunelveli N. S. Balasubramanian
Harihar Prasad Singh

Pakistan
Mohammed Riaz Malik

Philippines
Maybel B. Cruz
Nicanora B. Eroisa
Jose I. Ong, Jr.
Emilio C. Palencia

Sri Lanka
Langappulige Cecil Dharmasri
Yasoda Dayani Jayasuriya
Lakshman Lalith Ranasinghe

Tanzania
Laisi Elias Abel Letayo

Thailand
Wilai Klaklangsamorn
Sarayouth Phumiphon
Worapan Poopar
Boonguer Poosri

Vietnam
Quach Ngoc An

Editing and Publication I (EDPUB I)
2 Feb-8 May 1987

Bangladesh
Devi Prasad Mazumder
A. A. M. S. Arefin Siddique

Botswana
Mogotsi Joe Matebesi

China
Miao Zhuoran

India
Tapan Kumar Ghosh
Yateendra Joshi

Nigeria
Pius Nwacholife Ndedigwe

Philippines
Rebecca O. de Guzman

Tanzania
Issa Lembuya

Thailand
Rungtavan Pushpavesa

Editing and Publication II (EDPUB II)
20 Jul-23 Oct 1987

Brazil
Deizia Santos Barroso

China
Wang Zhenjiang

Ecuador
Maria Cuvi Sanchez

Kenya
Kipkoskei Sirma Arap Buigutt

Malawi
Richard John Mbando

Malaysia
Rosiah Binti Hamzah

Nigeria
Briggs Chinkata Nzotta

Philippines
Marites G. Yee

Sri Lanka
Seneviratne B. K. Bandara

Farming Systems Socioeconomic Research (FSSR)
5 Oct-4 Dec 1987

Bhutan
Shankar Chhetri

Brazil
Naldo Luiz Dalmazo

China
Fang Xianfa
Guo Jianjun
Huang Yaohui
Wang Guofa

Colombia
Leonardo Rey

Indonesia
A. Najamuddin
Al Sri Bagyo

Madagascar
Desire Andrianorosoa
Felice Rasambomanana

Malaysia
B. Abu Bakar Noor Rawi

Nepal
Dilaram Bhandari
Ajay Raj Sharma

Philippines
Gil Gabriel Bordado III
Jessie A. Lumbao
Consuelo Naeg

Sri Lanka
Ratnayake M. Abeyratne Bandara
Albert Naurunnage

Thailand
Phawinee Chotikunta
Penporn Janekarkij
Supon Thanooruk

Vietnam
Le Thac Trinh

Genetic Evaluation and Utilization (GEU)
2 Feb-22 May 1987

Brazil
Veridiano dos Anjos Cutrim

China
Chen Yixin
Song Xiaolu
Wu Guanting

India
Tajinder Singh Bharaj
Chintala Sadasiva Reddy
Ajmer Singh
Karayil Chathai Velayudhan

Madagascar
Xavier Roland Rakotonjanahary

Mexico
Jorge Salcedo Aceves

Nepal
Shambhu Prasad Khatiwada

Philippines
Primitivo G. Llano

Tanzania
Moses N. W. Mnzava

Thailand
Nantha Ananchaipatana

Vietnam
Thai Thi Hoe
Nguyen Quang Xu

Integrated Pest Management (IPM)
20 Jul-18 Nov 1987

Cameroon
Birang A. Madong

China
Mao Lixing
Jiang Jianyun
Tang Ying
Zhang Xiaoming

India
Gurusamy Alagarsamy
Mithilesh Narayan Lal
Ajit Kumar Pal

Indonesia
Gusti Putu Alit Diratmaja

Nepal
Shree Baba Pradhan

Nigeria
Ephraim Olufunso Bright

Philippines
Benigno G. Cruz

Sri Lanka
Salpadoruge Kingsley Lakshman Fernando
Loku Banda Mahagedera

Sudan
Idris Ali Mohamed Ahamed

Thailand
Sitthichai Limrateepong
Somchai Tangppoonpol

Vietnam
Vu Thi Hoi
Pham Lan La

International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER)
2 Feb-22 May 1987

China
Duan Binwu
Huang Weixiang
Lin Xinjiang

India
Ramachandra Boopathi
Rabindra Nath Samantaray

Madagascar
Justin Ratsimandresy

Nepal
Sanjay Kumar Gami

Nigeria
Emmanuel Ojo Oluwole Ajayi

Philippines
Leonardo M. de Leon
Floricadel B. Lopez

Sri Lanka
Jayalatharachchige D. Wijewardena

Thailand
Chaisak Paewpolsong
Im-erb Rungsun
Thongchai Sungnoy

Vietnam
Le Van Chat
Bui Quang Xuan

Irrigation Water Management (IWM)
24 Aug-2 Oct 1987

Bangladesh
Abu Saleque
Md. Ashraf Ali Choudhury

Bhutan
Kinzang

India
Ramesh Chandra Sirvastava
Sura Venkat Subbaiah
A. K. Choudhury

Indonesia
Abdul Haris Asdiyanto
Didiek Setio Budi
Abi Prabowo
Yanto Sugianto

Mexico
Ignacio Mendez Arevalo

Nepal
Sudarshan Dev Pan
Uttam Raj Timilsina

Philippines
Domingo F. Alcaraz
Edgardo P. Cruz
Edilberto Lomigo
Glicerio C. Nelmida
Theody B. Sayco

Sri Lanka
Tuan Amamath Booso
Wipula K. B. Elkaduwa
Appuhamyge Jayatilake

Thailand
Yongyuth Deewong
Pongput Kobkiat
Prasit Pichairurke
Lertchai Sri-Anunt

Vietnam
Nham Le Thi
To Phuc Tuong

Statistical Procedures and Computer Applications in Agricultural Research (SPCAAR)
30 Mar-5 Jun 1987

Bangladesh
Debi Narayan Rudra Paul
Badrul Alam Dewan

China
Xu Zhaoyao

India
Amit Kumar Vasisht

Laos
Nuokone
Kanyavong Bounphavanh

Malaysia
Yunus Jaafar

Pakistan
Mohammad Ashfaq

Philippines
Jesus Abella

Thailand
Nongyow Unyawong

Vietnam
Pham Trung Kien

Training and Technology Transfer Course I (T3C I)
2 Feb-24 Apr 1987

China
Fei Luting
Ge Jinping
Li Jian
Liao Xiyuan
Lu Yongliang
Zeng Heping

Thailand
Sumalee Arayangkura
Kanokrat Sittipoch
Veerasak Sri-Aun
Sunittha Sutthikitpong

Training and Technology Transfer Course II (T3C II)
20 Jul-9 Oct 1987

Bangladesh
Hafiz Uddin Ahmed
Khairul Alam Billah
Md. Abdul Jabbar

Indonesia
Joni Husein
Arifin Mustamin
Donna Purba
Sarono

Sri Lanka
Hillary Ajith Athapathu
Don Indrasiri Kommala
Abeyratne Basnayake Mudiyanselage
Dharmasena Galaboda Rallage
Tyuraippa Kandasamy Subramanian
Sarath Weeratunga

Upland Rice Training Course (URTC)
20 Jul-6 Nov 1987

Bangladesh
Ranjit Kumer Das

Brazil
Abilio Rodrigues Pacheco

Burma
Yan Thein

Costa Rica
Jorge Ahmed Loaiciga Guillen

Guinea
Souare Daouda

India
Ranjan Ghosh
Pichiah Gomathinayagam
B. H. Manjappa
Alla Peraiah

Indonesia
Irwan Nasution

Ivory Coast
Ncho Achiaye Ludovic

Liberia
Peter S. Clement
William K. Massaquoi

Mexico
Jose Luis Garcia Angulo

Nigeria
Olubunmi Ogundiya

PARTICIPANTS IN SPECIAL SHORT-TERM COURSES

Varietal Testing for Intensive Rice Farming Systems (VT)
1-26 Jun 1987

Bangladesh
Md. Solaiman Khan

China
Li Yimin
Wang Bujun

Indonesia
Abdul Gani
Sriwidodo

Philippines
Mario A. Cresencio
Jose Torres

Thailand
Boonoom Klawyotha
Pote Pimpanit

Legume Varietal Improvement for Rice-Based Cropping Systems (LVI)
26 Oct 1987-26 Feb 1988

Bangladesh
Md. Matiur Rahman

Indonesia
Suprapto

Nepal
Bai Dya Na Th Jha

Sri Lanka
Sinhe Wiriduge Kalyanee Weerasinghe

Thailand
Somchai Boonpradub

Field Methods for Pest Management Research for Deepwater Rice (PDWR)
31 Aug-19 Sep 1987

Bangladesh
Md. Mostak Ahmed Chowdhury
Md. Anowar-ul Hoque Mondal

India
Shiv Kumar Singh Chauhan
Chandra Sekhar Das
C. Kundu
B. N. Medhi
Ananta Prasad Samalo
Ramashrit Singh
Udai Pratap Singh
Basanta Ram Yein

Indonesia
Mukhlis Hamda
Erna Heryati

Philippines
Hilario D. Justo, Jr.

Thailand
Patchanee Chaiyawat
Sansook Ratanapol

Vietnam
Pham Van Giang
Nguyen Van Sanh

GEU Deepwater Rice (GDWR)
20 Jul-30 Oct 1987

Bangladesh
Md. Shamsher Ali

Burma
Chit Ohn

China
Liu Yong Sheng

India
Md. Tomizuddin Ahmed
Jawahar Lal Dwivedi
D. Mahapatra
Shiva Shanker Prasad
Vinoy Nandan Sahai

Indonesia
Tintin Suhartini

Thailand
Kachon Petchrit
Charuwan Bangwaek
Surapong Sripongpankul

Vietnam
Nguyen Ngoc De

Hybrid Rice Seed Production (HRSP)
1-22 Sep 1987

Brazil
Sidnei Bicca Da Rocha

India
Ayachitula S. R. Sarma
Rajendra Kumar Trivedi
C. S. Mani
R. N. Rao

Indonesia
Karyana
Satoto
Syarifuddin Tarigan

Korea
Hwang Hung-Goo
Shin Young-Seop

Malaysia
Ku Yahaya Hashim

Philippines
Celestina Agbigay
Hilario de la Cruz

Thailand
Sopit Suyasri
Thawatchai Teekachunhatean

Vietnam
Nguyen Huu Nghia

International Azolla Training Course (AZOLLA)
6-19 Jun 1987

Brazil
Maria Salete Alves Rangel

China
Chen Jian
Ding Wu
Li Ping
Ping Shuzhen
Shong Jingxian
Shong Tiejing
Xu Jing
Zheng Zhcan
Zhou Bengqing

India
Somasundaram Muthukkaruppan
Davendra Prataf Singh
G. S. Thangamuthu

Madagascar
Raymond Rabeson
Jacqueline Rabelolala Rakotoarisoa

Malaysia
Aini Zakaria

Pakistan
Sikander Ali

Philippines
Stella P. Cabas
Damaso P. Callo, Jr.
Cecilia Estrada
Emilia Manalastas

Sri Lanka
Amal Padmaja De Silva

Thailand
Somporn Choonluchanon
Hansa Khunathai

Multipurpose Dryer Design, Construction, and Maintenance (DDCM)
2-13 Nov 1987

China
Su Yingchen
Yuan Xiaode
Zheng Mingguan

Indonesia
Diden Trisnadi
Wahyu Subandrio
Ervan Adi Nugroho
Siswanto Budi Prasodjo

Philippines
Vicente del Pilar
Cesario Egos
Roberto Guarte
Jose Lorenzana
Manolo Loreto
Pedro S. Mojica
Nicasio M. Quindoza

Sri Lanka
J. T. B. Ratnayake

Thailand
Pimol Wutisin
Satis Thavornun

Prosperity Through Rice—Phase 2 (PTR2)
1-20 Jun 1987

Bangladesh
A. K. M. Anwarul Haque
M. Abul Quasem
S. M. Rezaul Karim
Bazlul Amin A. Mustafi
M. Abdur Razzaque

Indonesia
M. Ismunadji
Boy Sarwono
Ade Suprijatna
Ridwan Taher
Alamanda Kartika S.

Korea
Lee Eung Doo
Young Bae Kim

Philippines
Gonzalo C. Girasol

Sri Lanka
Tennakoon Mudiyanselage Abeyaratna Tennakoon
Gurunanaselage Anthony Caniute De Silva
Samarasinghe Herath Mudiyanselage Gamini Samarasinghe
Amangilihewa Tissa Sunil De Silva Abeysooriya
Senarath Nihal Jayawardena

Thailand
Vicharn Votong
Vichien Sasiprapa
Viboon Thepent
Kowit Nualvatna
Boontam Prommani
Chanuan Ratanawaraha

Rice Production Course for Kampucheans (RP/KM)
3 Aug-11 Dec 1987

Thien Chenn
Hem Chhon
Hak Khorn
Mom Kim Khorn
Chin Koeun
Sok Leang
Pich Nan
Sok Pauch
Hong On
San Smann
Kuy Sokun
Prom Kim Teng
Uch Yorn

International collaboration

International Rice Testing Program

International Rice Testing Program and Soils Department

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The International Rice Testing Program (IRTP), a cooperative network funded by the United Nations Development Programme for the worldwide exchange and evaluation of elite rice germplasm, completed its 12th year in 1987. The following sections summarize 1) the results of the 1986 nurseries, for which data were received and analyzed in 1987 (detailed results are published separately in IRTP annual nursery reports), and 2) the activities in 1987.

1986 NURSERY RESULTS

IRTP composed 1,464 sets of 29 types of nurseries—17 for cultural type and 12 for stress tolerance—and distributed them to 51 countries cooperating in the IRTP network. A new nursery, the International Rice Grain Quality Screening Set, was started during the year to identify and disseminate varieties and breeding lines with desirable grain quality.

Yield nurseries. Top ranking entries for the three maturity groups of irrigated rices—the International Rice Yield Nursery-Very Early (IRYN-VE), -Early (IRYN-E), and -Medium (IRYN-M)—are listed in Tables 1, 2, and 3. Some rices performed well in several regions. The yield and yield components by site and region are given in the detailed IRTP annual nursery reports, published separately. Tables 4 and 5 show yields of the best performing entries in the two rainfed shallow water yield nurseries: early (IRRSWYN-E) and medium (IRRSWYN-M). The highest yielding entries in the nurseries for the two maturity groups of upland rices—early (IURYN-E) and medium (IURYN-M)—are given in Tables 6 and 7.

During 1986, an F_1 rice hybrid, Wei You 64, developed collaboratively by hybrid rice researchers in China and IRRI (Annual report for 1984)

Table 1. Best performing entries in the International Rice Yield Nursery-Very Early (IRYN-VE) based on overall and regional mean yields, 1986.

Region and no. of trials	Designation	Origin	Days to flowering	Yield (t/ha)
Overall, 29	IR50	IRRI	92	5.2
	IR39357-133-3-2-2-2	IRRI	91	5.1
	IR31785-58-1-2-3-3	IRRI	86	4.9
	C1158-7	Philippines	102	4.8
	IR13539-100-2-2-2-3	IRRI	101	4.8
East Asia, 6	Wei You 64	China	90	7.3
	IR39357-133-3-2-2-2	IRRI	90	6.0
	IR50	IRRI	92	5.8
	IR31785-58-1-2-3-3	IRRI	86	5.6
	IR32429-47-3-2-2	IRRI	91	5.6
Southeast Asia, 6	IR50	IRRI	77	4.4
	IR22107-14-2-1	IRRI	79	4.1
	IR32429-47-3-2-2	IRRI	77	4.1
	IR13539-100-2-2-2-3	IRRI	84	4.0
	IR39357-133-3-2-2-2	IRRI	77	4.0
	IR39422-19-3-3-3-3	IRRI	76	4.0
South Asia, 13	IR39357-133-3-2-2-2	IRRI	97	5.1
	IR50	IRRI	99	5.1
	C1158-7	Philippines	107	4.8
	IR13539-100-2-2-2-3	IRRI	106	4.8
	IR31785-58-1-2-3-3	IRRI	91	4.8
	Wei You 64	China	92	4.8
West Asia and North Africa, 2	C1158-7	Philippines	123	10.5
	IR13539-100-2-2-2-3	IRRI	121	9.6
	Wei You 64	China	97	9.3
	IR31785-58-1-2-3-3	IRRI	92	8.1
	IR39357-91-3-2-3	IRRI	92	7.9

Table 2. Best performing entries in the 14th International Rice Yield Nursery-Early (IRYN-E) based on overall and regional mean yields, 1986.

Region and no. of trials	Designation	Origin	Days to flowering	Yield (t/ha)
Overall, 35	Chianung sen yu 26	Taiwan, China	106	5.0
	C662083	Taiwan, China	97	4.9
	IR13240-108-2-2-3	IRRI	99	4.8
	IR31805-20-1-3-3	IRRI	104	4.8
	IR32843-92-2-2-3	IRRI	100	4.8
East Asia, 4	Lu Chao 1	China	102	7.3
	Chianung sen yu 26	Taiwan, China	109	6.2
	C662083	Taiwan, China	99	6.1
	Iri 346	Korea	101	6.1
	UPLRi-4 (C1000-4)	Philippines	105	6.0
Southeast Asia, 12	IR32843-92-2-2-3	IRRI	88	4.4
	IR34615-4-2-3	IRRI	87	4.4
	IR31805-20-1-3-3	IRRI	90	4.3
	IR13240-108-2-2-3	IRRI	83	4.2
	IR31868-64-2-3-3-3	IRRI	86	4.2
	MTU5410-14	India	91	4.2
	SPRLR76102-26-1-1	Thailand	93	4.2
South Asia, 16	Chianung sen yu 26	Taiwan, China	113	5.0
	C662083	Taiwan, China	106	5.0
	Lu Chao 1	China	106	5.0
	MTU5410-14	India	109	4.9
	SPRLR76102-26-1-1	Thailand	116	4.9
West Asia and North Africa, 1	Chianung sen yu 26	Taiwan, China	113	10.3
	IR24632-60-3-3-2	IRRI	103	10.3
	IR13524-21-2-3-3-2-2	IRRI	103	10.2
	IR31802-48-2-2-2	IRRI	98	10.1
	S287B-39-1-3	Indonesia	103	10.1
	UPLRi-4 (C1000-4)	Philippines	110	10.1
Sub-Saharan Africa, 2	MTU5410-14	India	106	6.1
	Lu Chao 1	China	101	5.9
	UPLRi-4 (C1000-4)	Philippines	103	5.9
	Chianung sen yu 26	Taiwan, China	113	5.5
	IR32843-92-2-2-3	IRRI	104	5.4

Note: The single site representing the West Asia and North Africa region, where the highest yields exceeded 10 t/ha, was Sakha, Egypt.

was tested at 22 sites around the world in the IRYN-VE. The hybrid gave a mean yield of 5.3 t/ha, whereas IR50 and IR39357-133-3-2-2-2 had average yields of 5.1 t/ha. Both the hybrid and IR50—in 13 trials each—and IR39357-133-3-2-2—in 12 trials—produced the highest yields or were statistically on par with the highest yields. The hybrid was superior to the local check in 10 trials, whereas IR50 was superior in 5 trials. At 8 locations, Wei You 64 produced 0.2-1.8 t/ha (mean 0.7 t/ha) higher mean yields than the highest yielding inbreds IR50, IR39357-133-3-2-2, IR39357-91-3-2-3, Lu Hong Zhao, and a local check (Table 8). At the 14 other sites in the Philippines, Thailand, Bangladesh, India, Pakistan, and Egypt, it did not yield higher than the inbred cultivars. This further confirms our view that rice hybrids developed in China have very limited adaptability outside China and therefore we need to develop region-specific hybrids using locally adapted parental lines.

Observational nurseries. The best performing entries in the IRTP observational nurseries IRON, IRRSWON, IURON, IRDWON, IFRON, and ITPRON, based on their overall phenotypic acceptability ratings, are given in Table 9. A

Table 3. Best performing entries in the 14th International Rice Yield Nursery-Medium (IRYN-M) based on overall and regional mean yields, 1986.

Region and no. of trials	Designation	Origin[a]	Days to flowering	Yield (t/ha)
Overall, 13	IR29723-143-3-2-1	IRRI	110	5.3
	BR316-15-4-4-1	Bangladesh	97	5.2
	BG380-2	Sri Lanka	101	5.1
	BR4-34-13-5	Bangladesh	102	5.0
	DR29	Pakistan	97	5.0
East Asia, 2	DR29	Pakistan	114	7.8
	BG380-1	Sri Lanka	128	7.2
	BR316-15-4-4-1	Bangladesh	116	6.9
	BR4-34-13-5	Bangladesh	117	6.5
	IR18349-135-2-3-2-1	IRRI	126	6.5
Southeast Asia, 3	BG380-2	Sri Lanka	89	5.0
	IR42	IRRI	99	4.8
	IR28228-12-3-1-1-2	IRRI	95	4.6
	IR29723-143-3-2-1	IRRI	100	4.6
	Seberang	Malaysia	95	4.5
South Asia, 8	IR29723-143-3-2-1	IRRI	107	5.2
	BR316-15-4-4-1	Bangladesh	96	5.0
	BR4-34-13-5	Bangladesh	100	5.0
	C1333-4	Philippines	100	5.0
	DR29	Pakistan	97	5.0
	P1274-6-8M-1-3M-1	CIAT	97	5.0

[a]CIAT = Centro Internacional de Agricultura Tropical.

Table 4. Best performing entries in the International Rice Rainfed Shallow Water Yield Nursery-Early (IRRSWYN-E) based on overall and regional mean yields, 1986.

Region and no. of trials	Designation	Origin	Days to flowering	Yield (t/ha)
Overall, 10	IR21567-9-2-2-3-1-3	IRRI	99	4.4
	IR33383-23-3-3-3	IRRI	97	4.2
	IR21567-16-3	IRRI	97	4.0
	IR26933-16-2-3	IRRI	89	4.0
	IR21178-39-P1	IRRI	96	3.9
East Asia, 1	IR21015-80-3-3-1-2	IRRI	88	4.7
	IR21567-16-3	IRRI	103	4.4
	IR13427-40-2-3-3-3-3	IRRI	87	4.3
	IR21178-39-P1	IRRI	100	4.0
	IR26933-16-2-3	IRRI	98	3.9
Southeast Asia, 8	IR21567-9-2-2-3-1-3	IRRI	97	4.3
	IR33383-23-3-3-3	IRRI	95	4.0
	BRB11-448-1-4	Bangladesh	94	3.9
	IR21567-16-3	IRRI	95	3.7
	KKN7205-39-3-SKN-1-1-1	Thailand	92	3.7
	IR46	IRRI	96	3.7
West Asia and North Africa, 1	IR21178-39-P1	IRRI	99	6.9
	IR26933-16-2-3	IRRI	91	6.8
	IR33383-23-3-3-3	IRRI	103	6.4
	IR21567-9-2-2-3-1-3	IRRI	102	6.1
	IR21567-16-3	IRRI	103	5.7

Table 5. Best performing entries in the 6th International Rice Rainfed Shallow Water Yield Nursery-Medium (IRRSWYN-M) based on overall and regional mean yields, 1986.

Region and no. of trials	Designation	Origin	Days to flowering	Yield (t/ha)
Overall, 13	RP1057-184-5-3-2	India	129	3.9
	BR51-74-6/J1	Bangladesh	120	3.8
	IR13146-45-2-3	IRRI	116	3.3
	IR13610-72-2-2E-P1	IRRI	120	3.3
	IR13610-72-2-2E-P2	IRRI	121	3.3
	IR19083-22-2-2	IRRI	111	3.3
	Mahsuri	Malaysia	118	3.3
	Mat Candu	Malaysia	129	3.3
Southeast Asia, 8	RP1057-184-5-3-2	India	119	4.4
	BR51-74-6/J1	Bangladesh	110	3.9
	IR19083-22-2-2	IRRI	105	3.9
	Mat Candu	Malaysia	121	3.8
	IR13146-45-2-3	IRRI	106	3.6
	IR13610-72-2-2E-P2	IRRI	110	3.6
	Mahsuri	Malaysia	108	3.6
South Asia, 5	BR51-74-6/J1	Bangladesh	134	3.6
	IR13610-72-2-2E-P1	IRRI	137	3.1
	IR21037-2-1-2E-P1	IRRI	137	3.0
	RP1057-184-5-3-2	India	144	3.0
	IR13146-45-2-3	IRRI	132	2.9
	IR13610-72-2-2E-P2	IRRI	137	2.9
	Mahsuri	Malaysia	130	2.9

Table 6. Best performing entries in the 12th International Upland Rice Yield Nursery-Early (IURYN-E) based on overall mean yields, 1986.

Region and no. of trials	Designation	Origin	Days to flowering	Yield (t/ha)
Southeast Asia, 13	IR25588-7-3-1	IRRI	77	2.3
	IR10198-66-2	IRRI	77	2.2
	IRAT 110	Ivory Coast	72	2.2
	CR222-MW10	India	76	2.1
	IR9761-19-1	IRRI	80	1.9

Note: IURYN-E tests were conducted only in Southeast Asia.

number of entries were resistant to or tolerant of one or more important stresses at trial locations.

Nurseries for specific stresses. Tables 10 and 11 list the best performing entries in nurseries established for specific stresses. Insect nurseries were those for brown planthopper (IRBPHN), whitebacked planthopper (IRWBPHN), and stem borer (IRSBN). Disease nurseries were those for ufra nematode (IRUSS), bacterial blight (IRBBN), rice blast (IRBN), and rice tungro (IRTN). Nurseries for other stresses were those for salinity and alkalinity (IRSATON), acid upland and acid lowland soils, and cold tolerance (IRCTN).

1987 NURSERY DISTRIBUTION

A total of 1,550 sets of 29 types of IRTP nurseries (17 for cultural type, 11 for stress tolerance, and 1 for grain quality) were composed and distributed to 50 countries in the IRTP network (Table 12). In Asia, 1,098 sets went to national programs. Sub-Saharan Africa received 237 sets, of which 83 went

Table 7. Best performing entries in the 12th International Upland Rice Yield Nursery-Medium (IURYN-M) based on overall and regional mean yields, 1986.

Region and no. of trials	Designation	Origin	Days to flowering	Yield (t/ha)
Overall, 7	IR12979-24-1 (Brown)	IRRI	79	2.4
	BR319-1	Bangladesh	85	2.2
	IR13754-5-2	IRRI	93	2.2
	B2992b-Tb-73-4-2-3-3-3-2	Indonesia	82	2.1
	C894-7	Philippines	91	2.0
	IR43	IRRI	95	2.0
Southeast Asia, 5	IR12979-24-1 (Brown)	IRRI	74	2.8
	IR13754-5-2	IRRI	87	2.6
	BR319-1	Bangladesh	75	2.5
	B2992b-Tb-73-4-2-3-3-3-2	Indonesia	94	2.4
	IR43	IRRI	85	2.4
	IR5931-113-1	IRRI	77	2.4
South Asia, 1	BR319-1	Bangladesh	96	2.2
	IR12979-24-1 (Brown)	IRRI	87	2.1
	C894-7	Philippines	98	1.9
	B2992b-Tb-73-4-2-3-3-3-2	Indonesia	94	1.6
	ADT31	India	91	1.6
	NDR97	India	86	1.6
Latin America, 1	IR27078-11-2	IRRI	127	1.5
	C894-7	Philippines	120	1.0
	IR13754-5-2	IRRI	109	0.9
	IR7835-28-2-4	IRRI	119	0.8
	B2992b-Tb-73-4-2-3-3-3-2	Indonesia	111	0.7
	NDR97	India	79	0.7

Table 8. Yields of rice hybrid Wei You 64 and 3 best inbred rice cultivars at selected sites in the 7th International Rice Yield Nursery-Very Early (IRYN-VE), 1986.

Location	Yield (t/ha)			Name of second best cultivar
	Wei You 64 (1)	Second best entry (2)	Increase of (1) over (2)	
China				
Guangzhou, Guangdong	7.1	6.8	0.3	IR39357-133-3-2-2
Fuzhou, Fujian	7.9	6.9	1.0	IR39357-133-3-2-2
Luzhou, Sichuan	7.1	6.7	0.4	Lu Hong Zhao
Lian Tang, Nanchang	7.2	6.6	0.6	IR39357-133-3-2-2
Bangladesh				
Comilla	5.7	4.9	0.8	IR50
India				
Aduthurai, Tamil Nadu	6.7	6.2	0.5	IR39357-91-3-2-3
Pakistan				
Dokri, Sind	6.9	6.7	0.2	IR39357-133-3-2-2
Turkey				
Edirne	8.3	6.5	1.8	Local check
Mean	7.1	6.4	0.7	

to the West Africa Rice Development Association (WARDA) for distribution to member countries. Ninety-two nursery sets went to national programs in West Asia and North Africa. One hundred fifteen sets went to 13 countries in Latin America, 5 sets to 2 countries in Europe, and 3 sets to 2 countries in Oceania. Sources of entries in the 1987 IRTP nurseries distributed around the world appear in Table 13. A total of 1,291 nursery entries were distributed.

Table 9. Entries that received the best phenotypic acceptability ratings in the 1986 observational nurseries.

Nursery and no. of trials	Designation	Mean phenotypic acceptability score	Mean days to flowering
International Rice Observational Nursery (IRON), 27	C702015	4.1	101
	PDR76-D10-D8-D1	4.4	104
	IR39357-133-3-2-2-2	4.5	92
	IR39357-45-3-2-3	4.5	92
	IR24632-145-2-2-2-3	4.5	100
	Si-pi 692033	4.5	102
	IR31787-16-1-2-3-2	4.7	97
	IR28128-45-2	4.8	93
	IR29725-22-3-3-3	4.8	95
	IR31787-41-2-2-3-3	4.8	94
	Iri 352	4.8	96
	IR35295-82-2-1-3-2	4.8	102
	P2025F4-93-2-5-1B	4.8	114
	P2060F4-2-5-1B	4.8	109
International Upland Rice Observational Nursery (IURON), 17	KU82	4.1	90
	IR43	4.2	99
	ITA212	4.4	104
	UPLRi-7	4.5	84
	IR25898-57-2-3	4.6	79
	ITA233	4.6	101
	IR25890-82-5-3	4.7	77
	NDR80	4.7	86
	UPR231-28-1-2	4.7	87
	IR65	4.8	92
	Bala Late Mutant	4.9	88
	P1386-2-6M-5-1B	4.9	100
International Rice Rainfed Shallow Water Observational Nursery (IRRSWON), 19	BR11	3.1	113
	BRC16-127-4-1	3.2	114
	BRC16-127-4-2	3.6	114
	BR15-49-6/HR54	3.6	116
	RTN90-4	3.7	104
	BR51-49-6-HR63	3.7	117
	IR33360-60-1-2-2	3.8	107
	BR51-291-3-22	3.8	105
	MRC4917-3164	3.9	88
	BRB11-461-1	3.9	109
	BR113-47-1-2-1-2	3.9	115
	IR13149-43-2-P1	4.0	111
	IR31429-20-2-3	4.0	97
	BRB11-448-1-4	4.0	103
International Rice Deepwater Observational Nursery (IRDWON), 6	CN691-1	4.5	134
	DWCB-B-110-H3	4.5	134
	HTA7406-115-0-0-1	4.7	130
	Jalaplaban	4.7	138
	DWCT156-1-2	4.8	129
	IR11288-B-B-445-1	4.8	130
	IR31338-30-2-1	4.8	124
International Tide-Prone Rice Observational Nursery (ITPRON), 5	B5354-5D-MR-1	3.4	120
	IR25388-31-1-2	4.4	136
	Banih Kuning (Acc. 14681)	4.6	136
	B5332-13D-MR-4-4	5.0	117
	BR4	5.0	119
International Floating Rice Observational Nursery (IFRON), 8	BH2	2.7	123
	BKN6988-52-1-3	4.2	124
	HTAFR77028-6-2	4.2	132
	BR116-3B-28	4.3	127
	BR516-341-1	4.8	124

Table 10. Best performing entries in the 1986 insect and disease nurseries.

Nursery[a] and no. of trials	Entries rated resistant	
IRBPHN, 22	PTB33, IR27316-78-3-3, IR29725-109-1-2-1, IR28224-3-2-3-2, IR13427-45-3-1-2-2-2, IR29692-94-2-1-3, IR32822-2-2-3-2, RNR3070, Rathu Heenati (Acc. 11730)	
IRWBPHN, 9	A. *Field* C15662-2 (Acc. 3520) IR13427-45-3-1-2-2-2 IR29692-94-2-1-3 NP97 (Acc. 46464)	B. *Greenhouse* Bahbalon IR13475-7-3-2 IR13427-45-3-1-2-2-2 IR15527-21-2-3 IR15529-253-3-2-2-2 IR15795-151-2-3-2-2 IR17307-11-2-3-2 IR28154-101-3-2 Rathu Heenati (Acc. 11730)
IRSBN, 2		
Vegetative stage	IR45, IR4619-57-1-1-2-1, W1263 (Acc. 11057)	
Heading stage	IR15795-151-2-3-2-2, IR28150-84-3-3-2, IR4619-57-1-1-2-1, Ratna	
IRUSS, 2	Bazail 65, CNL319, CNM539, Karkati 161, NC487-77	
IRBBN, 27	IR54, RP2151-173-1-8, RP2151-192-1, RP2151-192-2-5, RP2151-33-2, RP2151-40-1	
IRBN, 20	IR17525-7-19-1-3-3-2, IR29506-60-3-3-2, IR29586-60-3-3-2, IR31892-100-3-3-3-3, IRAT144, IR39326-9-2-2-3, IR32799-107-3-3-2, IR32843-92-2-2-3, IR34583-19-3-3, IR37704-131-2-1-3-2, IR39326-146-3-1-3, Raminad Str. 3, Tetep, IR22103-26-6-2, IR31899-30-1-1-3, IR32429-47-3-2-2, IR32853-185-3-2-2, IR39422-163-1-3-2-2, IR5853-196-1-P1	
IRTN, 8	A. *Field* BR1356-32-1-3 BR308-B-2-3 IR28228-119-2-3-1-1 IR28228-12-3-1-1-2 IR29725-109-1-2-1 DM25 IR28228-96-3-2-1-3 IR28238-109-1-3-2-2	B. *Greenhouse* ARC11554 Tilakkachari IR29723-17-3-2-1 IR29725-109-1-2-1

[a]IRBPHN = International Rice Brown Planthopper Nursery, IRWBPHN = International Rice Whitebacked Planthopper Nursery, IRSBN = International Rice Stem Borer Nursery, IRUSS = International Rice Ufra Screening Set, IRBBN = International Rice Bacterial Blight Nursery, IRBN = International Rice Blast Nursery, IRTN = International Rice Tungro Nursery.

Table 11. Best performing entries in the 1986 IRTP soil and low-temperature stress screening nurseries.

Nursery[a] and no. of trials	Entries rated tolerant	Nursery[a] and no. of trials	Entries rated tolerant
IRSATON, 15		Acid Upland, 2	IRAT144, IR9764-45-2-2, Kinandang Patong, IRAT133, IR12979-24-1 (Brown)
Salinity	A69-1, Pokkali, IR14632-2-3, Bhurarata 4-10, IR19661-13-3-2, IR9808-9-2, IR18043-3-1-1, IR19661-150-2-2-2-1, IR19743-40-3-3-2-3, IR4227-28-3-2, IR4422-480-2-3-3, IR8073-231-3-3, IR8192-31-2, IR8608-75-3-1-3, RP975-109-2	Acid Lowland, 6	IR18349-53-1-3-1-3, IR31917-31-3-2, IR19657-87-3-3, IR13146-45-2-3, BR51-120-2, BW267-3
Alkalinity	IR8236-B-B-57-2-1, RP975-109-2, IR22083-105-3-3-3-3, IR4227-28-3-2, IR8608-75-3-1-3, IR9808-9-2, IR8073-231-3-3	IRCTN, 23	JKAU (K) 450-126-10, JKAU (K) 450-126-2, Ching-shi 15 (Acc. 368521), JKAU (K) 450-172-10, Z-Yah-Tsan (Acc. 4648), Akiyudaka, Suweon 303

[a]IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery, IRCTN = International Rice Cold Tolerance Nursery.

Table 12. IRTP nurseries dispatched from IRRI in 1987.

Region/Country	Nurseries for different cultural types[a]																													Total
	Yield							Observational										Screening for specific stresses												
	IRYN-VE	IRYN-E	IRYN-M	IURYN-E	IURYN-M	IRRSWYN-E	IRRSWYN-M	IRON-VE	IRON-E	IRON-M	IURON-E	IURON-M	IRRSWON-E	IRRSWON-M	IRDWON	IFRON	ITPRON	IRCTN	IRSATON	ACID LOWLAND	ACID UPLAND	IRBN	IRBBN	IRTN	IRBPHN	IRWBPHN	IRSBN	IRUSS	IRSGON	
East Asia																														
China	2	5	1	1	1	1	1	7	8	6	2	2	2	1	1			5	2			9	6		8	4	3			78
Japan																		3				2								5
Korea	1							2	1	1								4	2			4	1		1	1				18
Taiwan, China	1	1						1	1	1												1	1		1	1				9
Southeast Asia																														
Burma	1	1	1	2			2				1		1	1	2		1	1	2	1	1	2	2		1	1	2	1		27
Indonesia				1	1						2	2			2	1	1	1	1	2	1	3	1	2	5		1			27
Kampuchea														2																2
Malaysia		3	3		1		3		2	2		1		1						2		1	1	1	1	1	1			24
Philippines	10	9	9	10	10	7	10	1	1	1	12	12	6	6	1	1	6	2	15	2	3	1	1	1	1	1	1			140
Thailand	8	7	2	5	1	7	7	4	4	3	3	2	5	5	6	4	2	6	3	5	2	9	8	4	2	1	4	2		121
Vietnam	6	5	4	4	3	2	4	6	6	3	6	6	4	5	3	2	2	2	4	4	2	8	5	3	8	5	6	4	1	123
South Asia																														
Bangladesh	6	6	4	4	1	3	3	5	4	3	3	3	3	3	4	3	1	4	4		2	1	3	3	1			1		78
Bhutan	1	1	1					1	1	1			1	1				2							1					11
India	21	18	18	16	7	3	8	16	16	14	17	5	6	9	8	2	1	16	13	3	3	21	16	10	13	12	14	5	1	312
Nepal	3	3	3	2	3	2	2	2	2	3	2	2	1	1	1			5	1		1	7	4		2	1	4			57
Pakistan	4	6	6	1	1	1	1	5	5	5	1	1	1	1	1			1	5			1				6	6		1	61
Sri Lanka										1					1	1			1			1								5
West Asia and North Africa																														
Afghanistan	2	2	2					2	2	2								2				2	2				2	2		22
Egypt	2	2		2				2	2						3	3			2			2								20
Iran	4	1		1	1			3	3	1					2	2		1	4			1					2			26
Saudi Arabia				1	1																									2
Turkey	1							4			1								3			2								11
Sub-Saharan Africa																														
Cameroon	1	1	1					1	1									1												
Ethiopia	1			1		1	1				2	1			1	2		1											1	7
Liberia (WARDA)	2	2	2					3	3	3	3	2	7	6	6	5	3	4	8	6	3	8	2				5			11
Nigeria – IITA[b]	2	2	2	3	4	2	2	3	3	3	4	4	3	3				3		3	4	3	3							83
– NCRI[c]	1	1	1	1				1	1	1					1			1			1	1					1			56
Senegal	1	1	1																3	1		1								11
Sierra Leone								1	1	1			3	3	4	3	1		2	1		1								9
South Africa	1																													21
Tanzania	2	2	2	2	1	2	1	1	2	2	2	1	2	1				2	1			2						1		1
Uganda					1		1	1	1	1												1								29
Zaire				2	2						2	2										6								6
																														14

Continued on next page

Table 12 continued.

Region/Country	Nurseries for different cultural types[a]																	Screening for specific stresses													Total
	Yield							Observational																							
	IRYN-VE	IRYN-E	IRYN-M	IURYN-E	IURYN-M	IRRSWYN-E	IRRSWYN-M	IRON-VE	IRON-E	IRON-M	IURON-E	IURON-M	IRRSWON-E	IRRSWON-M	IRDWON	IFRON	ITPRON	IRCTN	IRSATON	ACID LOWLAND	ACID UPLAND	IRBN	IRBBN	IRTN	IRBPHN	IRWBPHN	IRSBN	IRUSS	IRSGON	
Latin America																															
Argentina										1																					2
Belize	1	1																	1												2
Brazil	2	1	1					3	2	1								2	1			1									14
Chile								1										1													2
Colombia								2	2	2	2	2						1			1	1									13
Cuba	1	1	1					1	1	1								1	1			1									9
Dominican Republic								2	2	2			1	1				2	2												12
El Salvador	1																														1
Guatemala								1	1	1	1	1										1									6
Honduras																						2									2
Mexico		2	1	4	3		1	3	2	2	2	4	1	1				3	3	1	1	6	1								41
Panama								1	1	1	1	1										1									6
Peru	1	1																	1			2									5
Europe																															
Hungary								1			1							1				1									4
Italy																						1									1
Oceania																															
Papua New Guinea																															1
Solomon Islands				1	1													1													2
Total	90	85	66	64	43	31	47	87	82	69	70	54	47	51	47	29	18	79	85	31	25	118	57	24	45	34	52	16	4	1550

[a]IRYN-VE = International Rice Yield Nursery-Very Early, IRYN-E = International Rice Yield Nursery-Early, IRYN-M = International Rice Yield Nursery-Medium, IURYN-E = International Upland Rice Yield Nursery-Early, IURYN-M = International Upland Rice Yield Nurse.,-Medium, IRRSWYN-E = International Rice Rainfed Shallow Water Yield Nursery-Early, IRRSWYN-M = International Rice Rainfed Shallow Water Yield Nursery-Medium, IRON-VE = International Rice Observational Nursery-Very Early, IRON-E = International Rice Observational Nursery-Early, IRON-M = International Rice Observational Nursery-Medium, IURON-E = International Upland Rice Observational Nursery-Early, IURON-M = International Upland Rice Observational Nursery-Medium, IRRSWON-E = International Rice Rainfed Shallow Water Observational Nursery-Early, IRRSWON-M = International Rice Rainfed Shallow Water Observational Nursery-Medium, IRDWON = International Rice Deep Water Observational Nursery, IFRON = International Floating Rice Observational Nursery, ITPRON = International Tide-Prone Rice Observational Nursery, IRCTN = International Rice Cold Tolerance Nursery, IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery, ACID LOWLAND = Acid Lowland Soils Screening Set, ACID UPLAND = Acid Upland Soils Screening Set, IRBN = International Rice Blast Nursery, IRBBN = International Rice Bacterial Blight Nursery, IRTN = International Rice Tungro Nursery, IRBPHN = International Rice Brown Planthopper Nursery, IRWBPHN = International Rice Whitebacked Planthopper Nursery, IRSBN = International Rice Stem Borer Nursery, IRUSS = International Rice Ufra Screening Set, IRSGON = International Rice Slender Grain Observational Nursery.

Table 13. Origin and types of entries in the 1987 IRTP nurseries dispatched from IRRI.

Nursery	Sets dispatched (no.)	Entries (no.)	Entries (no.) from			
			National program		IRRI	
			Improved (no.)	Traditional (no.)	Improved (no.)	Germplasm bank (no.)
Yield						
Irrigated						
IRYN-VE	90	24	6	0	18	0
IRYN-E	85	24	10	0	14	0
IRYN-M	66	24	17	0	7	0
Rainfed Upland						
IURYN-E	64	19	16	0	3	0
IURYN-M	43	20	15	0	5	0
Rainfed Lowland						
IRRSWYN-E	31	19	5	0	14	0
IRRSWYN-M	47	18	5	0	13	0
Observational						
Irrigated						
IRON-VE	87	26	7	0	19	0
IRON-E	82	61	37	0	24	0
IRON-M	69	90	73	0	17	0
Rainfed						
IURON-E	70	31	29	2	0	0
IURON-M	54	46	29	1	15	1
IRRSWON-E	47	14	4	0	10	0
IRRSWON-M	51	75	48	0	27	0
IRDWON	47	73	34	0	39	0
IFRON	29	14	12	0	2	0
ITPRON	18	29	12	0	17	0
Stress screening						
Diseases						
IRBN	118	109	51	0	58	0
IRBBN	57	47	30	0	74	3
IRTN	24	62	15	0	47	0
Insects						
IRBPHN	45	67	22	0	42	3
IRWBPHN	34	29	13	0	15	1
IRSBN	52	35	12	0	22	1
Nematode						
IRUSS	16	43	43	0	0	0
Problem Soils						
IRSATON	85	81	19	0	62	0
Acid Lowland	31	78	22	0	56	0
Acid Upland	25	52	21	0	29	2
Temperature						
IRCTN	79	63	40	0	9	4
Grain Quality						
IRGQSS[a]	4	18	12	0	6	0
Total	1550	1291	659	3	664	15

[a]IRGQSS = International Rice Grain Quality Screening Set.

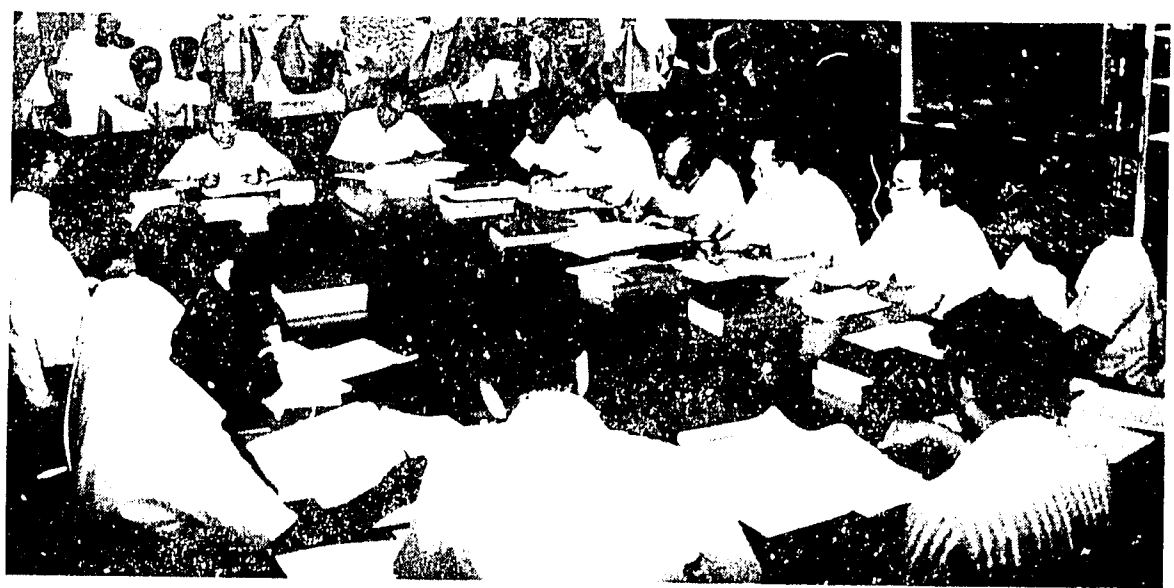
USE OF IRTP ENTRIES

National rice improvement programs continued using IRTP materials. One hundred thirty-six entries were used as donors in hybridization programs. Seventeen were selected for further yield testing: Chianung sen yu 20, DR33, IR32419-81-2-5-3, Lei Zhong 124, S818B-10-2, Taichung sen yu 223, B5185B-64-MR-2-2, IR32876-54-2-2, Suweon 340, Suweon 341, IR7732-RGA-B-A96-1, HPU5010-PLP21-2-1B, IR13524-21-2-3-3-2-2, IR31787-41-2-2-3-3, IR32429-122-3-1-2, IR39379-20-1-2-1-1, and Suweon 339. Nineteen were released as varieties in 2 Asian and 8 Latin American countries in 1987: 6 in India (IR19728-9-3-2, BG367-4, IR21820-154-3-2-2-3, NC492, CN499-160-13-6, CN505-5-32-9), 1 in Vietnam (IR1820-210-2), 4 in Brazil (Taichung sen yu 195, P921-57-2-2-3-1B, P1035-5-6-1-1-1M, P1342-6-6-M-1-2M-3), 2 each in Bolivia (IR5853-118-5, P1364-4-16M-1-2M-4) and Panama (P1381-1-8M-2-1B-CH4, P2062F4-17-33-1-RH1), and 1 each in Colombia (IP2231F4-138-6-2-1-1B), Dominican Republic (IR2153-276-1-10-PR509), El Salvador (P1429-8-9M-21M-5), Guatemala (P1428-8-9M-21M-5), and Mexico (P1035-5-6-1-1-1M-OHui).

1. IRTP Deepwater Monitoring Tour participants observing breeder's plots in deepwater tanks in Huntra, Thailand, October 1987.

MONITORING VISITS AND PLANNING MEETINGS

The 1987 monitoring tours and workshops organized by IRTP further strengthened the linkages among rice scientists with common interests in various aspects of varietal improvement (Fig. 1). The IRTP advisory committee, composed of rice scientists from selected countries, met at IRRI in March 1987 to review the progress and formulate the future plans of the program (Fig. 2).



2. The IRTP Advisory Committee, composed of rice scientists from selected countries, met at IRRI in March 1987 to review progress and formulate plans for the program.

The following monitoring tours and workshops were organized in 1987.

- Drought monitoring tour in South and Southeast Asia, 6-13 Sep
- Deepwater rice monitoring tour, 10-25 Oct
- Rice ufra monitoring tour in Bangladesh and India, 21-26 Sep
- West African rice monitoring tour in Ivory Coast, Gambia, Senegal, and Nigeria, 4-13 Oct
- IRTP-Africa rice workshop, 14-16 Oct
- Discussion panel on rice breeding for low temperature tolerance in Latin America, 6 Oct

The observations and recommendations relative to these monitoring tours and workshops are published separately.

IRTP IN AFRICA

IRTP-Africa—a joint program of IRRI, the International Institute of Tropical Agriculture, WARDA, and African national programs—has made remarkable progress since its establishment in 1985. The program has identified 30 and 28 varieties with superior performance in irrigated and upland ecologies, respectively. Two hundred forty-four nursery sets were distributed to 27 African countries and 2 countries in South America in 1987 (Table 14). The promising entries from the 1985-86 IRTP-Africa nurseries are listed in Table 15.

IRTP-East Africa continued its effort to evaluate IRTP-Africa and global nurseries to identify

Table 14. Distribution of 1987 IRTP-Africa nurseries.[a]

Country	Sets (no.)						
	Upland			Irrigated			Total
	AT	ON	PSS	AT	ON	PSS	
Benin Republic	1	1	–	1	1	–	4
Brazil	–	1	1	–	1	–	3
Burkina-Faso	1	1	–	1	1	–	4
Burundi	2	1	1	3	1	–	8
Cameroon	2	3	2	2	2	2	13
Colombia	–	1	1	–	–	–	2
Congo Brazaville	1	1	–	1	1	–	4
Ethiopia	1	1	–	1	1	–	4
Gambia	1	1	–	1	1	–	4
Ghana	2	2	1	3	3	1	12
Guinea	5	2	1	4	1	–	13
Guinea-Bissau	1	1	–	2	2	–	6
Ivory Coast	4	4	2	1	1	–	12
Kenya	2	1	–	2	1	–	6
Liberia	2	2	2	3	3	3	15
Malawi	1	1	–	2	2	1	7
Mali	1	1	–	–	–	–	2
Nigeria	6	6	5	15	9	5	46
Rwanda	1	1	1	4	3	3	13
Senegal	2	2	1	3	3	2	13
Sierra Leone	1	1	–	1	1	–	4
Somalia	1	1	–	1	1	–	4
Sudan	1	1	–	1	1	–	4
Tanzania	3	2	1	5	5	1	17
Togo	1	1	1	–	–	–	3
Uganda	2	1	–	–	–	–	3
Zaire	2	1	–	1	–	–	4
Zambia	2	2	1	2	2	1	10
Zimbabwe	1	1	–	1	1	–	4
Total	50	45	21	61	48	19	244

[a]AT = advanced trial, ON = observational nursery, PSS = preliminary screening set.

Table 15. Promising entries in Africa based on 1985-86 IRTP-Africa trials.

Nursery[a]	Entries
AIRAT	ITA222, ITA212, BG400-1, BG90-2, ITA306, IR4422-98-3-6-1, ITA234
AURAT	IRAT104, IRAT156, IRAT170, IDSA6, IRAT161, ITA315, ITA307
AIRON	HPU741, IR19670-263-3-2-2-1, ITA302, 18447, ITA222, BW348-1, ITA231, Bouake 189, IR19743-25-2-2-3-1, IR54, ITA123, TOX960-42-1
AURON	IRAT109, ITA116, ITA118, ITA130
AIRPSS	IR28118-138-2-3, RAU2004-6-69-2-13, Taichung sen 10, 18453, 19934, IR35366-40-3-2-2
AURPSS	Farox 299, IRAT168, IRAT169, IR14632-22-3, IR17494-32-1-1-3-2, IR25924-51-2-3, ITA216, TOX1768-3-1-1-101, Wabis 737, Wabis 786, Wabis 822, Wabsoka

[a]AIRAT = African Irrigated Rice Advanced Trial, AURAT = African Upland Rice Advanced Trial, AIRON = African Irrigated Rice Observational Nursery, AURON = African Upland Rice Observational Nursery, AIRPSS = African Irrigated Rice Preliminary Screening Set, AURPSS = African Upland Rice Preliminary Screening Set.

suitable varieties and breeding materials for the region. Many promising lines were identified in three countries in Eastern Africa (Table 16). Various nurseries were evaluated in Ifakara, Zanzibar, and Morogoro, Tanzania, in collaboration with Tanzanian rice scientists.

IRTP IN LATIN AMERICA AND THE CARIBBEAN

In 1987, 76 sets of IRTP observational nurseries for Latin America were sent to requesting national programs in the region (Table 17). Additionally, 115 sets of IRTP global nurseries were distributed to 13 Latin American countries. IRTP-Latin America observational nurseries consist of entries with tolerance for major biological or chemical stresses such as rice blast (Bl) and Al toxicity. Twenty-nine percent of total entries were nominated by various national programs.

An average of 18.4% of 1986 nursery entries were selected and advanced further by individual national programs in Latin America for yield trials during the first crop, and 9.4% during the second crop. Six lines, 4 for the first crop season in the tropical zone and 2 for the second crop season in the temperate zone, were selected in at least 50% of the testing sites (Table 18).

Table 16. Promising lines in East Africa identified from IRTP nurseries.

Country	Entries
Ethiopia	IR21178-39-P1, IR26933-16-2-3, IR3383-23-3-3-3, IR21567-9-2-2-3-1-3, IR21567-16-3, IR9217-6-2-2-3, IR19083-22-2-2, Mahsuri, IR14497-15-2, RP1057-184-5-3-2
Tanzania	Katrin (IET2397), IR42, ITA283, BG400-1
Zambia	IR54, RNR36781, RTN500-5-1, IR19743-46-2-3-2, IR21071-53-2-3-2, RP1082-24-1-1-1

Table 17. IRTP observational nurseries for Latin America distributed in 1987.

Germplasm group[a]	First crop		Second crop		Total[b]	
	Lines (no.)	Sets (no.)	Lines (no.)	Sets (no.)	Lines (no.)	Sets (no.)
Tolerance for:						
Bl and LSc	206	38	179	5	315	43
Bl, LSc, HB, and sogatodes	86	13	101	1	163	14
Bl, LSc, and Al toxicity	25	8	25	1	25	9
Earliness	–	–	130	10	130	10
Total	–	59	–	17	–	76

[a]Bl = leaf and neck blast, LSc = leaf scald, HB = hoja blanca. [b]Some lines were included in both crops.

Table 18. Days to flowering and disease reactions of lines from the IRTP-Latin America Observational Nurseries selected for yield trials in 1986.[a]

Designation	Days to flowering[b]	Disease reactions[c]			
		Blast	Neck blast	Leaf scald	Brown spot
Tropical (first crop)					
P3621F2-1-2-8-1B	104	3	1	3	3
P3634F4-5-7	91	3	5	3	2
P4382F3-17-6-1B	98	3	3	3	4
P4725F2-16-7	95	1	1	3	2
Temperate (second crop)					
P5601-12-1-5	93	5	5	3	8
P4718F2-9-5-M-5P	95	5	5	3	–

[a]Lines selected in at least 50% of total evaluation sites. Sites consist of 14 tropical locations and 4 temperate locations. [b]Mean number of days after seeding in locations where lines were selected. [c]SES scores in locations with highest disease pressure.

In 1987, the Caribbean Rice Improvement Network focused on germplasm evaluation and selection and distribution of promising lines to cooperators in the region. Twenty-nine sets composed of 189 promising lines were distributed to different countries in the Caribbean region (Table 19). Also, 214 of 910 entries from IRTP-global and Centro Internacional de Agricultura Tropical nurseries were selected for multilocation evaluation based on preliminary evaluation in Juma, Dominican Republic. These will be distributed in 1988.

GEOGRAPHICAL VARIATION OF GEOVIRULENCE PATTERNS OF THE RICE BLAST FUNGUS

Stability of host resistance against diverse Bl pathogens is a major component for durability of a variety under Bl-prone environments. IRBN is a convenient medium to evaluate a set of diverse genotypes and improved breeding lines against diverse Bl populations under different environments. Characterization and monitoring of the virulence pattern of the Bl populations globally can generate information with which more efficient international collaborative evaluation schemes could be formulated.

The virulence patterns of the rice Bl populations at 24 testing sites in 14 countries were compared by multivariate analysis of the 1985 IRBN. Four major patterns were recognized (Table 20). The first two patterns, I and II, have a narrow range of virulence against a total of 226 entries. These patterns were observed in East Asia, Nepal, and Italy, where japonica or indica/japonica derivative cultivars are grown (Fig. 3). Patterns III and IV, whose spectra are wider than those of I or II, were observed in South and Southeast Asia and in Latin America, where indicas or upland japonicas are the predominant cultivars. Although a close association between virulence pattern and geographical proximity can be recognized, similarity of virulence pattern at geographically distant testing sites was also observed. This indicates that cultivars grown at those sites may have a common genetic background in relation to Bl resistance.

Table 19. Observational nurseries dispatched from the Caribbean Rice Improvement Network in 1987.

Nursery[a]	Entries (no.)	Sets (no.)	Country[b]
Irrigated - Disease + Fe-toxicity tolerance	65	9	All cooperating countries
Irrigated - Low temperature tolerance	21	2	Cuba, Dominican Republic
Irrigated - Salinity tolerance	14	8	All cooperating countries except Belize
Rainfed - Shallow deepwater	41	4	Jamaica, Dominican Rep., Trinidad and Tobago
Upland - Moderately favorable	47	6	Belize, Guyana, Haiti, Dominican Republic, Trinidad
Total	188	29	

[a]Formed according to the ecosystems present in the region and needs of cooperators. [b]Cooperating countries: Belize, Cuba, Dominican Republic, Guyana, Haiti, Jamaica, Trinidad and Tobago, and Surinam. Two sets of each nursery were sent to Trinidad and Tobago. Other countries received one set each.

HOT-SPOT SCREENING FOR ADVERSE SOILS TOLERANCE IN ILOILO, PHILIPPINES

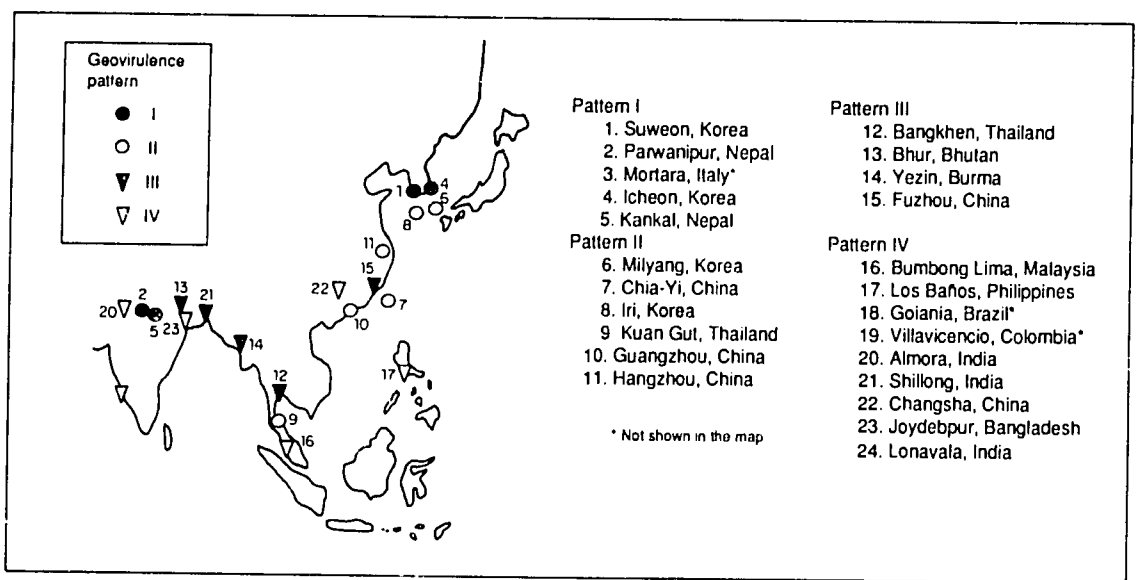
Acid upland soils. In acid upland soils in Balabag, San Dionisio, Iloilo, 300 upland rices were screened for tolerance for drought, rice Bl, and overall adverse soil and climatic conditions. Of the promising entries, 28 were included in IURYN and the acid upland screening set of IRTP for multilocation testing: C1158-7, CR138-1040, FAROX 299, IR12974-24-1, IR13146-45-2-3, IR1514A-E666, IR21018-97-1, IR26950-123-5, IR26957-45-1, IR29723-17-3-2-1, IR43, IR47686-12-5-B-1, IR47686-30-2-1, IR47691-17-1-B, IR47698-4-3-1, IR47699-27-1-1, IR8073-65-6-1, IR9171-60-2-2, IR9217-58-2-2, IRAT170, ITA239, KMP34, M55, NDR117, P1356-1-3M-2-1B, P1386-2-6M-5-1B, RP1158-85-1, and TOX718-1-24. All these entries have drought tolerance scores of 4-5 and phenotypic acceptability ratings of 4-5.

Inland toxic and phosphorus-deficient soils. About 480 rices were evaluated for their tolerance for acid soil conditions having Fe toxicity, P deficiency, and low pH in San Dionisio, Iloilo. The soils used have properties similar to those used in mass screening. Of the 75 promising lines from this site, 29 entries were nominated for inclusion in the acid lowland and IRON screening sets of IRTP for

Table 20. Major virulence patterns and average percentage of entries showing compatible reaction.

Pattern	Varietal group[a]										
	1 (7)	2A (23)	2B (13)	3A (12)	3B (30)	4 (30)	5A (26)	5B (26)	6A (28)	6B (13)	7 (18)
I	10	0.9	1.5	1.7	7.3	2.7	2.3	2.3	14.3	18.5	61.5
II	8.3	2.9	0	5.6	20.0	7.8	12.8	36.6	74.4	62.8	84.6
III	0	48.9	57.7	89.6	46.7	63.3	48.1	73.3	41.1	48.1	88.5
IV	33.3	46.4	60.7	52.8	77.0	93.0	93.6	95.7	93.2	84.6	98.3

[a]Varietal grouping is based on Ward's cluster analysis of leaf Bl reaction at 24 testing sites of the 1985 IRBN. Numbers in parentheses are total number of entries classified as a varietal group.



3. Classification of geovirulence patterns of 24 test locations based on Ward's cluster analysis of leaf Bl reaction. * = not shown on the map.

multilocation testing: B41960-MR-52-1-5, B4459-H-MR-32-3-1, BR51-282-8-1, BRC16-127-4-1, BW288-1-3-52-1-5, IR13610-72-2-2E-P2, IR25912-63-2-2, IR2674-246-1-1, IR27325-27-3-3, IR28179-67-2-1-1, IR28179-80-3-3-2, IR28211-43-1-1-1-2, IR28228-12-3-1-1-2, IR29668-34-1-1-2, IR29706-94-1-3-2, IR29723-143-3-2-1, IR29723-88-2-3-3, IR31787-85-3-3-3-2, IR31836-42-1-3-2, IR31917-45-3-2-2, IR32307-107-3-2-2, IR32429-115-3-2-6, IR32453-20-3-2-2, IR32727-138-2-1-1-2, IR34583-75-1, IR35293-178-2-3-1, IR4414F-MR-6-1, P2025F4-159-3-1B, and RP1045-25-2-1. All these lines have vegetative vigor ratings of 2-4 and phenotypic acceptability scores of 2-4.

Saline and acid sulfate soils. We characterized 300 rice entries at 2 sites in farmers' fields in Lanjagan and Pili, Ajuy, Iloilo, used as hot-spot testing sites for saline and acid sulfate soil conditions. Thirty rice varieties that obtained a score of 4 or better at both sites were nominated for inclusion in the IRSATON and acid lowland screening sets of IRTP for multilocation testing: IR18152-CN-7-1-3-3, IR29337-36-3, IR33219-67-33-1, IR33360-5-1-3-1, BRC16-127-4-1, CR1022, IR17491-5-4-3-3-P1, IR21037-37-2-1-2E-P2, IR33238-25-2-3-2, IR3338-66-1-2-2, IR3646-9-1-1, IR4432-28-5, IR4744-295-2-2, IR5853-196-1-P1, R114-2-1-1-1, BKNFR780-22-44-506-H3, IR21033-58-1-1-2-1-3, IR33535-1-9-3-2-1, IR2135-42-3-1-2-2, IR31432-5-4, IR21738-44-1-2-1-3, IR33306-150-9-2-2-23, IR2609-5-3-3-1-3-3-1, IR3313-8-9-3-2-3-3, IR33138-39-1-2-2-3-1, IR3360-5-1-3-2-1-2, IR33477-753-1-3-3-1, IR33477-37-3-2-2-1-3, IR26940-20-3-3-3-2-2-1, and TCA80-4.

International collaboration

International Network on Soil Fertility and Fertilizer Evaluation for Rice

Agronomy, Agricultural Economics, and Training and Technology Transfer Departments

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NITROGEN FERTILIZER EFFICIENCY TRIAL IN IRRIGATED RICE

Agronomy Department

The seventh N fertilizer efficiency trial of the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) was conducted at IRRI in the 1987 dry season (DS) and wet season (WS). In both seasons, no fertilizer source-rate interaction was significant.

In DS, N increased yields significantly. Urea supergranules (USG) gave significantly higher yields than did prilled urea (PU) applied either as modified researchers' split (RS) (2/3 broadcast and incorporated [B&I] with standing water + 1/3 topdressed at 5-7 d before panicle initiation [DBPI], or as standard RS (2/3 B&I onto mud without standing water + 1/3 topdressed at 5-7 DBPI) (Table 1). However, PU applied as standard RS yielded significantly higher than modified RS. No significant yield differences were observed in WS.

Table 1. Effect of N source and N fertilizer application rate and method on IR64 yield. Seventh trial on N fertilizer efficiency in irrigated rice, INSFFER, IRRI, 1987 DS.

Treatment[a]	Grain yield (t/ha)
No fertilizer N	3.1
Source and application method	
PU modified RS	5.9 c
PU standard RS	6.4 b
USG	6.8 a
N rate (kg/ha)	
29	–
58	5.3 c
87	6.3 b
145	6.7 b
203	7.2 a

[a]PU = prilled urea, RS = researchers' split, USG = urea supergranules. PU modified RS = 2/3 broadcast and incorporated (B&I) with standing water + 1/3 topdressed at 5-7 d before panicle initiation (DBPI). PU standard RS = 2/3 B&I without standing water + 1/3 topdressed at 5-7 DBPI.

INTERNATIONAL TRIALS

Agronomy Department

Seventy-five INSFFER trials were conducted in 1986 at 41 sites in 9 countries. Of these, 35 trials were on N fertilizer efficiency (24 in irrigated lowland and 6 in rainfed lowland); 17 were long-term fertility trials in irrigated rice; 12 compared hand- and machine-applied N fertilizers in irrigated rice; 11 were on the integrated use of inorganic and organic N fertilizers in irrigated rice; and 5 concerned soil fertility management of acid upland soils for rice (3 for soils with pH <5 and 2 for soils with pH 5-7).

In 1987, 180 sets of fertilizer materials and fieldbooks were sent to 58 collaborators in 12 participating countries. Eight collaborative research trials were conducted, as follows:

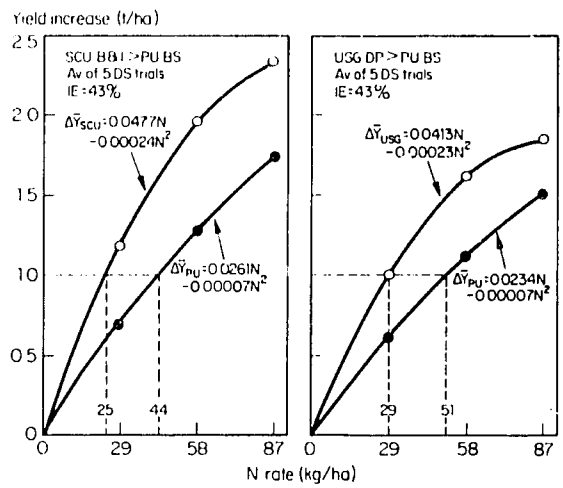
- Seventh N fertilizer efficiency trial in irrigated lowland rice (formulated and implemented in 1987);
- Fourth N fertilizer efficiency trial in rainfed lowland rice (1987);
- Second hand- vs machine-applied N fertilizer trial in irrigated lowland rice (1987);
- First long-term fertility trial in irrigated lowland rice (1976);
- Second integrated use of inorganic and organic N fertilizers in irrigated lowland rice (1987);
- First integrated use of inorganic and organic N fertilizers in rainfed lowland rice (1987);
- Second soil fertility management of acid upland soils for rice (1987)
  - a) for soils with pH <5.0 (a P × lime interaction trial)
  - b) for soils with pH 5-7 (essentially a long-term trial using a minus-one element design).

The N efficiency trials are basically maintenance research to defend or further improve present yield gains. The long-term fertility trials essentially look into the long-term effects of fertilizer management and intensive cropping on soil physical and chemical properties, as well as the issue of whether current yield levels can be maintained. Studies on the integrated use of inorganic and organic N sources in lowland rice focus on the sustainability of rice production; maintenance and enhancement of the environment, particularly the soil; and social and equity issues that arise with the adoption of intensive rice-based cropping systems.

Nitrogen fertilizer efficiency trials. *Irrigated rice.* In the sixth international trial on N fertilizer efficiency in irrigated lowland rice, 24 trials were conducted in 1986 at 18 sites in 7 countries, bringing the total number of trials conducted since 1984 to 56, the sites to 35, and the participating countries to 9. Forty-nine of the 56 trials showed a significant mean response to N. Average grain yields from all responsive trials showed that responses of irrigated lowland rice to B&I sulfur-coated urea (SCU) and to deep-placed (DP) USG were identical and higher than responses to local best split (BS) and standard BS PU, which were equally effective at all N rates in both seasons. Yields in DS were higher than those in WS. In both seasons, increasing the N level increased yield. However, a maximum yield increment of 0.5 t/ha was obtained between low and medium N rates.

Regression analysis using the multifertilizer response model (MRM) and the fertilizer test model (FTM) showed that SCU B&I was superior to PU local BS in 47% of the N-responsive irrigated lowland rice trials, USG DP to PU local BS in 49% of the trials, and PU standard BS to PU local BS in 7% of the trials (Table 2). The estimated average yield responses to SCU B&I, USG DP, and PU local BS showed that, for an initial yield increase of 1 t/ha over control, 43% less N was required if N were applied as SCU B&I and USG DP rather than PU local BS during DS (Fig. 1), and 53 and 51% less N were required if applied as SCU B&I and USG DP, respectively, during WS (Fig. 2).

Rainfed lowland rice. In the third international trial on N fertilizer efficiency in rainfed lowland rice, 56 trials were conducted at 34 sites in 10 countries from 1981 to 1986. The average grain

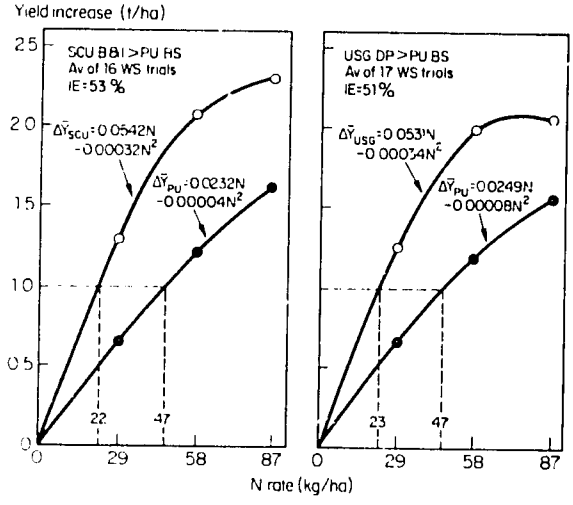


1. Estimated average yield responses of irrigated lowland rice to sulfur-coated urea (SCU) broadcast and incorporated (B&I), urea supergranules (USG) deep-placed (DP), and prilled urea (PU) (local best split [BS]) in trials where yield responses to the test fertilizers were significantly greater than PU. Sixth international trial on N fertilizer efficiency in irrigated lowland rice, INSFFER, 1984-86 DS.

Table 2. Trials in 9 countries by response category when SCU B&I, USG DP, and PU standard BS were compared separately with PU local BS. Sixth international trial on N fertilizer efficiency in irrigated lowland rice, INSFFER, 1984-86.

Country	Trials (no.)			
	Response category[a]			Total
	SCU > PU local BS	USG > PU local BS	PU standard BS > PU local BS	
Burma	1	1	0	2
Cameroon	1	1	0	5
China	1	1	0	5
Cuba	0	0	0	3
India	9	8	1	21
Nepal	0	0	0	2
Pakistan	1	0	0	5
Philippines	4	5	0	6
Vietnam	4	4	2	7
Total	21 (48)	20 (45)	3 (7)	56

[a]Fertilizer testing model (FTM) linear differential estimate of quadratic function was used to classify individual trials into response categories. Values in parentheses are percentages of the 44 trials where positive N response was obtained.



2. Estimated average yield responses of irrigated lowland rice to SCU B&I, USG DP, and PU local BS in trials where responses to the test fertilizers were significantly greater than to PU. Sixth international trial on N fertilizer efficiency in irrigated lowland rice, INSFFER, 1984-86 WS.

yield from 51 N-responsive rainfed lowland trials showed that SCU B&I and USG DP were superior to PU BS at all N rates.

MRM and FTM analysis showed that yield responses to SCU B&I and USG DP were significantly greater than yield responses to PU BS in 36% of the responsive trials (Table 3). An initial yield increase of 1 t/ha over control required 53% less N if it were applied as SCU, and 61% less if applied as USG (Fig. 3).

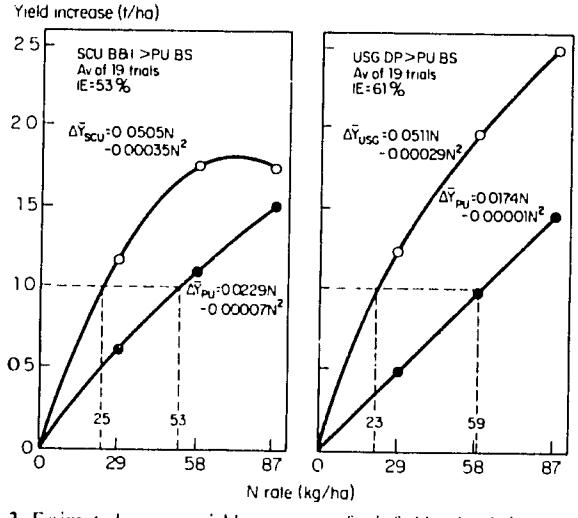
Hand- and machine-applied N fertilizers. In 1986, 12 trials comparing hand- and machine-applied N fertilizers in irrigated lowland rice were conducted at 8 sites in 5 countries, bringing the total number of trials conducted since 1984 to 27, the sites to 21, and the participating countries to 11. Twenty-one of the 27 trials were N-responsive; 9 of these were conducted in WS and 12 in DS.

Average yield increases over control among the responsive trials ranged from 0.6 to 1.7 t/ha during WS (Fig. 4) and from 1.0 to 2.3 t/ha during DS (Fig. 5). Machine-applied N fertilizers produced yields comparable to those with conventional farmers' and researchers' split applications at 58 kg N/ha. At higher N rates, however, machine-applied N performed less effectively. Among the methods tested, deep placement of USG by hand remains the most effective for increasing N fertilizer use efficiency in irrigated lowland rice.

Table 3. Trials in 10 countries by response category when SCU B&I and USG DP were compared separately with PU BS. Third international trial on N fertilizer efficiency in rainfed lowland rice, INSFFER, 1984-86.

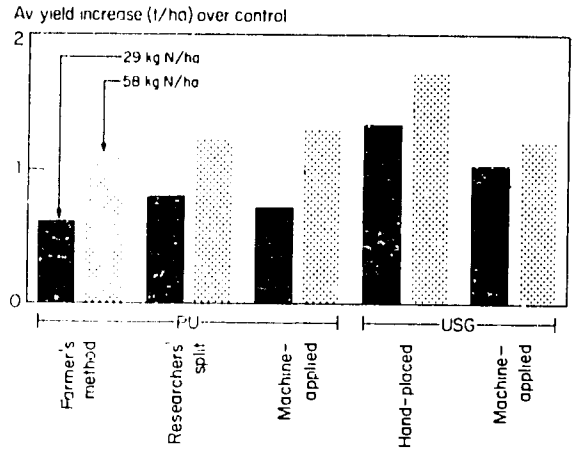
Country	Trials (no.)			
	Response category[a]			Total
	SCU > PU	USG > PU	No response	
Bangladesh	2	0	0	4
Burma	2	2	0	5
Cuba	0	0	0	1
India	8	6	1	27
Indonesia	1	1	0	3
Nigeria	0	0	1	1
Philippines	3	5	1	10
Sri Lanka	2	1	0	2
Thailand	1	1	0	2
Vietnam	0	1	0	1
Total	19 (36)	19 (36)	3	56

[a]FTM linear differential estimate of quadratic function was used to classify individual trials into response categories. Values in parentheses are percentages of the 53 trials where positive N response was obtained.

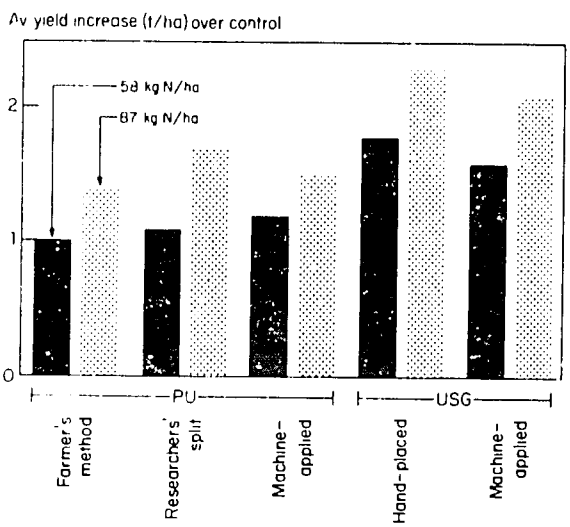


3. Estimated average yield responses of rainfed lowland rice to SCU B&I, USG DP, and PU BS in trials where responses to the test fertilizers were significantly greater than to PU. Third international trial on N fertilizer efficiency in rainfed lowland rice, INSFFER, 1981-86.

Integrated use of inorganic and organic N fertilizers. In 1986, 36 trials were conducted at 13 sites in 5 countries to evaluate the effectiveness of inorganic N fertilizers applied alone or in combination with biofertilizers such as azolla, green manure, and fresh straw; and to determine their long-term effects on soil fertility.



4. Significant yield responses of rice to PU and USG with different methods of application at 2 N rates tested in 9 N-responsive trials in 8 countries during WS. First international trial on the comparison of hand- and machine-applied N fertilizers in lowland rice, INSFFER, 1984-86.



5. Significant yield responses of rice to PU and USG with different methods of application at 2 N rates tested in 12 N-responsive trials in 7 countries during DS. First international trial on the comparison of hand- and machine-applied N fertilizers in lowland rice, INSFFER, 1984-86.

A significant response to N was observed at all sites. Average responses across 74 sites where azolla and rice straw were used as organic N sources showed that inorganic N as either PU BS or USG DP combined with azolla or fresh straw produced yields comparable to those with inorganic sources alone (Table 4). However, at three sites in India and one site each in China, Nepal, and the Philippines, azolla combined with either PU or

Table 4. Average yield increases of irrigated lowland rice with application of PU or USG alone or in combination with azolla or straw at 2 N rates. First international trial on integrated use of inorganic and organic N fertilizers in irrigated lowland rice, INSFFER, 1984-86.

Treatment[a]	Yield increase[b] (t/ha)	
	58 kg N	87 kg N
Control		
PU	1.2	1.7
PU + azolla	1.3	1.9
PU + straw	1.1	1.7
USG	1.5	2.2
USG + azolla	1.6	2.3
USG + straw	1.3	1.9

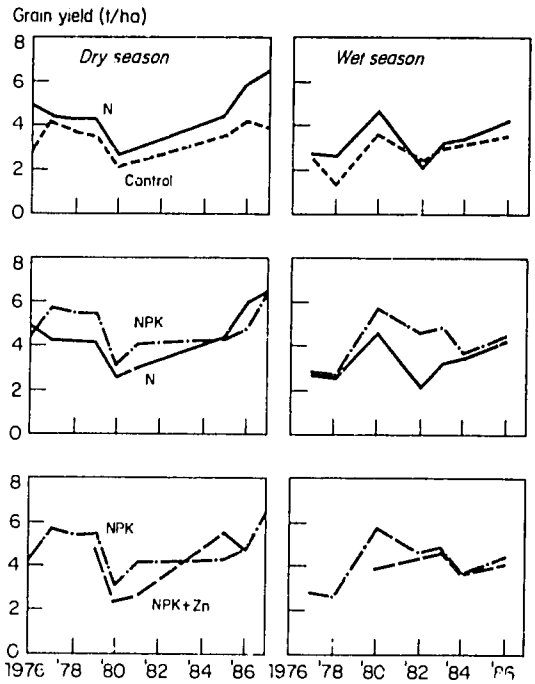
[a]For combinations, organic N was fixed at 29 kg N/ha.
[b]The control (no fertilizer) yielded 3.3 t/ha. Yield increases over control are the average of 29 trials conducted at 11 sites in 4 countries.

USG produced yields higher than inorganic N alone. Moreover, PU or USG combined with azolla gave higher yields than PU or USG with fresh straw at 9 sites in 4 countries. This may be attributed to higher N immobilization when an organic source with wide C:N, such as straw, is combined with inorganic N. At all sites, USG alone or combined with azolla or straw produced better yields than treatments involving PU.

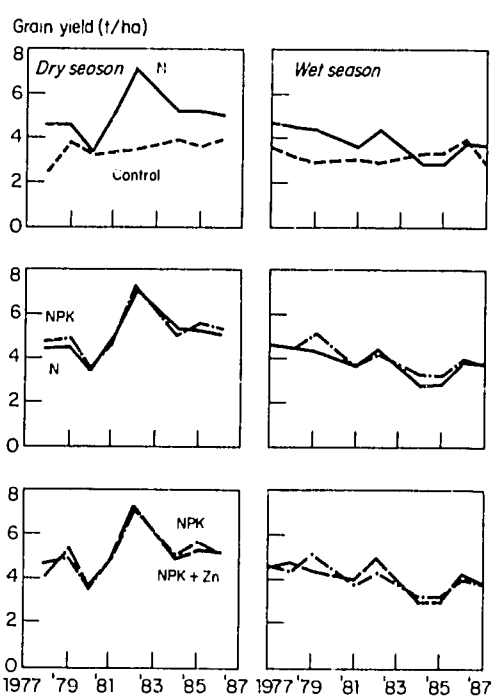
Long-term fertility trial in irrigated rice. Ten sites in four countries were still conducting this trial as of 1986. These include three sites each in China and Indonesia, and two each in India and the Philippines. In Indonesia, in Lanrang and Sukamandi, NPK consistently gave the highest yield, while in Maros, NPK and N alone were comparable, especially during DS (Fig. 6, 7). N remains the major limiting nutrient; P and K are effective only when combined with N. Yield responses from NPK + Zn in Lanrang and Maros trials were comparable to those with NPK alone. A long-term trial was recently initiated in Cicurung, Sukabumi.

In the Philippines, results of 21 croppings in Luisiana and 20 croppings in Tanay since 1976 showed that N continues to be the limiting nutrient (Fig. 8, 9). Eighty-five percent of all trials at both sites showed significant responses to N alone, while NPK consistently gave a 100% significant response. A gradually declining trend in grain yield was observed at both sites.

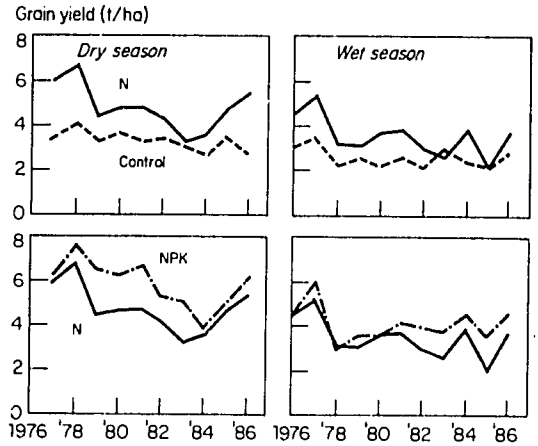
Eight trials in Shipai and 7 trials each in Qingpu County and Guanshanping, China, have been



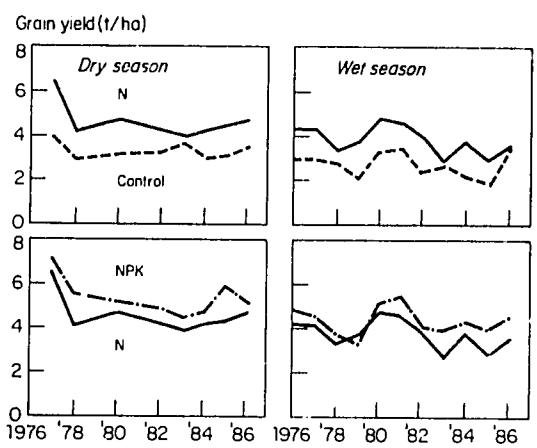
6. Grain yield trends during wet and dry seasons over 12 yr of continuous trials in Lanrâng, Indonesia. First international long-term fertility trial in irrigated rice. INSFFER, 1976-87.



7. Grain yield trends during wet and dry seasons over 11 yr of continuous trials in Maros, Indonesia. First international long-term fertility trial in irrigated rice. INSFFER, 1977-87.



8. Grain yield trends during wet and dry seasons over 10 yr of continuous trials in Luisiana, Philippines. First international long-term fertility trial in irrigated rice. INSFFER, 1976-86.



9. Grain yield trends during wet and dry seasons over 10 yr of continuous trials in Tanay, Philippines. First international long-term fertility trial in irrigated rice. INSFFER, 1976-86.

conducted since 1983. In general, N, alone or combined with P and K, gave significant yield increases, especially during DS. N is the major limiting nutrient; P and K are effective only when combined with N.

In Kanpur and Pantnagar, India, N is also the limiting nutrient, especially in Pantnagar, where P and K applications seem to have no effect on yield.

Soil fertility management of acid upland soils. *pH* <5. Interaction between 3 P sources—triple superphosphate (TSP), Christmas Island phosphate rock (CIPR), and fused magnesium phosphate (FMP)—and lime, and its effect on rice yield were tested in 5 WS trials at 3 sites (with pH

ranging from 4.1 to 4.6) in the Philippines from 1984 to 1986.

The average response from 5 trials showed a stepwise increase in grain yield with increasing TSP level (Fig. 10). TSP was more effective with lime than without, although yields were lower at higher rates of lime. Without lime, TSP gave higher yields than the less soluble CIPR and FMP. The results indicate that both P and lime are essential in increasing rice yields in highly acidic upland soils.

pH 5-7. In response to the need to study and develop more relevant soil fertility management practices for upland rice grown on moderately acid soils, we initiated in 1984 a long-term trial that monitors changes in soil physical and chemical properties upon continuous fertilizer application and intensive cropping. Six sets of experimental materials were sent to two collaborators in two countries in 1986. Six trials have been conducted at 2 adjacent sites with pH 5.7 on the IRRI upland farm since 1985. Site 1 was planted to a rice - legume (cowpea) cropping pattern and site 2 to a rice - cereal (sorghum) pattern.

Results of the trials showed that yields of upland rice from treatments involving N were not significantly different from each other but were significantly different from PKS and the control, which had similar yields (Table 5). Apparently, N remained the only limiting nutrient after five continuous croppings at each site. Different treatments on rice had no significant effect on the yields of cowpea or sorghum.

Table 5. Yields of 8 treatments tested at 2 adjacent sites in the first international trial on soil fertility management of acid upland rice soils (pH 5-7), INSFFER, 1985-87.

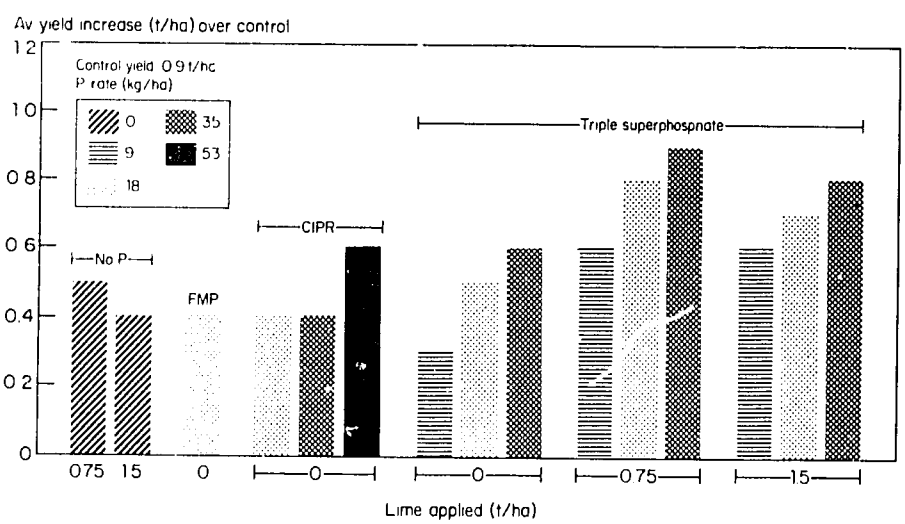
Treatment	Grain yield (t/ha)			
	Rice[a]		Cowpea[b] (Site 1)	Sorghum[b] (Site 2)
	Site 1	Site 2		
NPKS	2.7	2.7	0.9	2.8
PKS	2.4	2.2	0.9	2.7
NKS	2.7	2.7	0.9	2.6
NPS	2.9	2.7	1.0	2.9
NPK	2.9	2.9	0.9	3.1
Control	2.3	2.5	0.8	3.0
Control	2.1	1.9	0.9	3.0
Control	2.2	2.1	1.0	2.8

[a]Av of 3 WS trials. [b]Av of 2 DS trials.

ECONOMIC EVALUATION OF DEEP-PLACEMENT FERTILIZER APPLICATORS

Agricultural Economics, Agronomy, and Training and Technology Transfer Departments

The overall objective of the study was to compare the economic performance of deep-placement



10. Average yield response of rice in 5 trials conducted at 3 acid upland sites - 1 in Caliraya and 2 in Claveria, Philippines - during 1984-86 DS. First international trial on soil fertility management of acid upland soils (pH<5) for rice, INSFFER, 1984-86. FMP = fused magnesium phosphate, CIPR = Christmas Island phosphate rock.

applicators and hand placement of USG with the recommended RS method using PU. Machines evaluated were the spring auger, oscillating plunger and plunger-auger for PU, and the press wedge for USG. Information was drawn from several field trials conducted in the Philippines by IRRI scientists, and from the multicountry fertilizer trials conducted by INSFFER.

Comparative costs of deep-placement applicators. The fixed and variable costs of each of the fertilizer applicators are presented in Table 6. The lowest fixed cost was $30/yr. This means if rice sells at $194.40/t, the minimum incremental yield from the machine for the total cropped area must be 154 kg to cover all fixed costs.

The machines require about 20 h to fertilize 1 ha, compared with 8 h using hand broadcasting. The additional labor, valued at $2.52, needs to be offset by an additional yield of 13 kg/ha.

Shifting from manual to mechanical fertilizer application would require an incremental yield sufficient to cover the fixed cost and the additional variable cost. At $194.40/t of rice, the minimum yield advantage from using the machine should be 167 kg/ha for a monocropped 1-ha farm, 180 kg/ha for a double-cropped 1-ha farm, or 206 kg/ha for a double-cropped 2-ha farm.

Net benefits from manual and mechanical fertilizer application. Economic comparison of manual and mechanical fertilizer application was done using the net benefit criterion.

$$\text{Net benefits} = \text{Total revenue} - \text{total cost}$$
$$= Y_N \cdot P_Y \cdot S \cdot 1/(1+r)^n - P_i \cdot X_i \cdot (1+r)^n - K/A$$

where: Y_N = yield at N level (t/ha),
P_Y = price of rice ($/t),
S = farmer's share of the harvest (%),
r = interest rate per month (%),
n = length of the growing period (mo),
P_i = price of inputs (N and labor),
X_i = quantity of inputs (kg for N, h for labor),
K = fixed cost for machine use ($/yr), and
A = cropped area (ha).

The four sets of field trials generated different yield results for each location, season, and fertilizer level. Yields from fields using machine applicators varied greatly, and on the average were nearly equal to those of the recommended RS. Fields that used machine applicators did not consistently give statistically high yields. Only hand placement of USG consistently produced superior yields. The high degree of variability obtained from many locations, several seasons, and a range of equipment can be attributed to both site-related factors and the vintage of the machine designs.

The net benefits from the use of machine applicators and hand placement of USG as compared with those from RS were either very low or negative. There was an equal number of cases where machine application produced lower as well as higher net benefits than RS at equal fertilizer

Table 6. Comparative costs of 4 fertilizer placement machines (1985).

Item	Press wedge	Spring auger	Oscillating plunger	Plunger-auger
Machine cost ($)	66.67	83.33	66.67	66.67
Machine life (yr)	4	4	4	4
Repair and maintenance cost (% of machine cost)	5	5	5	5
Salvage value (%)	0	0	0	0
Interest (%)	30	30	30	30
Capacity (h/ha)	20	18	20	20
Wage ($/h)	0.21	0.21	0.21	0.21
Fixed cost ($/yr):				
Depreciation	16.67	20.83	16.67	16.67
Repairs and maintenance	3.33	4.17	3.33	3.33
Interest	10.00	12.50	10.00	10.00
Total	30.00	37.50	30.00	30.00
Variable cost ($/ha)	4.20	3.78	4.20	4.20

Table 7. Summary of net benefits relative to researchers' split for INSFFER, TTTD, and IRRI-MRRTC trials, 1983-85.

Field trials	Season	Researchers' split (no.)	Hand placement (no.)	Net benefits for machine placement relative to researchers' split		Total cases (no.)
				Higher (no.)	Lower (no.)	
INSFFER	Wet	12	12	11	13	48
	Dry	18	18	21	15	72
	Total	30	30	32	28	120
TTTD	Wet	21	15	17	25	78
	Dry	21	21	13	4	59
	Total	42	36	30	29	137
IRRI-MRRTC	Wet	6	6	4	2	31
	Dry	7	6	–	3	27
	Total	13	12	4	5	58

levels (Table 7). The evidence suggests that machine applicators are not yet practical alternatives to recommended manual methods such as KS. There is clearly a need to improve machine designs for better performance, increased efficiency, and reduced costs to enhance farmer acceptability. Finally, at current prices for fertilizer, rice, and unskilled farm labor, it is doubtful that deep-placement fertilizer applicators will be widely adopted in small-scale lowland rice production.

SITE VISIT TOUR, WORKSHOP, AND PLANNING MEETING

Agronomy Department

An INSFFER site visit tour, workshop, and planning meeting organized jointly by the Indian Council for Agricultural Research and IRRI was held in India, 21 Sep-1 Oct 1987. Twenty-one participants representing 11 national programs, the International Fertilizer Development Center, the Commonwealth Scientific and Industrial Research Organization, and IRRI joined the tour. The group visited and observed soil fertility and fertilizer trials at five experiment stations in India. They also visited several villages to observe rice farmers' fertilization and cultural practices.

A 4-d planning meeting and workshop with the theme "Nutrient Management in Rice-Based Cropping Systems," attended by 59 participants, was held in New Delhi after the tour. Twenty-seven papers dealing with rice-based cropping systems and nutrient management practices in different regions in India as well as in some of the INSFFER participating countries were presented. During the meeting, the participants ratified the change in the network's name from INSFFER to International Network on Soil Fertility and Sustainable Rice Farming (INSURF). The network will focus on the issues of sustainability, equity, and environmental quality. The Advisory Committee for the INSURF program was reconstituted.

International collaboration

Asian Rice Farming Systems Network

Rice Farming Systems Program and Agricultural Economics, Training and Technology Transfer, and Statistics Departments

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In the Asian Rice Farming Systems Network (ARFSN), scientists from IRRI and 16 nations work together to increase food production by identifying more productive rice-based farming systems. Countries collaborating are Bangladesh, Bhutan, Burma, China including Taiwan, India, Indonesia, Korea, Madagascar, Malaysia, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Vietnam. The Network's methodology for on-farm research is used in all countries.

The many disciplines and commodities involved in rice farming require coordinated research at the national, regional, and local levels. Countries vary in their level of research coordination. A national coordinator or leader represents the country in the Asian Rice Farming Systems Working Group, which meets annually.

In addition to doing farming systems research, national programs are extending the technologies identified. Bangladesh, Sri Lanka, Indonesia, the Philippines, Nepal, and Thailand are implementing the preproduction phase of the methodology (multilocation testing and pilot production program) at various locations. Large-scale cropping systems production programs are implemented in Nepal, Indonesia, and the Philippines. The Philippines is now reorienting commodity production programs such as "Masagana 99" (rice) and "Maisagana" (maize) to a farming systems perspective to increase farm production and income.

Collaborative research in the Network includes cropping systems research, rice - wheat cropping systems, women in rice farming, crop - livestock farming systems, varietal testing of upland crops, long-term cropping patterns, fertilizer studies, and farm implements for intensive systems.

In late 1987, rice - fish farming systems research began in collaboration with the Central Luzon State University, the International Center for Living Aquatic Resources Management, and five national programs.

CROPPING SYSTEMS RESEARCH

Rice Farming Systems Program

Most national programs research cropping systems based not only on rice but on other commodities such as coconut, maize, livestock, agroforestry, and aquaculture. In 1987, ARFSN had more than 250 rice-based research sites in Asia. Most sites focus on cropping pattern testing in rainfed lowland, irrigated lowland, partially irrigated lowland, and upland rice. Some look at tidal wetland (Indonesia) and deepwater rice (Bangladesh). All conduct component technology trials such as varietal evaluation and fertilizer, pest, and other agronomic management studies.

In 1987, we discontinued the monitoring of cropping systems sites (43 sites in 1986). We began, instead, to collaborate with a few key sites in cropping pattern testing and in-depth research on cropping systems to develop technologies, methodologies, and techniques that all national programs can use. Philippine sites are Guimba in Nueva Ecija, and Claveria in Misamis Oriental Guimba represents the partially irrigated and favorable rainfed lowland, and Claveria represents the acid upland. A third site, Ubon, Thailand, represents unfavorable rainfed lowland (drought- and flood-prone). (See the section on Design and Evaluation of Cropping Patterns.) We plan to begin work at deepwater and irrigated sites in Bangladesh and India.

CROP - LIVESTOCK SYSTEMS RESEARCH

Rice Farming Systems Program

The crop - livestock research project consists of on-station research at the University of the Philippines at Los Baños (UPLB) Institute of Animal Science (IAS) and IRRI and on-farm research at ARFSN sites. IAS research focuses on determining nutritional values of local fodder, dual-purpose crops, and other forages. IRRI studies focus on evaluating forage crops in the lowland and upland and on food-forage production systems. On-farm research is conducted in the Philippines in collaboration with the Department of Agriculture and IAS, in Thailand with the Farming Systems Research Institute (FSRI), in Indonesia with the Central Research Institute for Food Crops (CRIFC), in Nepal with the Department of Agriculture, and in China with the Chinese Academy of Agricultural Sciences.

Philippines. The key Philippine sites are Santa Barbara, Pangasinan (lowland), and Trece Martires, Cavite (upland). Crop - livestock systems tested in 1987 were cowpea + rootcrop + swine

and crop + cattle. Farmer cooperators who planted cowpea + cassava in Trece Martires and cowpea + sweet potato in Santa Barbara will raise swine for fattening, starting in April 1988. This combination reduces dependence on commercially mixed feeds and solves a potential marketing problem for cowpea. The farm-mixed swine ration will be 30% cowpea, 50% sweet potato, and 20% premix.

With crop + cattle, farmers in Trece Martires intercropped maize with siratro, planted after upland rice. Cassava will be used to supplement these feeds for fattening cattle.

Economic analysis in Malanay, the partially irrigated site, showed that income came from on-farm (60%), nonfarm (30%), and off-farm (10%) sources. Farm income came mainly from sales of rice and livestock, especially swine. Carpentry, business, and remittances from relatives were important sources of nonfarm income, and hired labor was the main source of off-farm income. In Carosucan, the rainfed site, income came from on-farm (42%), nonfarm (56%), and off-farm (2%) sources. Total gross income per farm was higher in Malanay than in Carosucan (US$563 vs US$385). Rice, vegetables, and swine provided most farm income.

On-farm trials in Carosucan evaluated IR65, a glutinous rice variety, and farmers' varieties Imelda, Waray, Milagrosa, and BPIRi-3. Varieties had similar fresh grain weight; however, Milagrosa had lower dry grain yield. The most appropriate N level for IR65 was 30 kg N/ha.

In Trece Martires, varietal trials for upland rice in banana fields using local variety Dalikit, UPLRi-5, UPLRi-7, IRAT115, and CNA5164 showed grain yields from 2.1 to 2.9 t/ha, not significantly different. Dalikit had the highest fodder (straw) yield. The average yield in an upland rice + maize + siratro pattern was 4.3 t/ha vs 3.5 t/ha for farmers' pattern.

Indonesia. The project site — Batumarta, South Sumatra — is in a dryland transmigration area. Scientists from CRIFC and the Central Research Institute for Animal Science collaborate. Four farming systems (A, B, C, D) were tested to increase income and use land more effectively: system A = farmers' system without livestock, B = farmers' system with livestock, C = improved livestock system (1 cattle, 3 goats, 11 chickens), and D = introduced system (2 cattle, 5 goats, 23 chickens). Cropping patterns have produced enough calories and protein for families. In 1985-86, farming systems C and D (improved farming system + livestock) produced higher income than systems A and B. The livestock contribution was 10-16% of total income; income from rubber was 15-42%. Income during the 1986-87 wet season (WS) showed an increasing contribution of livestock (22-30%) and rubber (34-60%). Net income between farming systems C and D, and A and B differed greatly ($995 and $929 vs $340 and $265, respectively). Rice yields were low (0.5-0.7 t/ha).

Systems with improved livestock management (C and D) achieved better productivity for cattle, goat, and chicken than did the traditional (B). Efficiencies were highest with chicken, next with cattle, and least with goat.

In component technology research, 6 rices and 11 cowpeas were evaluated. Local rice variety Sirendah Bulat had the least blast infection and the highest grain yield, with 1.9 t/ha. TVx 133-16D2 and IT82 D-89 cowpea varieties showed the highest yield with 1.12 and 1.11 t/ha, respectively.

Two legumes as cover crops (*Pueraria javanica* and *Centrosema pubescens*) were evaluated using eight establishment methods. *Pueraria* grew much faster than *Centrosema*, especially with row cultivation.

Farmers grew Setaria grass for animal feed. Production was highest from cutting at 30-d intervals.

Nine male and one female Etawah goats, introduced during the year, performed well. Average weight gain before weaning was 66.1 g/d and after weaning 62.6 g/d.

Thailand. The Thailand site — Ban Bon Paw Daeng, Ban Phai, Khon Kaen — is in a drought-prone rainfed lowland area. The collaborators are scientists of the Departments of Agriculture and Livestock Development, the Office of Agricultural Economics, and Khon Kaen University.

Cropping pattern trials in late 1986 confirmed previous findings that the best first crops before rice for upland and upper ricefields were peanut and green maize, with crop biomasses of 10.6 and 9.2 t/ha, respectively. Cowpea followed peanut and maize. Net returns amounted to $707 for peanut - cowpea, $368 for maize - cowpea, and $675 for peanut - dry seeded rice. Under upland

field conditions, the most promising combination was peanut - dry seeded rice, with a net return of $676.

The animal growth rate fluctuated, decreasing after October-November because of inadequate forage. With fresh rice straw after harvest, weights increased in January-February, but declined in March-April as farmers planted field crops like cassava and kenaf. Trials on farmers' management of backyard forage grasses (such as Hamil-Guinea grass) produced low yields (10.5 t/ha, 5 cuttings) due to drought.

In dairy cattle management trials (5 cattle), average daily milk production was 7.7 kg in dry season (DS) (October-March) and 9.7 kg in WS. Although dairy production was promising, prolonged drought and marketing problems hampered its adoption. The project will introduce beef cattle to use crop residues.

China. Key sites in China are Chang Ping in Beijing, and Fumazhuang in Jiangsu. The Beijing site represents irrigated lowland, with rice, wheat, maize, soybean, and vegetables combined with dairy cattle. Silage crops are being introduced into dry seeded rice to increase feed for cattle. A triticale - dry seeded rice pattern will provide triticale for ensiling. Dairying involves both individual and collective farming.

In Fumazhuang, an irrigated lowland with wheat, soybean, rapeseed, and maize, swine is the livestock component. Maize and soybean replace rice in higher fields. Scientists have crossed native swine (Taihu) with Yorkshire, and have improved swine rations for on-farm trials. The results indicate that the improved breed plus the improved ration produced better gains than did native swine and rations.

Other countries. In Nepal, the Farming Systems Research Division of the Department of Agriculture is researching crop - livestock patterns in Naldung, a hillside area in the northeast corner of Kabhre district of the Central Development Region. Crops in the rice-based pattern are wheat, maize, oats, and finger millet. Fodder trees are being introduced, and the livestock component is dairy buffalo.

In Bangladesh, livestock scientists have joined the Farming Systems Research teams from various government agencies and institutions such as the Bangladesh Agricultural Research Institute and Bangladesh Rice Research Institute, through the Bangladesh Agricultural Research Council Site surveys show inadequate livestock feed and a severe shortage of draft power. Feeding urea-treated rice straw to milking cows increased milk yield about 7%.

Burma is comparing farmers' crop - livestock practices with those in an experimental crop - livestock program at the research station.

Vietnam will examine swine raising as a component of rice-based farming systems, and growing maize after rice to feed swine.

Component technology research at UPLB. Researchers at UPLB are evaluating siratro and pigeonpea hays as cattle feed, using 8 bulls, 1.5-2 yr old and weighing 165-250 kg. Ration treatments are 1) rice straw + sorghum stover + siratro (*Macroptilium atropurpureum*) hay + concentrate; and 2) rice straw + sorghum stover + pigeonpea (*Cajanus cajan*) hay + concentrate. The roughage-to-concentrate ratio is 70-30 (dry matter [DM] basis), with 15% of DM from siratro or pigeonpea. Pigeonpea hay had higher crude protein than siratro hay (23 vs 17%) as well as higher N-free extract (40 vs 34%). Sorghum stover and rice straw had identical crude protein (5.2%). Average daily gain for the 27-d feeding period was higher for pigeonpea than for siratro hay (0.46 vs 0.43 kg), but the differences were not statistically significant. Pigeonpea hay was more palatable, especially when some twigs were separated before feeding. Siratro hay, although its vines were tough for cattle, was acceptable after a few days adjustment.

In another study testing the digestibility of rice straw, lye solution was extracted from rice straw and rice hull ash previously soaked in tap water (1 kg water) overnight. The in vitro digestibility of lye-treated straw was higher than that of untreated straw. Trials using cattle and carabao indicated that lye-treated straw improved apparent digestibility for DM, crude fiber, gross energy, and consequently total digestible nutrients, compared with untreated straw. The DM intake of treated straw was higher than that of untreated straw (2.6 vs 2.2% of body weight). Rice hulls could provide ash for lye solutions.

Forage crops and forage - food intercropping. Component technology research in forage crops is searching for better forage species and cultural

practices to increase animal feeds, especially during DS in rice-based farming systems.

Forage monocropping. Seven grasses and four legumes were established on lowland ricefield bunds to study sole crop forage production. Two years of testing showed that these species gave satisfactory forage yield: *Pennisetum purpureum* (Napier grass), *Andropogon gayanus*, *Setaria splendida*, *S. anceps* cv Nandi, *Desmanthus virgatus*, and *Clitoria ternatea*. Other species yielded less than 20 t DM/ha per yr.

Four forage grasses—*Brachiaria mutica*, *Echinochloa picta*, *S. splendida*, and *S. anceps* cv Nandi—grown by rootstocks after rice harvest yielded 5.66, 5.64, 4.70, and 3.20 t DM/ha, respectively, from 4 harvests at 45-d intervals. All except Nandi setaria suppressed weeds somewhat. In the succeeding IR66 rice crop, some *B. mutica* and *E. picta* grew in the ricefield and along the bunds, but neither persisted. Rice grain yield in the plot previously grown to *S. splendida* (4.1 t/ha) was significantly higher than that in the previous fallow plot (3.5 t/ha).

Some rice varieties have potential for being a dual-purpose (forage and grain) crop. Five IR varieties (IR34, IR40, IR42, IR48, and IR62) with 120- to 130-d duration were tested in a farmer's field (Santa Barbara, Pangasinan) during February-June 1987 and on the IRRI farm in August-December 1987. Rice plants in half of each plot were cut for forage, 30 cm from the base, at 45-50 d after transplanting. Fresh herbage yields ranged from 3.3 to 5.7 t/ha in the farmer's field and from 2.1 to 3.5 t/ha at IRRI. IR34 yielded significantly better at both sites. Grain yields were low in the farmer's field due to drought at panicle initiation. IR34, IR48, and IR62 yields were reduced by cutting, but IR40 and IR42 yields were not.

Forage-food intercropping. Forage crops intercropped with food crops produce human food and animal feed at the same time. The food crop can be cereals or legumes, while forages are normally legumes. Legumes provide high protein value and improve soil fertility.

Four combinations of two grain legumes—mungbean and cowpea—and two forage legumes—siratro and sunn hemp—were intercropped 1:1 in rows in rainfed fields after rice harvest on the IRRI farm. Legumes yielded as well when intercropped as in monocrop. Cowpea + sunn hemp was best, with 1.30 t/ha grain yield, 1.41 t DM/ha crop residue, and 9.78 t DM/ha forage yield.

On-farm trials of grain legume + siratro intercroppings were conducted on rainfed lowland in Pangasinan, La Union, and Ilocos Sur during DS (November-May). The grain legume main crops were mungbean (IPB M79-13-29), cowpea (TVx 2724-01F), and pigeonpea (QPL 72). Grain yields were not significantly reduced by the siratro intercrop. Cowpea + siratro was best, giving a cowpea grain yield and a total fodder DM yield (main crop + intercrop) of, respectively, 0.72 and 2.48 t/ha in Pangasinan, 1.03 and 5.35 t/ha in La Union, and 0.75 and 1.75 t/ha in Ilocos Sur.

Combinations of grain + forage legumes were tested on upland during WS at IRRI. Four grain legumes (mungbean, soybean, cowpea, and peanut) and four forage legumes (*Centrosema macrocarpum*, *Clitoria ternatea*, *Cajanus cajan*, and *Desmanthus virgatus*) were intercropped in various combinations at 25-cm alternate-row spacing. Main crop yields in intercroppings were usually reduced compared to those of monocroppings. Pigeonpea, taller than the legume food crops, suppressed their growth and grain yield but gave the highest forage yield among the intercropped species. Clitoria and siratro were the better intercropped species because they grow slowly at early growth stages and compete less with main crops. Peanut was best in total productivity.

One cereal - forage legume intercropping experiment was conducted during DS on upland at IRRI. Maize (IPB Var 1) and sorghum (UPL SG 5) at 3 population densities (26,666, 35,555, and 53,333 plants/ha for maize and 66,666, 133,333, and 266,666 plants/ha for sorghum) were intercropped with siratro, stylo (CIAT 136), cowpea (TVx 2724-01F), *Lablab purpureus* (cv Highworth), and *Desmanthus virgatus* to determine grain and fodder production.

Maize grain and fodder yields at 53,333 plants/ha density were a little higher than those at lower densities. However, maize yields of combinations within each density did not differ. Similarly, the fodder yield of each forage legume was not significantly affected by maize density. Average fodder DM yields of legumes across main crop densities were 2.85 t/ha for siratro, 1.46 t/ha for lablab, 1.19 t/ha for stylo, 0.98 t/ha for cowpea,

and 0.67 t/ha for *D. virgatus*. Grain yields of sorghum in different combinations and densities were usually not statistically different, ranging from 1.99 to 2.85 t/ha. Forage yields of intercropped legumes ranged from 0.20 to 1.95 t DM/ha, with siratro yielding best in every treatment.

WOMEN IN RICE FARMING SYSTEMS

Agricultural Economics Department

Collaborative research on women in rice farming has begun in Thailand, Indonesia, Philippines, Nepal, Bangladesh, and India. Research is reported here from the Philippines, Thailand, and Indonesia.

Glutinous rice in Santa Barbara, Pangasinan, Philippines. At the rainfed lowland site in Santa Barbara, Pangasinan, in 1986, researchers from IRRI, IAS, and the Department of Agriculture collaborated to discern women's needs in rural rice-growing areas and to identify and extend technologies to improve their productive capacity and welfare. Researchers described the gender-specific tasks and decision-making responsibilities of men and women, clarified constraints in women's participation in farming systems, and identified and introduced technology to enhance women's productive capacity.

Processing glutinous rice is a major traditional activity and a significant source of income for women in Carosucan, a rainfed village. The major constraints identified by men and women involved in the production and processing of glutinous rice were the low yields (3 t/ha) and long duration (130-140 d) of the varieties commonly grown, and the drudgery and inefficiency of processing.

To surmount these constraints, we introduced IR65, a high-yielding and early-maturing glutinous rice, at the site. We are also testing several machines developed at IRRI.

Changes in area and production. Table 1 shows the growth in area and production of glutinous rice from 1986 to 1987, due mainly to IR65's short growth duration, better tillering capacity, higher yields, better quality filled grains, and good eating qualities. Yields were lower in 1987 because of late planting, lack of water during transplanting, and drought before ripening.

Table 1. Changes in area and production of glutinous rice, Carosucan, Santa Barbara, Pangasinan, 1986-87.

Item	1986		1987	
	IR65	Local	IR65	Local
Total area planted (ha)	.91	1.48	2.85	.98
Farmers (no.)	22	22	36	15
Av yield (t/ha)	5.4	4.7	4.1	3.4

Source of data: 1986 and 1987 survey, IRRI, Agricultural Economics Department.

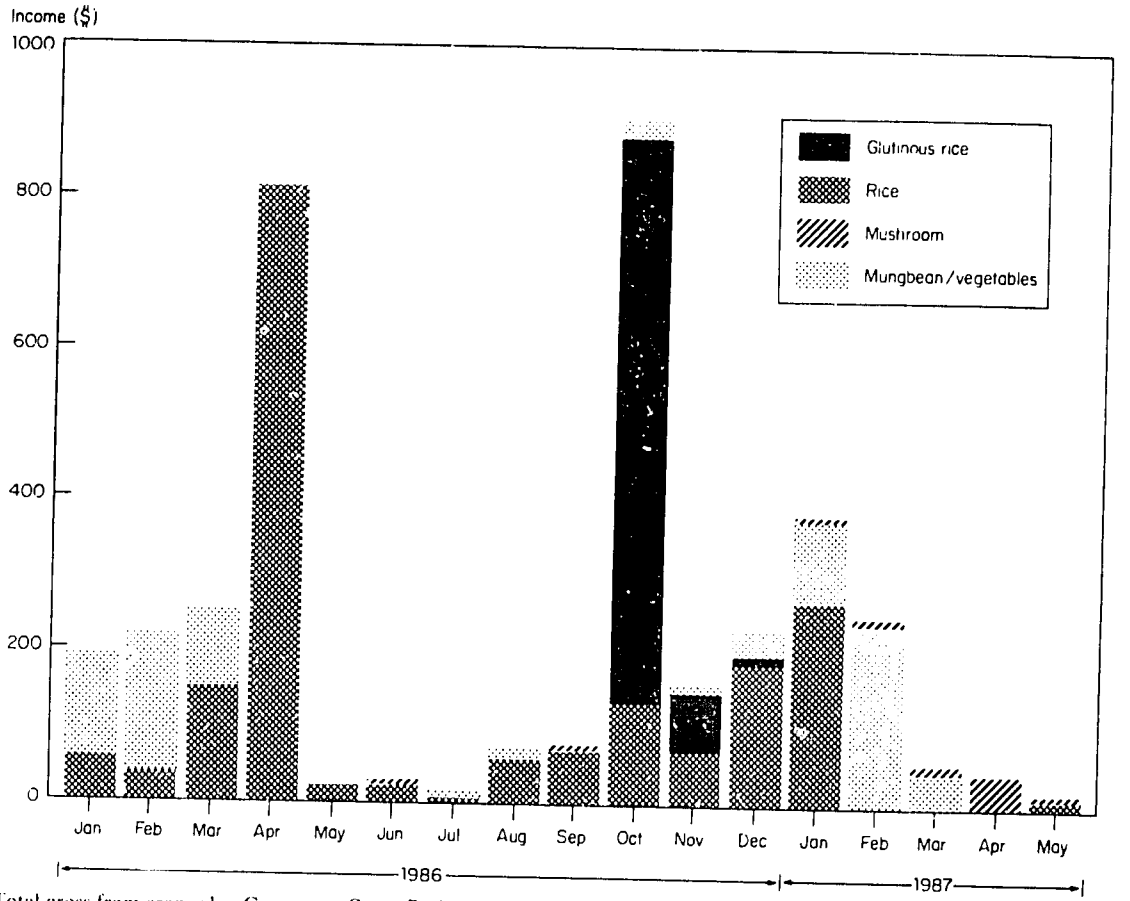
Cash income. Despite the limited areas planted to glutinous rice compared with those for ordinary rice, women from farming and landless households generate considerable income by selling glutinous rice in rough or processed form. In 1986, we monitored monthly cash sales from rice, glutinous rice, and other crops of 15 farming and 4 landless households. Figure 1 shows that crop sales were highest in October, when total cash sales for the 15 farming households were $907 ($60.50/household), 82% from rough glutinous rice. The total nonfarm gross income of 4 landless families in October was $1,275. ($320/household), 97% obtained by women processing and selling glutinous rice.

In 1986 and 1987, we interviewed women merchants whose major source of income is from buying, processing, and selling glutinous rice. The number of women who processed IR65 increased from 20 in 1986 to 46 in 1987, and the volume processed increased from 3.0 to 11.4 t, or 37% of all glutinous rice. Due to its scarcity in Carosucan, women merchants bought glutinous rice from neighboring villages.

Tests of the cooking and eating qualities of IR65 and local glutinous varieties indicated high acceptability of IR65.

Processing. In Pangasinan, consumers prefer glutinous rice processed into black grains. Glutinous rice is grown and harvested 2 wk earlier than other rice to take advantage of the high price on 1 Nov (All Saints Day), a Filipino holiday. Processed glutinous rice, called *dudumen* in the dialect, is used in rice delicacies.

IRRI engineers observed processing—boiling, drying, dehulling, mixing with charcoal, and winnowing. The rough rice is boiled and continuously stirred with a long ladle until dry (about



1. Total gross from crop sales, Carosucan, Santa Barbara, Pangasinan, 1986-87. (n=15)

40-50 min for a 12 kg batch). The rice is cooled, then hand pounded six times with a boat-shaped wooden mortar and pestle, and winnowed. Usually, women cook, and men, women, and children pound in rhythmic motion. Processing several batches of rice a day is strenuous and time-consuming.

Based on interviews and observations, the IRRI Agricultural Engineering Department designed and fabricated a pan cooker with a wooden rotary stirrer, a portable wooden dehuller, and a portable rotary parboiler-dryer for site testing and demonstration. The equipment is being tested and modified to attain efficiency and suitability.

Amphoe Phrao, Chiang Mai, Thailand. A study on the roles of men and women was conducted in October 1986 at the Phrao farming systems site by Chiang Mai University and the FSRI. Amphoe Phrao has lowlands and uplands. In the lowlands, dominant cropping patterns are monocropped glutinous rice and glutinous rice - soybean. In the uplands, they are monocropped peanut, peanut - mungbean, monocropped soybean, soybean - soybean, monocropped maize, monocropped upland rice, and peanut - peanut.

Women participate in crop production and poultry husbandry. Females contributed these percentages of labor: glutinous rice (28%), upland rice (39%), peanut (45%), maize (50%), mungbean (41%), and soybean (40%). They participated less than males in land preparation, and more in planting, culture, and harvesting. Culture includes fertilizer and chemical application, weeding, and irrigation. Peanut and soybean planting in the early rainy season required more female participation than did other activities. Planting soybean after rice in the lowlands provided employment and income for women harvesters.

To determine gender differences in agricultural knowledge, we interviewed 80 men and 80 women.

Men scored 36.3 and women 24.5. Women received agricultural information largely from informal sources like spouses and neighbors. The national agricultural extension systems rely upon men as contact agents and reach out to women only in home economics matters. Consequently, women had less knowledge and contact than men concerning buying inputs, selling produce, and borrowing money from banks and cooperatives. Women participated less in formal meetings. Women were usually custodians of household income and managed daily expenditures. Decisions about large expenditures are made by husband and wife, or by the husband only.

Women worked on other farms as hired labor, but received lower wages than men: $1.24/d compared with $1.44/d. Construction work offered $2.64/d for men, while tobacco industries offered $1.68/d for women, who commonly worked from December to April. Women earned as much as $32.76/yr as agricultural laborers, and $459.48/yr in tobacco grading. Working in tobacco industries required them to spend at least 3-4 mo away from home.

Ban Phai, Khon Kaen, Thailand. A study on women's participation in farming systems was conducted in the Crop - Livestock Development Project in Don Por Deang, Ban Phai, Khon Kaen, Thailand, by the FSRI and Khon Kaen University. The site is unfavorable rainfed lowland. In October 1986, data collected by the Office of Agricultural Economics were analyzed to examine women's role in farming as a basis for introducing technologies suited to their needs.

Because of three continuous droughts in northeast Thailand, farmers had shifted from rice farming to cultivation of cassava, and some farmers had migrated to the Middle East. Women were left to manage livestock and upland crops like cassava. Mulberry trees survived the drought, so silkworm raising became a very important income source, particularly during DS. Due to inadequate mulberry care, women had to buy mulberry leaves in other villages. To overcome these problems, the FSRI provided technical advice to women on pruning practices and larger spacing for mulberry trees. Women in 10 families experimented with mulberry - peanut intercropping.

Batumarta, Indonesia. The study was conducted in the transmigration area at the Crop - Livestock Farming Systems Research site by CRIFC to examine the economic role of women in agricultural production. The site is acid upland.

The time allocation study used observations and interviews to measure women's agricultural activities. Women contributed 32.5% of agricultural labor. Men usually prepared land and transported farm products; women transplanted, weeded, applied animal manure, and harvested crops. Women also worked as hired labor on other farms, particularly in harvesting upland rice with a sickle knife called *ani-ani*. Aside from rice, other upland crops grown in the site were soybean, mungbean, cowpea, and cassava. Women obtained additional income by processing soybean into *tempe*, mungbean into sprouts, and cassava into chips, using time-consuming traditional methods. Seed selection and management were women's responsibility. They tended chickens and goats, but lacked technical information on doing so.

Traditionally, rural women are obedient to their husbands. In Batumarta, most men consulted their wives in making farming decisions. Wives helped decide on the purchase of inputs and on the sale of produce.

PROSPERITY THROUGH RICE

Training and Technology Transfer Department

IRRI and UPLB collaborate to demonstrate and provide training in rice farming systems methods that maximize rice yield and in methods of postharvest crop management and scientific use of the entire plant biomass. At the IRRI farm, demonstrations show production, rice farming systems, and postharvest/rice biomass utilization. Pilot village projects operate in Bangladesh, Indonesia, Sri Lanka, and Thailand.

Sri Lanka. In Sri Lanka, 113 farm cooperators demonstrate 6 cost-reducing technologies in 3 villages (Kalwara, Kegalle; Giritale, Polonnaruwa; and Galnewa, Kalawewa). The technologies are incorporating decomposed rice straw, improved dapog method, urea-enriched straw, integrated pest control, mechanical transplanter, and cono weeder.

Indonesia. In Serang, Bumijaya represents irrigated lowland and Kendayaban represents rainfed lowland. At the irrigated site, the patterns

rice - rice, rice - rice - soybean, and rice - rice + fish are demonstrated on 12 farms. Cucumber - rice - rice ratoon, rice - mungbean, and direct seeded rice - rice are demonstrated at the rainfed lowland site. Traditional and hut methods of rice straw mushroom culture were introduced.

Thailand. At the Nakhon Sawan site (rainfed lowland), a small village rice mill shed with two small rooms was constructed by hired workers. A rice mill with a capacity of 1 t/d was installed. The eight farmer cooperators selected for the project will bring their rice to the mill for milling. The rice bran and husks will be used for animal feed and cooking fuel. The project in Phrao (partially irrigated lowland) will demonstrate rice - fish farming and ridge vegetable growing. Mushroom culture, composting, and a mungbean - rice cropping pattern have already been demonstrated.

Bangladesh. Dual-purpose legumes were introduced into the rice - rice cropping pattern. For livestock, fast-growing grasses were introduced. Rice - rice - legume is demonstrated using improved seeds, fertilizer management, crop protection, and biomass production. Low-cost postharvest equipment and biomass use technologies are also demonstrated.

RICE - WHEAT CROPPING SYSTEMS

Rice Farming Systems Program and Agricultural Economics Department

Pattern testing (*Rice Farming Systems Program and Agricultural Economics*). Rice - wheat cropping is important in subtropical Asian countries, especially India, Bangladesh, Nepal, and Pakistan. In central and northern China, rice - rice - wheat and rice - wheat are dominant patterns. China, Bangladesh, Pakistan, Burma, Nepal, and India collaborate in rice - wheat testing. Rice - wheat is compared with patterns involving legumes (mungbean, soybean, chickpea, and others) and cereals (maize, sorghum, and others). Experimental cropping patterns are always compared with farmers' dominant cropping patterns.

In Bangladesh, rice - rice - wheat is recommended for multilocation testing under irrigated conditions. Yield was 85-89% better than farmers' production, and income was 110-135% better. Rice - wheat - jute is recommended for multilocation testing under rainfed conditions. Income was 60% better than with the farmers' cropping pattern.

In Khandburi, Nepal, the improved practice of planting rice - wheat - mungbean increased income 93% over the farmers' practice of rice - wheat. Under rainfed conditions, rice - wheat - sesbania increased net returns by 432% over the farmers' practice of 1 rice crop. In Bahuari, Parsa, the net return of improved rice - chickpea + mustard was 230% better than the farmers' practice of rice - wheat.

In India, rice - wheat is tested in Jorhat, Assam; Ludhiana, Punjab; Modipuram, Uttar Pradesh; Burdaman, West Bengal; and Pharbani, Maharashtra. In Jorhat, of 7 cropping patterns tested, rice - mustard was the most promising. Rasi rice yielded better than Mahsuri rice. Aside from higher yield, a second crop of mustard or other crop can be introduced. Winter crops failed except wheat and mustard. In Ludhiana, rice - wheat - cowpea (fodder) gave $1,541 net returns and rice - potato + wheat - mungbean gave $1,855. In Modipuram, of 8 cropping patterns, rice - wheat - maize + cowpea gave $1,138 net returns and rice - potato + wheat - cowpea + maize gave $1,045. In Burdaman, rice - wheat - mungbean and rice - wheat - jute were tested with four other cropping patterns. Wheat yields were 2.26 and 2.46 t/ha, respectively. Rice yield varied from 3.5 to 4.1 t/ha. In Pharbani, rice - wheat - mungbean was tested with five other upland cropping patterns. Rice yield was 2.4 t/ha, wheat 2.09 t/ha, and mungbean 0.62 t/ha.

Farmer management in Upper Sind, Pakistan (*Agricultural Economics*). The Rice Research Institute (RRI), Dokri, in collaboration with the IRRI Agricultural Economics Department, studied farmer management of rice - wheat systems in the Upper Sind of Pakistan. A full report is available from the RRI.

Researchers interviewed 100 farmers (5 in each of 20 villages) who grew irrigated rice and wheat in 1986-87. Interviews followed rice harvest and wheat harvest.

Cropped areas. Nearly two-thirds (65%) of farmers interviewed were tenants; the remainder were owners (31%) and owner-tenants (4%).

The mean cultivated area of rice was 2.3 ha with range of 0.5 ha to 4.9 ha. Ninety-four percent of

respondents claimed they grew the same area to wheat as to rice in rabi season for a 1.94 multiple crop piag index.

Field duration. Half the rice crop was transplanted by the first week of June, and 80% was harvested between the first week of October and the first week of November. Typical field duration was 115 d.

Earliest wheat sowing was in the first week of November, a month after rice was harvested; half the wheat was seeded by the beginning of December. Wheat harvest began at the end of March and was completed by the beginning of May. More than 80% of the wheat was harvested over 3-4 wk in April. The field duration of the wheat was about 130 d.

Turnaround time (between rice harvest and wheat planting) averaged a little more than 4 wk, ranging from 3 to 8 wk.

The most important factor explaining turnaround time was how long it took a field to drain and dry before wheat cultivation after rice. Farmers with a late rice harvest had a significantly shorter turnaround. As farm size increased, so did turnaround time, but power was not a major constraint.

Crop management. All respondents planted IRRI-6; none reported growing recently released varieties DR82, DR83, or Latify. Mean seedling age at transplanting was 5.5 wk, older than the 3-4 wk considered optimal. A wide range of wheat varieties was reported: dominant was Pak 70 (45%) followed by C591 (19%); neither is recommended. No farmer used certified seed; most farmers retained their own seed or used seed supplied by landlords.

Midseason drainage was not practiced with rice. All farmers irrigated their wheat after sowing: 28% irrigated wheat twice, 60% 3 times, and 12% 4 times.

One-third reported applying Zn to rice. Zn deficiency was widespread in the study area. All respondents applied diammonium phosphate (18-46-0), and 98% applied urea (46-0-0) to rice (Table 2). Urea was applied to wheat by 99% of farmers, diammonium phosphate by 40%. Farmers who applied diammonium phosphate had smaller farms and light soils. However, use of diammonium phosphate on wheat was independent of the rate of P applied to the previous rice crop, and independent of tenure.

Table 2. Fertilizer management practices, Upper Sind, Pakistan, 1986-87.

Item	Unit	Rice	Wheat
Fertilizer users			
Diammonium phosphate	%	100	40
Urea	%	98	99
Level of use			
Diammonium phosphate	kg/ha	121	102
Urea	kg/ha	131	122
Level of N and P			
Urea and diammonium phosphate users	no.	100	40
N	kg N/ha	80	72
P	kg P/ha	56	47
Urea users only	no.	–	60
N	kg N/ha	–	55

Hand weeding was the only method of weed control, averaging two weedings for rice and one for wheat. The most troublesome weeds in rice were *Cyperaceae* sp. and *Echinochloa colona*, and in wheat, *Melilotus alba* and *Chenopodium album*.

Farmers did not believe that diseases limit rice yields, although rust (*Puccinia* sp.) and loose smut (*Ustilago tritici*) were regarded as problems in wheat. Important insects in rice were whitebacked planthopper (*Sogatella furcifera*) and pink stem borer (*Sesamia inferens*). Nineteen percent of respondents sprayed rice where hopperburn was evident. Pink stem borer was also regarded as a problem in wheat, but farmers did not spray to control it.

Yields. All rice and wheat was hand harvested. Rice was threshed by bullock treading (98%), while all wheat was machine-threshed.

The mean yield of rough rice was 4.3 t/ha, ranging from 2.9 to 7.4 t/ha. Mean wheat yield was 2.0 t/ha, ranging from 1.1 to 4.0 t/ha. There was no significant difference in rice or wheat yields between owners and tenants.

Rice and wheat yields are a function of many factors interacting in a complex way. Also, rice and wheat yields on the same plot are likely to be related, suggesting that factors affecting them may be specified by a jointly estimated two-equation system. The simultaneously estimated production functions are reported in Table 3. The model

Table 3. Three-stage least squares estimates of rice and wheat yields in rice - wheat cropping patterns, Upper Sind, Pakistan, 1986-87.

Exogenous variable	Regression coefficient	Standard error	Significance level (%)
Weighted R^2 for system	0.62		
Equation I: Rice yield			
Plowings (no.)	-89.20	137.15	52
Transplanting date	-104.66	43.84	2
N	9.04	4.30	4
P	-7.05	5.67	22
Insecticide user	-47.74	175.06	79
Village dummy	1665.63	248.82	1
Soil dummy	427.28	142.05	1
Intercept	4597.01	753.92	1
$\bar{R}^2$	0.59		
F-ratio	19.05		1
Equation II: Wheat yield			
Rice yield	0.11	0.06	8
Sowing date	1 39	20.45	95
N	12.52	4.20	1
Total P	4.93	1.88	1
Irrigation	68.48	52.80	20
Variety dummy	-167.32	101.51	10
Village dummy	792.33	91.92	1
Intercept	16.43	843.68	98
$\bar{R}^2$	0.64		
F-ratio	23.26		1

explains over 60% of the variability in rice and wheat yields and is significant at the 1% level.

Rice yields were significantly related to

- transplanting date (each week's delay in transplanting resulted in a yield loss of about 100 kg/ha or 2.5 maunds/ha per wk),
- N rate (each kg of N increased rice yields by about 9 kg/ha), and
- soil type (light, well-drained soils, on average, yielded 0.4 t/ha higher than low-lying, waterlogged soils).

Yields were significantly higher in Bakraini and Hyder Brohi villages than in the other surveyed villages. However, rice yields were not significantly related to the number of times a field was plowed, or to the rate of P applied.

Wheat yields were significantly related to

- rice yield (when other factors were accounted for, fields with higher rice yields also tended to have higher wheat yields),
- N rate (each kg of N increased wheat yield by about 13 kg/ha),
- total P (each kilogram of P increased wheat yield by >2 kg/ha),
- number of irrigations (an added irrigation increased wheat yield by 68 kg/ha), and
- farmer's choice of variety—with local varieties yielding slightly higher (by 0.1 t/ha) than modern varieties.

However, when other factors were considered, wheat yields were not significantly related to sowing date.

All farmers reported that they sold some of their rice and wheat harvest, averaging 37% of the rice and 29% of wheat crop (Table 4). Farmers on average sold more rice (3.5 t) than wheat (1.3 t). Quantities of rice and wheat sold were positively correlated with cropped area ($r = 0.6$**); a 1% increase in cropped area resulted in an approximately 1% increase in grain sales (calculated elasticities of 0.95 for rice and 1.12 for wheat, both significant at the 1% probability level). Less than 50% of the respondents sold more than 80% of the rice and 75% of the wheat marketed.

More than 70% of sales was to the private sector (Table 4). Few farmers sold to government buying agencies and the Pakistan Food Department. Farmers selling rice to the government sold significantly larger quantities (4.3 t) than those selling to the private sector (3.3 t). However, wheat quantities sold did not differ between government agencies and private buyers.

Farmers' effective yields. Farmers did not benefit from the gross crop yield because they normally

Table 4. Rice and wheat sales, Upper Sind, Pakistan, 1986-87.[a]

Item	Rice	Wheat
Crop sales		
Harvest sold (%)	37	29
Quantity sold (t)	3.5	1.3
Main buyer (%)		
Government agencies	17	16
Wholesaler/retailer	2	41
Miller/input supplier	54	42
Unreported	0	1
Quantity sold (t)		
Government	4.3	1.4
Millers and retailers	3.3	1.2
Difference	1.0+	0.2ns

[a] + = significant at 10% probability level; ns = not significant, based on Student t-tests.

paid for the cost of harvest and postharvest operations in kind (Table 5). A farmer with a typical rice yield of 4.3 t/ha paid out more than 20% of the crop for harvest-related activities, and a farmer with a typical wheat yield of 2.0 t/ha paid out 25% of the crop for these services. In 1986-87, farmers received an effective price of about $76/t for rice and $106/t for MV wheat, after marketing charges were deducted. Thus, the net value of the crop standing in the field was about $60/t ($6/quintal) for rice, and $79/t for wheat; about three-quarters of their market prices. The net value of grain plus straw in the field was about $65/t for rice and about $96/t for wheat.

Costs and returns. There were no significant differences in resource use or yields between owners and tenants. Thus, cost and return differences between owners and tenants were a consequence of differences in sharing of input costs and crop output, as opposed to differences in resource use, or yields, per se.

Variable costs per hectare were considerably higher for rice production than for wheat production (Table 6). However, rice cost less to produce than wheat per kilogram of grain produced.

Gross returns for rice were higher than for wheat due to higher grain yield (although rice was lower priced); but the value of wheat straw was higher than that of rice straw (Table 6).

The gross margin (the difference between gross returns and costs that vary) of wheat was higher than that of rice, both for owners ($78/ha vs $46/ha) and for tenants, who registered a loss (-$22/ha vs -$69/ha). This difference in gross margin between crops was largely the result of the higher production cost of rice compared to that of wheat. A tenant could not cover production costs for rice or wheat if all inputs were valued at their market prices. This particularly applied to labor costs. A tenant's imputed wage in growing these crops was considerably less than the market wage of hired labor.

Returns to rice - wheat patterns. On average, owners earned a pattern net return of more than $125/ha, while tenants lost about $100/ha when all inputs were valued at market prices. Owner net returns varied from -$50/ha to nearly $300/ha, and tenant returns ranged from -$200/ha to $100/ha. While the probability of loss for owners was small, only 20% of tenants covered production costs, when all inputs were valued at market costs.

IMPACT OF CROPPING SYSTEMS RESEARCH

Rice Farming Systems Program and Agricultural Economics Department

During the 17th meeting of the Asian Rice Farming Systems Working Group, members agreed to study the impact of cropping systems research in four countries: Bangladesh, Indonesia, Sri Lanka, and the Philippines.

The sites in Bangladesh are in Sitakunda, Chittagong, and Kamalganj, Moulvibazar. Both sites used traditional varieties until a new cropping systems technology developed in Bogra was introduced. The new technology consists of a rice - rice pattern using improved varieties, use of basal

Table 5. Calculation of farmer-effective yield of rice and wheat and net crop prices, Upper Sind, Pakistan, 1986-87.

Item	In-kind payments					
	Local units			Metric units		
	Unit[a]	Rice	Wheat	Unit	Rice	Wheat
Harvesting	maunds/acre	3.0	2.0	kg/ha	297	198
Bundling, stacking	maunds/acre	1.5	1.5	kg/ha	148	148
Threshing	kg/maund	5.0	4.0	kg/q	12.5	10.0
Net quantity sold	kg/maund	31.4	29.7	kg/q	78.5	74.3
Net values:						
Grain in field	$/maund	2.4	3.1	$/q	6.0	7.9
Crop in field	$/maund	2.6	3.8	$/q	6.5	9.6

[a]1 maund = 37.32 kg.

Table 6. Production costs and returns ($/ha) for rice and wheat crops for tenant and owner operators, Upper Sind, Pakistan, 1986-87.

Item	Rice		Wheat	
	Tenant (n = 65)	Owner (n = 35)	Tenant (n = 65)	Owner (n = 35)
Operating costs				
Input cost				
Land preparation[a]	31	31	30	30
Seed	3	6	7	13
Fertilizer				
Seedbed	7	9		
Main crop	21	41	13	25
Insecticide	7	7		
Irrigation	0	5	0	3
Labor				
Seedbed	15	15		
Transplanting/seeding	23	23	1	1
Weeding	24	24	15	15
Irrigation	18	18	7	7
Others	3	3	2	2
Opportunity cost on cash[b]	12	15	7	10
Harvest/postharvest	44	44	42	42
Threshing	41	41	23	23
Total variable costs				
Variable cost/ha	249	282	147	171
Variable cost/kg	0	0	0	0
Returns				
Gross yield	170	309	107	214
Straw	10	19	18	35
Farmer returns	180	328	125	249
Gross margins	−69	46	−22	78

[a]Includes plowing, planking, and covering of seeds. [b]14% interest on cash cost.

fertilizer, and an improved planting method. Almost 70% of the farmers now use improved varieties.

At the Indonesian site in Biruen, Banda Aceh, one crop of lowland rice is traditional under rainfed conditions. The cropping systems program introduced several food crops and found soybean the most successful. Soybean after rice increased from 19,000 ha in 1980 to almost 85,000 ha in 1985.

In Sri Lanka, two sites selected have been conducting cropping systems research since 1976. Katupotha represents the intermediate zone, where 60% of the riceland cannot be grown to a second rice crop. The research team showed that grain legume (cowpea and mungbean) can be grown. In Uva Paranagama, new technology uses an early-maturing rice followed by two more rice crops.

In the Philippines in Oton and Tigbauan, Iloilo, cropping systems research was started in 1975. Ajuy, Iloilo, is in the production program. New technology involves a high-yielding, early-maturing rice variety and use of direct seeding under dry conditions. This enables farmers to grow two rice crops and possibly a third, upland crop.

In these studies, production and consumption activities and income are recorded daily. Final analysis will be done in 1988.

VARIETAL TESTING OF UPLAND CROPS BEFORE AND AFTER RICE

Rice Farming Systems Program

Entries came from breeding programs of the Institute of Plant Breeding (IPB) (Philippines), Field Crops Research Institute (Thailand), CRIFC (Indonesia), and other national programs. Cowpea entries came from the IRRI screening in collabora-

tion with the International Institute of Tropical Agriculture (IITA). Sorghum and pigeonpea came from IRRI screening in collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Maize entries came from the International Maize and Wheat Improvement Center (CIMMYT) and other national programs.

In 1987 we increased seed of 34 mungbean, 21 cowpea, 8 soybean, 14 peanut, 6 maize, and 10 sorghum varieties from IPB, ICRISAT, CIMMYT, IITA, and national programs (Indonesia, Bangladesh, and Thailand).

A total of 67 trials before lowland rice (18 mungbean, 17 cowpea, 11 soybean, 8 peanut, 1 pigeonpea, 10 maize, and 2 sorghum) and 83 trials after lowland rice (16 mungbean, 15 cowpea, 14 sorghum, 14 peanut, 4 pigeonpea, 12 maize, 7 sorghum, and 1 sesame) were distributed to Thailand, Indonesia, Burma, China, Nepal, Sri Lanka, Vietnam, Philippines, and Madagascar. National programs are encouraged to include these varieties in their preliminary trials, using two local checks.

Varietal trials after and before rice were conducted in the 1986-87 cropping pattern year in the Philippines, Indonesia, Thailand, Vietnam, Sri Lanka, and Burma. The most promising varieties in grain and fodder yields are presented in Tables 7 and 8.

Indonesia released a peanut variety for national distribution, identified through this collaboration. The variety is Kelinci, formerly Acc-12 from the IPB.

LONG-TERM CROPPING PATTERN STUDIES

Rice Farming Systems Program

Sustainability of agriculture is a major concern because continuous cropping reduces soil fertility. Collaboration on long-term cropping pattern and fertilizer studies was continued in 1987. The institutions involved were BRRI (Bangladesh), CAAS (China), CRIFC (Indonesia), Agricultural Research Institute (Burma), Integrated Cropping Systems Project (India), and IRRI. Collaborators designed their own experiments.

Many experiments in Indonesia were discontinued. Work in Bangladesh was in Comilla

Table 7. Upland crop varieties better than the local check or highest yielding across locations in the Asian Rice Farming Systems Network when planted before wetland rice, 1986-87.

Mungbean		Cowpea		Bush sitao		Peanut (shelled bean)	Maize (grain)
Grain	Fodder	Grain	Fodder	Fresh pod	Fodder		
				Philippines			
IPB M79-13-29	IPB M79-13-29	IT 82D-889	IT 82E-16	BS1 (6-14R X AS)	BS1 (6-14R X AS)	–	SHC HY 502
Pag-asa 2	VC 1973A	IT 82D-755	TVX 1850-01E	BS3 (6-14R X AS)	BS3 (6-14R X AS)		Los Baños Lagkitan
IPB M79-9-82	IPB M79-13-29	IT 82D-892	IT 82D-787				Glut Pop'n 41C
				Thailand			
VC 1973A	IPB M79-13-29	83F-780-3	TVX 1650-01E	BS1 (6-14R X AS)	BS3 (6-14R X AS)	–	TFE 112
Uthong 1	Pag-asa 3	TVX 133-1602	83F-780-3	BS3 (6-14R X AS)	BS1 (6-14R X AS)		Suhan 2
IPB M79-13-60	VC 1973A	IT 81D-891	IT 82E-9	BS7 (LBBS #1 X CO)4-1-2	BS7 (LBBS #1 X CO)4-1-2		XC 11
				Sri Lanka			
–	–	IT 82E-9	–	–	–	IPB PN 48-93-EG PN-18	
		CES 41-6				Hong Mei Chao No. 45	
		IT 82D-787					

Table 8. Upland crop varieties that performed better than the local check or highest yielding across locations in the Asian Rice Farming Systems Network when planted after wetland rice, 1986-87.

Crop	Varieties					
	Philippines	Thailand	Burma	Vietnam	Sri Lanka	Indonesia
Mungbean						
Grain	IPB M79-13-60 IPB M79-13-29 MG 50-10A (G)	IPB M79-13-29 VC 2762-B-45-2B Uthong 1	–	VC 2755A	–	IPB M79-13-29 IPB M79-13-60
Fodder	VC 2762-B-45-2B IPB M79-13-29 Uthong 1	IPB M79-13-29 VC 2762-B-45-2B Uthong 1	–	–	–	–
Cowpea						
Grain	IT 82D-892 TVX 1850-01E CES 41-6	TVX 2724-01F CES 41-6 IT 81D-1137	TVX 2724-01F TVX 2902-02D TVX 3236-01G	IT 81D-1137 CES 41-6 IT 82E-16	Vita 4 CES 41-6 IT 81D-1137	–
Fodder	83F-780-3 TVX 1850-01E IT 82D-889	TVX 2724-01F TVX 289-46 IT 82E-18	TVX 289-4G TVX 2724-01F IT 81D-1137	–	–	–
Bush sitao - fresh pod	–	Kalasin BS3 (6-14R X AS) IT 81D-1228-12	–	–	LBBS #1 IT 81D-1228-12 IT 81D-1228-15	–
Soybean - grain	ACC 99 ACC 200 Jupiter R	AGS 129 EG SY-173 SJ-4	Improved Pelican Willis AGS 229	–		IPB SY 138-28 IPB SY 159-2
Peanut						
Shelled bean	EG PN-18 Tainan UPL PN-4	–	IPB PN48-90 IPB PN2-25 Tainan	Hong Mei Chao IPB PN42-14 IPB PN2-25	IPB PN46-12 IPB PN42-14 EG PN-18	IPB PN42-14 EG PN-18
Fodder	EG PN-11 UPL PN-4 Tainan	–	Tainan Hong Mei Chao JL 24	–	–	–
Pigeonpea						
Grain	QPL 72 (TCFC) J-1 ICPL-6	–	–	–	–	–
Fodder	ICPL-6 QPL 72 ICPL 142	–	–	–	–	–
Chickpea - grain	ICCL 11141 BDN 95 ICCL 83149	–	–	–	–	–

Continued on next page

Table 8 continued

Crop	Varieties					
	Philippines	Thailand	Burma	Vietnam	Sri Lanka	Indonesia
Maize						
Grain	Early DMR Comp 1 Muneng 8331 Suwan 2 XC #1	Early Comp 1 Muneng 8331 XC #1	Ranjuna Showa 1 Comayagua 8130 Muneng 8331	–	–	–
Fodder	IPB Var 2 IPB Var 1 Early Thai Comp Comayagua 8130	Early Thai Comp IPB Var 2 Comayagua 8130	Early Thai Comp IPB Var 2 Showa 1	–	–	–
Sorghum						
Grain	CS 116 CS 137 CS 110	ICSV 159 ICSV 163 ICSV 126	ICSV 163 ICSV 126 CSH 5	–	–	–
Fodder	ICSV 126 ICSV 137 ICSV 138	DK 4 Uthong 1 ICSV 138	ICSV 138 DK 64 CSH 5	–	–	–
Sweet potato						
Root	G 50-1A G 454-23A V 10-95	–	–	–	–	–
Fodder	G 449-6 G 525R-2 G 207-37A	–	–	–	–	–

(irrigated) and Joydebpur (irrigated and rainfed lowland). Trials in China (including Taiwan) were irrigated. Long-term trials in China use cropping pattern rotations. In India, collaboration on integrated production trials in irrigated areas has been conducted at 14 institutions since 1985. All trials are conducted for at least 3 yr.

DATA MANAGEMENT FOR ON-FARM TRIALS

Statistics Department

An important component of the farming systems approach is on-farm trials designed to compare the most promising (experiment station-developed) technology with farmers' practices. A major bottleneck is the lack of efficient data management systems that can cope with the large volume of diverse data generated in the farming systems research program, and the different types of data analysis and data utilization by the four client groups—researchers, extension technicians, farmers, and policymakers.

To help ARFSN cooperators manage their data:

- We designed, and started developing, a generalized data management system that can cope with the data requirements of each cooperator and also achieve data compatibility.
- We tested the applicability and feasibility of the system in the Philippines' nationwide network of on-farm trials.
- We initiated a study to strengthen the methodology for on-farm trials, design test technology, and identify extrapolations/recommendations for the test technology.

International collaboration

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COUNTRY REPORTS

Various departments

Below are brief reviews of IRRI's collaborative work with various national programs. They are followed by examples of the range of research activities undertaken. Other collaborative projects are discussed earlier in this Annual report under the various program areas.

Bangladesh. IRRI and the Bangladesh Rice Research Institute (BRRI) have cooperated in carrying out rice research since BRRI was founded in 1973. This relationship was formalized with the establishment of the BRRI-IRRI Rice Research and Training Project in December 1975 with funds from the Ford Foundation and the Australian and Canadian Governments, which continued until December 1987. Throughout the project, the overall goal was to increase rice production to make Bangladesh self-sufficient in rice.

In addition to general collaborative research activities in varietal improvement and rice crop management, more specific joint efforts have been initiated through special projects dealing with rice quality, botanical pest control, differential impact studies, and Prosperity Through Rice. Additional funds have been made available through these projects to facilitate research and encourage collaboration among IRRI, BRRI, and other national agricultural research institutes. Also, intensive collaborative efforts have been made to study the impact of rice farming systems research at two sites where BRRI has carried out either site research or multilocation testing with the Bangladesh Department of Agricultural Extension. This study is monitoring all income and expenditures and all crop production activities, and will provide insight into the benefits families have received from adopting new technologies. An important side benefit of the project has been to increase the computer proficiency of BRRI scientists.

Bhutan. Collaboration with the Bhutan Department of Agriculture continued during 1987. Most progress continues to be made in the medium altitude zone (1,000-1,500 m), where IR36 and more recently IR64 have shown excellent adaptation. During 1987, 250 farmers in Punakha and 50 in Wangdiphodrang grew IR36. In 10 farmers' field evaluations with farmyard manure as the only fertilizer, IR64 yielded 4.7 t grain/ha and 9.5 t fresh straw/ha, whereas local varieties yielded 4.0 t grain/ha and 10.7 t fresh straw/ha. With the addition of 35 kg N/ha as topdressing, IR64 produced 5.7 t grain/ha and 11.9 t fresh straw/ha. On the basis of these and previous years' data, IR64 is to be released and recommended to farmers in 1988.

In the lower altitudes of southern Bhutan, IRRI focused on strengthening the research capability of the Bhur Farm, a substation of the Center for Agricultural Research and Development (CARD). Two lines continue to stand out: BR153-2B-10-1-3 and BG379-20. The former will be released for southern Bhutan in 1988.

A major constraint to production in southern Bhutan is poor soil fertility. Trials in 1987 confirmed the potential of *Sesbania bispinosa* as a green manure (GM) crop.

Varietal improvement in the high altitude areas (>2,000 m) is based mainly on our shuttle breeding program, which is designed to improve traditional cold-tolerant varieties. At IRRI, popular local varieties from Bhutan were hybridized with selected IR varieties with high yielding ability and pest and disease resistance. Forty-eight F_2 populations were sent to Bhutan for evaluation. Of these, 14 were evaluated by CARD at Wangdiphodrang, representing medium altitudes, and 34 at the Simthoka Farm near Thimphu, representing high altitudes.

Of the populations planted at medium altitudes, five were mass-selected and brought to IRRI for rapid generation advance. Desirable genotypes in populations planted at high altitudes were extremely few. They were selected for a pedigree nursery.

IRRI produced more breeding material for the program, taking into consideration the japonica nature of Bhutanese varieties. We also considered the possibility of reducing the growth duration of medium-altitude varieties with the long-term objective of obtaining two rice crops, or at least a main crop and a ratoon, during a season.

Preliminary experiments at CARD and in farmers' fields during 1987 indicated that 2 rice crops are feasible under selected conditions; combined yields of more than 11 t/ha were

obtained. In 1 trial, the ratoon crop of No. 11 yielded more than 4 t/ha, and the main crop yielded 6.6 t/ha.

The IRRI Agricultural Economics Department, in cooperation with the Bhutan Department of Agriculture, conducted a baseline survey in the Punakha and Wangdiphodrang valleys in late 1987 to identify constraints to and opportunities for intensifying rice-based farming systems. Analysis of the survey data, to be completed by the end of March 1988, will serve as a basis for measuring the impact of Bhutan's medium-altitude rice development program.

The IRRI-Bhutan Rice Farming Systems Project held its work plan meeting for 1988 in December 1987. Aside from a continuation of research and training activities, the main emphasis in 1988 will be on the development of a Bhutan National Rice Program.

Burma. The Burma-IRRI Farming Systems (BIFS) Project, begun in 1986, is the offshoot of a memorandum of agreement on technical and scientific cooperation between the Agriculture Corporation (Burma) and IRRI signed on 7 Jan 1977. BIFS is funded by the Canadian International Development Agency (CIDA). Its components are research on rice farming systems, varietal improvement of crops in rice farming systems, small-scale mechanization implements supportive of rice farming in Burma, and manpower development of Burmese scientists.

As of December 1987, BIFS had arranged, through IRRI, for nondegree training for 8 Burmese scientists and for degree training for 8 MS and 2 Ph D scholars, and it had sent 9 Burmese scientists on study tours and to scientific conferences. In close collaboration with more than 60 Burmese scientists and extension workers, BIFS maintained its research activities on rice farming systems and crop varietal improvement at 24 sites and research stations spread throughout Burma. BIFS has so far identified 9 new cropping patterns as promising at 6 sites; demonstrated *Sesbania rostrata* as an effective GM for rice production; popularized the use of single-work animals in place of double-work animals in rice farming; initiated research in crop - livestock patterns; released 10 new rice selections for 5 environments (Table 1); arranged for 9 International Network on Soil Fertility and Sustainable Rice Farming (INSURF) trials and 27 International Rice Testing Program (IRTP) nurseries for 1987; arranged the translation into Burmese of 3 IRRI technical books; and concentrated on improving animal-drawn farm implements like the plow, knife harrows, crop seeders, and manual water pumps. IRRI has a farming systems agronomist in residence in Burma to oversee all BIFS and IRRI global research in the country.

Table 1. Rice varieties recommended for release in Burma in 1987. Agricultural Research Institute (ARI), Rice Division, 1988.

Variety (local name)	Original name	Origin
	Lowland environment	
Theedat 4	IR18269 Yn 5	IRRI
Theedat 5	Yan 63-1	ARI crosses (Burma)
Sin-Ekari 5	IR18048 Yn 5	IRRI
Sin-Ekari 6	IR18048 Yn 15	IRRI
	Upland environment	
Yar 8	Yn 92-17	ARI crosses (Burma)
Taung baw saba war	(Burmese traditional)	Burma
	Deepwater environment	
Yenet 8	BKNFR76023	Thailand (through IRTP)
	Cold environment	
Ahyekhan-1	IR8845-10-3-3	IRRI (through IRTP)
Ahyekhan-2	IR13155-60-3-1-2-1	IRRI (through IRTP)
	Saline environment	
Sagankhan-4	X-73-12-7	ARI crosses (Burma)

Caribbean. The Caribbean Rice Improvement Network (CRIN) is sponsored by the Centro Internacional de Agricultura Tropical (CIAT) with funding from CIDA and the United Nations Development Programme through IRTP. The Secretary of State of Agriculture of the Dominican Republic (SEA) provides support facilities, and the Interamerican Institute for Cooperation on Agriculture in Santo Domingo provides communication facilities. CRIN started its activities in February 1986. Its headquarters is in the Centro de Investigaciones Arroceras (CEDIA) in Juma, Bonao, 90 km north of Santo Domingo. Partici-

pating countries are Belize, Cuba, Dominican Republic, Guyana, Haiti, Jamaica, Trinidad and Tobago, and Surinam. The primary purpose of the network is to strengthen the capabilities of national rice programs to increase production and productivity.

From nurseries introduced from IRRI and CIAT and evaluated in the second half of 1986, 188 promising entries were selected and included in an observational nursery for 5 ecosystems (3 irrigated, 1 rainfed, and 1 upland) and distributed to cooperators in March 1987. In 1987, 214 entries were selected from various nurseries received from CIAT and IRRI, including 911 entries for distribution in March 1988. Among the 214 entries, 46 combine good plant type, tolerance for Fe toxicity, resistance to fungus diseases and hoja blanca virus, good grain quality, and high yield potential. Another 47 entries combine earliness (110-120 d) with good plant type, resistance to fungus diseases, and good yield potential. Also, 21 entries have good grain quality and salinity tolerance.

A package was developed to transfer available technology to rice farmers of the Dominican Republic. This project is aimed at controlling red rice, reducing production costs, and increasing productivity.

The project includes 1) N fertilization with 100 kg/ha in a split application (1/3 basal, 1/3 at tillering, and 1/3 at panicle initiation; 2) weed control with oxyfluorfen at 0.74 kg ai/ha; 3) insect control with 15 kg carbofuran/ha, basally applied; and 4) seed density (80 kg/ha for direct pregerminated seed, 30 kg/ha for mechanized transplanting at 4-5 seedlings/hill, and 50 kg/ha for mechanized transplanting at 5-8 seedlings/hill. The results of this project conducted at CEDIA indicated that, with direct seeding, costs were reduced 22% and net returns were increased 213% as compared with manual transplanting using farmers' technology. Also, costs were reduced 19%, and net returns were increased 192% with mechanical transplanting and 140% with 30-50 kg seed/ha. This project is now being demonstrated in farmers' fields of the Instituto Agrario Dominicano in Bonao. It is being conducted by the Rice Extension Department of SEA with technical assistance from CRIN.

Three scientists from CEDIA underwent special training at CIAT in basic seed production, seed certification, and laboratory analysis under the guidance of the CIAT Seed Unit. Four scientists from Cuba trained at CIAT in the evaluation and selection of breeding material, biotechnology, plant pathology, and entomology. The National Rice Training Center of SEA and CRIN organized an intensive course (1 Jun-31 Jul 1987) on Research and Production of Irrigated Rice. Fifteen agronomists from the Dominican Republic, 2 from Haiti, and 2 from Cuba participated. The bulletin *Rice in the Caribbean* was created for publication in Spanish and English. The first issue was edited and distributed to cooperators in June 1987. Also, the proceedings of the first meeting of the Technical Advisory Committee, held 1-2 Dec 1986, were edited and distributed to cooperators in November 1987.

The lack of small machines for land preparation, seeding, harvesting, and threshing is one of the main constraints on small rice farmers in Belize, Dominican Republic, Haiti, Jamaica, and Trinidad and Tobago. To solve this problem, CRIN introduced from IRRI the TH-8 axial-flow thresher, 1-m reaper, and PT-3 power tiller. These machines were tested at CEDIA and in farmers' fields with excellent results. Rice farmers invited to observe the performance of the equipment indicated that these machines are what they need for their small holdings. All information and IRRI designs were provided to SEA, and an agreement was made for local production.

China. Although IRRI has collaborative work with other Chinese institutions like the Chinese Academy of Agricultural Mechanization Sciences, Academia Sinica, 10 Provincial Academies of Agricultural Sciences, and 5 Agricultural Universities, the Chinese Academy of Agricultural Sciences (CAAS) remains the focal point of IRRI-China collaboration. CAAS is the forum for discussion and coordination of IRRI's activities in China. It is the lead agency in holding annual planning meetings. And all requests from Chinese research institutions for training grants or scholarships for graduate work pass through CAAS for discussion and decision.

Collaborative research and training activities in 1987 covered the following areas:

- network activities: IRTP, INSURF, Asian Rice Farming Systems Network;
- rice germplasm resources;

- hybrid rice;
- shuttle breeding;
- tissue culture;
- azolla research;
- evaluation of P sources;
- bacterial blight (BB) and sheath blight;
- pest control; and
- training allocation for graduate degrees.

Scientists from many countries have participated in China-IRRI-sponsored training courses in tissue culture, azolla, hybrid rice, and other fields. One of the objectives of IRRI's training program is to help strengthen local research capacities. IRRI accelerated its training program in China to achieve a critical mass of research scientists who will be involved in serious research collaboration with IRRI. IRRI scientists conducted short-term training at the China National Rice Research Institute (CNRRI) for trainees of CNRRI and other rice research institutions. The lectures in English were sent in advance so that they could be translated into Chinese and given to the trainees for study. Thus, the lecture period became a discussion period where ideas were exchanged.

East Africa. Although rice is not an important food in most East African countries except Tanzania, there is considerable scope in the region for bringing more area under hydromorphic rice with varying depths of water table. Although many of the countries have been participating in rice varietal testing programs since 1965, the launching of IRTP during the mid-1970s systematized and improved the testing procedures considerably. IRTP is IRRI's single largest activity in Africa and is implemented in collaboration with the International Institute of Tropical Agriculture (IITA), the West Africa Rice Development Association (WARDA), and national rice research programs. Based on the recommendations of two IRRI missions on rice research and production in East and West Africa in September 1985, the Regional Coordination Unit for East, Central, and Southern Africa became operational in July 1986 with headquarters in Morogoro, Tanzania.

Of 244 IRTP-Africa nurseries distributed through IITA during 1987, 80 were allocated to the East, Central, and Southern African countries in the network (see the IRTP section). Additionally, a few IRTP-global nurseries were received directly from IRRI for testing at specific stress locations for cold and salinity and in hydromorphic rice areas. Twelve field experiments including five IRTP-Africa nurseries, four IRTP-global nurseries, and three agronomic trials were conducted at the Sokoine University of Agriculture campus, Morogoro, during the year, making use of the University's facilities and staff support. Some of the entries that had higher grain yields and better phenotypic acceptability in Morogoro are listed in Table 2.

Table 2. Promising entries in IRTP nurseries, Morogoro, Tanzania, 1987.

International Rainfed Rice Shallow Water Observational Nursery (IRRSWON), 1987

Early duration: CN834-1-2-1-9, IR46, IR31429-14-2-3, IR134237-20-4E-P1, IR29341-41-1, IR31429-20-2-3

Medium duration: CN213-1002, IRAT116, ITA231, Xiang Chou V, 915-A (Affa Kilombero/IR1746), IR25924-92-1-3, RP1017-169-1-14, IR33356-14-3-1-3, 177-D

International Rainfed Rice Shallow Water Yield Nursery (IRRSWYN), 1987

IR26933-16-2-3, IR31429-14-2-3, IR46, CR213-1002, IR8073-65-6-1-1E-P2, Ratna

International Rice Cold Tolerance Nursery (IRCTN), 1987

HPU741, JKAU(K)450-126-10, JKAU(K)450-172-6, B4070C-kn-79-31, B4138C-kn-3-0-0-5, B4448D-14-S, B4574B-SR-4, IR13105-60-30-3-1-2-1, IR13155-60-3-1-1, IR22006-P12-12-2-2, Earlirose, H408-85, AkyuJaka, IRI 346

International Upland Rice Observational Nursery (IURON), 1987

BG367-7, RP1140-28-3-3-6, RR51-1, CR222-MN 10, BG621-1, RP1670-1418, Kalakari (Acc 53347), IRAT112

African Irrigated Rice Advanced Variety Trial (AIRAVT), 1985

Karin, ITA212, ITA234, IR54, EIT6279, BG90-2, IR46

African Irrigated Rice Yield Trial (AIRYT), 1985 selected varieties

IR46, IR58, BG90-2, FARO-15, ITA306

African Irrigated Rice Observational Nursery (AIRON), 1986

Farox 228-3-1-1, Katrin, IR13603-30-10-P1, IR21015-80-3-3-3-1-2, TKM9, ITA123, Farox 233-1-1-3, HPU741, IR18348-36-3-3, Si-Pi 692033, TOXS94-28-201-1-2, ITA222

Second African Upland Rice Observational Nursery (AURON), 1986

BAU-180-61-18, IRAT109, IRAT110, IRAT142, IR12979-24-1, P1332-3-8M-1-1-B, TOX1757-1-7-201-1, 11292 and 11365, BG29928-T6-73-4-2-3, IRAT133, IRAT141, IRAT144, ITA150, Seratus malaum, Wabri 7, Wabis 581

African Upland Rice Advanced Variety Trial (AURAVT), 1985

ITA235, ISA6, OS6, ITA305

East Africa continued to send candidates for specialized nondegree and degree training programs at IRRI. Table 3 shows the number of participants who have trained at IRRI since 1972. A 2-wk Rice Production Training Program for 24 officer trainees from research stations, training institutes, and extension and irrigation projects in Tanzania was conducted at the Institute of Continuing Education, Sokoine University, in September 1987.

Egypt. The Egyptian Ministry of Agriculture and the United States Agency for International Development (USAID) agreed that the Rice Research and Training Center (RRTC) in Sakha should collaborate more closely with IRRI, and thus entered into a contract with IRRI under the umbrella of the National Agricultural Research Project. The contract was signed 23 Feb 1987, to become functional 1 yr later. It covers two main components: research and training. Seven objectives are listed in the contract:

- Under the direction of the Ministry of Agriculture Project Director, emphasize the research management component of the project to make all the new facilities at the RRTC completely functional, and coordinate the various research and extension programs and activities.
- Give extra support to the research already under way to develop high-yielding, disease-resistant varieties with improved agronomic and quality characteristics.
- Develop land-intensive and water use-efficient rice farming systems for the New Valley.
- Develop techniques for growing deepwater rice (DWR) on the shores of Lake Nasser.
- Establish appropriate relationships with the Egyptian seed industry and facilitate use of the new seed multiplication facilities at the RRTC.
- Help transfer new technology packages to farmers.
- Undertake the training requirements needed to help meet the above objectives.

The research component encompasses operational support for the new facilities in Sakha and off-station research trials in Giza, Gommeza, Zarzora, and Sirw, as well as on-farm research trials and demonstrations. Three full-time international scientists will help facilitate research management, plant breeding, and plant pathology research. The latter two experts are to concentrate on the breeding program aimed at finding genetic resistance to blast (Bl). Short-term visits by international scientists, mostly from IRRI, are aimed at encouraging research collaboration within each of the eight research programs at the RRTC.

Table 3. East African participants (no.) in IRRI nondegree training programs, 1962-87.

Country	Trainees (no.)		
	1962-May 1985	June 1985-1987	Total
Tanzania	7	13	20
Kenya	5	1	6
Sudan	6	1	7
Ethiopia	3	3	6
Somalia	1	0	1
Uganda	1	0	1
Malawi	0	1	1
Botswana	0	1	1
Zambia	0	1	1
Total	23	21	44

The major research effort concentrates on developing high-yielding, nonlodging, relatively early varieties with improved levels of resistance to Bl and stem borers. A separate program concentrates on salinity tolerance. In both cases, screening for improved grain quality is a top priority. Another program covers screening for a high-quality, slender-grain variety suitable for capturing more export trade while at the same time maintaining lodging and Bl resistance. Short-duration varieties are being selected and tried in different rice-based cropping systems for comparison with medium-duration rice planted in the major rice season. Two short-duration rice crops planted in succession have so far yielded lower than one main crop. Also, prospects for hybrid rice are being examined.

New crop management practices are being developed for short-straw, dwarf varieties. Various rice-based cropping systems are being tested to select the most remunerative. Various water regimes and fertilizer practices are being tested to increase the efficient use of these resources. Appropriate agronomic practices are being devel-

oped for rice grown on problem soils, mostly saline.

Research continues to seek improvements in existing weed control methods, mostly based on flooding; herbicides are being tested to find effective and economical chemical control of persistent weeds. Methods of weed control for mechanically transplanted and direct seeded rice are being developed.

A disease survey was conducted and will be done yearly to assess the severity of Bl and brown spot, the two major diseases, and to check for the occurrence of any new diseases. Specimens are collected, and Bl races are isolated and identified using international differential varieties in a nursery. The level of resistance of breeding material is evaluated in a Bl nursery. The relationships between N fertilizer practices and rice Bl and brown spot are being studied. Systemic and protective fungicides are being investigated. Yield loss estimates are being made from various levels of disease. And epidemiological studies are being conducted.

Entomologists are collaborating with plant breeders to develop varieties showing resistance to the stem borer. Effective and economical chemical control of the stem borer and bloodworm is being tested. Host, pest, and pest parasite interrelationships are being studied, along with the surveillance of all major rice pests. Methods of crop loss estimation are being studied.

Farm machinery is being developed to help the small farmer work faster and more easily. Farmers are being trained in operating and maintaining this equipment. Local manufacturers are given technical assistance to fabricate the new improved machines.

Researchers and extension agents work together to expose farmers to new varieties and improved production techniques. On-farm trials evaluate new varieties and their associated technologies under farmer's field conditions of varying soil types and water regimes. Researchers train extension workers in the improved production technology and expose them to on-farm research demonstrations and field days.

Breeding material grown and tested during May-September in the Egyptian Delta can be grown and evaluated at IRRI during October-March, allowing two generations per year to be processed and decreasing variety development time by half. The Bl nursery at IRRI is also used.

Rice from Egypt has been tested around the world by IRTP, and rice varieties from around the world have been evaluated in Egypt. Data on promising varieties are obtained from both national and international trials, thus identifying the varieties with the widest adaptive nature and screening for the widest range of possible pest and disease resistance.

The training component of the contract consists of overseas fellowships for Ph D candidates, postdoctoral fellowships at IRRI, practical training at IRRI in short courses, training in research management, and funds for attending conferences. At the root of all training is the continual need for improvement in the English language, with training being conducted at the University of Cairo.

India. The Indian Council of Agricultural Research (ICAR)-IRRI collaborative program was established in 1974 to undertake joint research in the collection and exchange of germplasm, exchange and evaluation of breeding material, study of diseases and insect biotypes, and crop production; and to participate jointly in workshops, symposia, and training programs.

Two ICAR-IRRI projects for the development of rainfed rice in Eastern India, funded by the Asian Development Bank and the International Fund for Agricultural Development, were initiated during 1987: Pest Management in Deepwater Rice and Development of Rainfed Rice Production in East India. Logistic and collaborative arrangements were made with ICAR and cooperating institutions. The research program is being carried out jointly by Indian and IRRI scientists.

Major achievements of the DWR project during 1987 were the mapping of deepwater areas in East India; detailed studies of the population dynamics of main pests; study of the rice - fish culture ecology; a training program with networking in Thailand, Bangladesh, Vietnam, Kampuchea, and Indonesia; and an ufra monitoring tour.

The project on the development of rice production in rainfed areas of Eastern India is being carried out in 4 lead centers and 11 associate

centers with the cooperation of more than 1,500 farmers through on-farm trials. The centers represent specific agroecological environments: rainfed upland, rainfed shallow, flood-prone, and deepwater.

Indonesia. New collaborative projects with IRRI include Prosperity Through Rice Phase 2, an impact study of the cropping systems program in Indonesia, initial development of a Regional Center for Breeding Improved Rice Varieties for Peat Soils, and Agency for Agricultural Research and Development (AARD)-IRRI-International Irrigation Management Institute (IIMI) collaboration in irrigation management for *palawija* crops.

In 1987, 43 IRRI staff visited Indonesia under the AARD-IRRI collaborative research program. In addition to the usual network programs, particular attention was focused on rice tungro virus, Prosperity Through Rice Phase 2, food demand/supply prospects and rice policy, agricultural engineering, and IIMI-IRRI collaborative activities with AARD.

Assistance was given to the Central Research Institute for Food Crops to provide international training in rice production, now that the course is no longer offered by IRRI, in the form of coordination among AARD, Malaysia, and Brunei. The second course was conducted from 15 Jun to 6 Jul in Bogor for six participants from Malaysia and Brunei. IRRI provided the training materials.

Kampuchea. The Australian Government provided IRRI with a grant to initiate a program of cooperation and assistance in Kampuchea during 1987. Under the program, a consultant agronomist was appointed for a 6-mo period. In addition, 11 IRRI scientists, including the Director General, made a total of 14 consultative visits during 1987. As a result of these efforts and the full support of the Kampuchean Government, significant progress was made in agronomic research, research priority assessment, human resource development, and translation and publication.

With the involvement of IRRI at the research planning stage in 1987, the major problems confronting rice production in Kampuchea were addressed. After discussions with researchers, appropriate experiments in varietal evaluation, fertilizer use, cropping systems, weed control in DWR, and environmental classification were designed.

A wide range of genetic material was described and documented for future breeding and selection. Some traditional lines have been sent to the IRRI germplasm bank, and the remaining varieties will be sent after their phenotypic characteristics have been recorded. Although grain yield was determined, it is mainly plant type that the IRRI plant breeders and local agronomists are observing. In subsequent seasons, replicated yield trials will attempt to match varieties with specific rice environments.

To determine the response of rainfed lowland rice to N, P, and K application with optimum water supply or occasional flooding, a factorial combination of 5 N rates and 3 P rates plus a comparison of urea supergranules (USG) and prilled urea as the N source was used with transplanted IR42 at 2 sites. In addition, the need for K was assessed at both sites, while the effect of locally produced rock phosphate was tested at one. Very high yields obtained from the zero-N and -P treatments indicated that the fertility of the research station soils is much greater than that of farmers' soils. This might explain the relatively poor response to fertilizer, suggesting that a yield plateau is being approached. This might also explain the variable response to USG and the apparently good response to rock phosphate.

To develop improved rice-based cropping systems differing in cropping intensity and legume components and to compare them with the traditional rice monocrop of the rainfed lowlands, eight rainfed cropping systems, consisting of one to three crops per season with legumes planted before and/or after rice, were established in Prey Phdau and Day Eth. In Day Eth, the legumes preceding the rice crop grew very well, but in Prey Phdau, dry conditions resulted in stunted growth. The different rice varieties and planting methods—wet seeded, dry seeded, and transplanted—all did well in Day Eth, but at year's end only the dry seeded rice had been harvested, yielding 1.5 t/ha, a creditable performance considering the season. In Prey Phdau, only the transplanted crops survived the drought, indicating a need for direct seeding. Early season plantings of sesbania, mungbean, and cowpea performed well.

An economist and an anthropologist visited Kampuchea in November 1987 to identify priority areas for the IRRI-Kampuchea Project. The team

was allowed access both to farming communities and to unpublished national and regional data from the Ministry of Agriculture and thus obtained an idea of the constraints to output growth at both the farm level and the macrolevel.

A special rice production course for 13 Kampuchean agricultural officers was conducted at IRRI, 3 Aug-11 Dec 1987. The practical course provided trainees with the basic skills of modern rice production. In addition, the trainees underwent intensive English language instruction.

Ten thousand copies of the Khmer language edition of *Field problems of tropical rice* were printed in Manila with financial assistance from the Mennonite Central Committee, and distribution by the Kampuchean Ministry of Agriculture was begun. Translation of *A farmer's primer on growing rice* was completed, and translation of *Helpful insects, spiders, and pathogens* was begun.

Korea. The Korea-IRRI Collaborative Project was formalized in 1977, although informal collaboration began in 1962. The collaboration between the Rural Development Administration of Korea and IRRI initially included rice cold tolerance, seed multiplication and generation advancement of breeding material, and basic studies on disease and pest problems. Subsequently included were innovative breeding methods such as anther culture and hybrid rice, soils, multiple cropping, and Prosperity Through Rice. Training and the exchange of scientists are integral parts of the collaboration. Planning sessions are held annually to discuss the research results, experiments to be conducted, and priorities. Seed multiplication and generation advancement of breeding material at IRRI, and most of the collaborative experiments are funded by Korean donations. Results of the 1987 collaboration are reported in various sections of this Annual report.

Laos. In March 1987, IRRI fielded its first mission to the Lao People's Democratic Republic. The IRRI team concluded that a cooperative country project with Laos should focus on the development of low-cost technologies for Laos' main rice-growing environments, with the complementary development of Laos' human resources devoted to rice research and production.

A memorandum of understanding between IRRI and the Lao Government was finalized and signed in December 1987. Under this agreement, IRRI will seek donor support to prepare and initiate a long-term program of cooperation with Laos in rice research and human resource development.

Madagascar. The goal of the Madagascar-IRRI Rice Research Project is to assist in increasing rice production by strengthening the research capabilities of Madagascar's National Center for Applied Research on Rural Development (FOFIFA). This will be accomplished by improving the professional skills of FOFIFA researchers, increasing FOFIFA's institutional capacity, and conducting relevant research on rice and rice-based cropping systems.

Five short-term outputs have been identified as attainable during the project:

- introduction and testing of rice germplasm from national and international centers for adaptability to irrigated and upland conditions; selection of pure varieties within the existing collection of germplasm adaptable to irrigated and upland conditions;
- development of a system for the exchange of information between IRRI and the Malagasy rice research institution;
- completion of a countrywide research strategy plan for long-term development of the rice research institution;
- training personnel for the rice research institution; and
- undertaking on-farm research within a farming systems context.

Seven FOFIFA researchers and one agricultural engineer from the Ministry of Agriculture received training during 1987. At year's end, a total of 25 FOFIFA and 1 Ministry staff had received training under the project. Many of the training candidates were weak in English listening comprehension and conversation. Whenever possible, these candidates were enrolled in English language courses in Antananarivo. Additionally, IRRI arranged for candidates to undertake 2 wk of intensive English language training in Manila. This English language training has been excellent, and graduates have not experienced great language difficulties at IRRI. In May, the IRRI Agricultural Economics Department conducted a training course in statistics and computer applications in socioeconomics for Department de Recherche Developpement staff; this formal training was followed by on-the-job

training through analysis of data gathered from a farming systems diagnostic survey. In September, the IRRI Statistics Department conducted statistics and computer training for 12 agronomists. The project funded 13 FOFIFA scientists and the head of the Quarantine Service of the Ministry of Agriculture to participate in various conferences.

The agricultural development program of the Malagasy Lutheran Church translated and printed 10,000 copies of the Malagasy edition of *A farmer's primer on growing rice*. The translation had been reviewed by FOFIFA agronomists. The project also arranged for the printing of 2,000 copies of the Malagasy translation of *Field problems of tropical rice*. A FOFIFA scientist completed the French translation of *Techniques for field experiments with rice*.

IRRI made 82 crosses between Malagasy and elite introduced materials. These materials will be grown out in 1988.

Malaysia. The first Malaysian Agricultural Research and Development Institute (MARDI)-IRRI collaborative research planning meeting was held in Penang, 29 Mar-1 Apr, attended by eight MARDI staff and four IRRI staff. Mechanized rice cultivation, stimulated by the labor shortage as younger people move out of farming, was a major concern.

Nepal. In May 1987, the Director General of the Department of Agriculture visited IRRI for in-depth discussions on collaboration between IRRI and Nepal. At his invitation, IRRI sent a team of four scientists to visit the rice research centers and rice-growing areas of Nepal. The team evaluated the total rice research and development program in Nepal, and made suggestions that would strengthen rice research and production. Their work was guided by the ambitious government goal to double rice production by the end of this century.

The team gave detailed attention to those areas where stronger collaboration between Nepal and IRRI would be desirable, with a view to developing a joint proposal between Nepal and IRRI for a cooperative project.

Philippines. IRRI's collaborative research and training activities with the Philippine Government involve mainly the Philippine Rice Research Institute (PhilRice) and the Regional Integrated Agricultural Research Systems (RIARS) of the Department of Agriculture (DA). Some projects also involve the University of the Philippines at Los Baños (UPLB), the Bureau of Plant Industry (BPI), and the National Irrigation Administration (NIA).

Collaboration between IRRI and Philippine scientists was strengthened with the signing of a memorandum of understanding between IRRI and PhilRice on 29 May 1987. The first PhilRice-IRRI Planning Meeting was held at IRRI on 4 Jun 1987. The participants proposed collaboration in varietal improvement, planting and fertilizer management, integrated pest management, rice farming systems, mechanization and postharvest technology, grain quality and nutrition, social science and policy research, and technology transfer.

The International Rice Germplasm Center donated seed of 544 traditional rice varieties to PhilRice. Seed of 232 varieties found promising in acid soils was given by IRRI for the national upland rice breeding program.

IRRI's long-term experiments at the Maligaya Rice Research and Training Center continued in 1987. Additional experiments were planned under INSURF.

PhilRice and IRRI scientists met to discuss farming systems research findings in Guimba, Nueva Ecija. Plans for further field experiments in farming systems were made, for implementation in the 1988 wet season (WS).

IRRI has worked jointly with BPI in designing and testing farm implements and machinery during the last decade. USAID support for this project was terminated on 30 Jun 1987, but work continued with the Agricultural Engineering Section of BPI.

Two PhilRice research assistants participated in IRRI's training course on farming systems. In addition, 2 groups underwent training in Prosperity Through Rice, each group consisting of 24 from the 12 regions of the country plus a few trainees from the DA central office.

Farming systems research in collaboration with RIARS or DA agronomists was conducted in three strategic areas: Claveria, Misamis Oriental (acid upland site); Solana, Tuguegarao, Cagayan (drought- and submergence-prone sites); and

Guimba, Nueva Ecija (irrigated rainfed lowland site). The common scope of activities in Claveria and Solana included

- rice and upland crop cultivar evaluation;
- soil fertility management, including green manures;
- insect and disease management; and
- weed management.

An important study in Claveria concerned contour hedgerow farming systems, and one in Solana dealt with surface drainage studies on prerice crops.

Many IRRI departments (Agronomy, Entomology, Plant Pathology, Multiple Cropping, Water Management, Soils, Agricultural Economics, and Agricultural Engineering), along with DA and NIA, are involved in research in Guimba. There are two major rice environments in the area: the deepwell pump-irrigated rice environment and the rainfed favorable lowland rice environment.

Crop - animal farming systems research is being conducted in collaboration with the A and the Institute of Animal Science of UPLB. The important sites outside of UPLB are Santa Barbara in Pangasinan, and Tres Martires in Cavite. Results of the 1987 research show that gross income was high for cowpea + root crop (cassava or sweet potato) + swine and for crop + cattle.

The 11th DA-IRRI Technology Transfer Workshop was held at IRRI, 1-3 Oct 1987. The theme "Increasing rice production after an abnormal wet season" was selected due to the drier than usual 1987 monsoon season. The workshop was attended by 120 Philippine Government staff and IRRI scientists. Participants debated and developed several options for increasing rice availability to offset an anticipated production shortfall of up to 500,000 t of milled rice.

The Rice Production Enhancement Program was developed to provide subsidized N fertilizer to farmers. By the end of 1987, the program had reached 245,000 farmers planting more than 365,000 ha of rice in 70 provinces.

Soviet Union. In November 1987, IRRI and the V. I. Lenin All-Union Academy of Agricultural Sciences signed a protocol on scientific and technical collaboration covering

- collecting and conserving rice genetic resources;
- testing varieties for adaptation to various ecological conditions;
- breeding high-yielding varieties with good grain quality, tolerance for low temperature and salinity, and resistance to pests and diseases; and
- studying rice blast caused by *Pyricularia oryzae*.

The collaboration will be carried out on the basis of annual working plans to include

- exchange of scientists;
- lectures, consultations, and symposia;
- coordinated projects;
- exchange of materials and information;
- exchange of breeding material; and
- exchange of trainees.

Thailand. The IRRI Bangkok office, located in the Rice Research Institute of the Department of Agriculture, provides administrative support for collaborative projects, and regional support for the Indochina Project because of its convenient links with Kampuchea, Laos, and Vietnam. It also provides joint administrative services for CIAT, Centro Internacional de Mejoramiento de Maiz y Trigo, and Centro Internacional de la Papa on a cost-sharing basis.

Two major collaborative projects with core support for research in specific environments are the Deepwater Rice Project, with research on flooded areas of the Central Plain, and the Rainfed Lowland Rice Project for Northeast Thailand, which officially started in 1987. The latter is investigating the constraints to production in rainfed areas that have irregular rainfall, very low native fertility, and low yields. Research is on nutrient management in sesbania - rice sequences, the evaluation of P sources in acid soils, environmental characterization, direct seeding methods to remove labor constraints, adaptation of prerice upland crops, evaluation of rice breeding lines, and social science research to understand the dynamics of the whole-farm system. Six IRRI senior staff from Los Baños are participating in the project. A senior research assistant from Los Baños spent 6 mo doing fieldwork at the Ubon Research Center in 1987 in collaboration with Thai researchers and with the help of a full-time IRRI research assistant employed in Thailand.

The Deepwater Rice Project is a collaborative IRRI core program, with an IRRI agronomist located in Thailand and four locally employed research assistants. A plant breeder operates from Los Baños. Research in Thailand is aimed at improving the total productivity of DWR areas, and not just the production of DWR itself. The program has a regional component for collaborative research and exchange of technology with other countries growing DWR.

Drought is a major factor in DWR stand establishment and the effect of cultural practices. Usually, large plots of more than 25 m^2 have been used to determine DWR yields, but a small-plot technique developed to determine varietal response to fertilizer application has given good results. DWR response to fertilizer has been unpredictable, but N uptake studies have shown large differences in uptake between soil types and flood patterns, which have not been reflected by yield measurements. These results have given an understanding of the conditions under which N responses may be obtained, and a simple model has been developed.

Floodwater patterns from locations in Bangladesh and Thailand have been compared by determining characteristics with a computer program, and the technique has been used to evaluate conditions in Kampuchea, where DWR will be reintroduced.

Intercropping studies have shown that yields of up to 1 t/ha can be obtained from an early-maturing rice between rows of DWR without reducing DWR yield, but at present this technique may not appeal to farmers. Upland crops such as soybean, mungbean, and sunflower would give better returns, and techniques are being evaluated for growing them on flat plains subject to temporary flooding after heavy rainfall. Future research will emphasize understanding and manipulation of the interactions between the crop and the environment.

Technology resulting from research on DWR agronomy in Thailand is directly applicable to Vietnam and Kampuchea, as the environments are very similar, and to some extent to Burma. Collaborative research is under way in Vietnam on grain shattering, reduction of surface soil acid at sowing, and economic levels of P, and in Kampuchea on the reestablishment of DWR varieties. In India and Bangladesh, latitude and rainfall distribution are different, and hence DWR varieties have different characteristics, but the principles concerning total production of the system are relevant.

The Deepwater Rice Newsletter published by the Bangkok office has been enthusiastically accepted by national scientists in the region.

United Kingdom. IRRI carries out collaborative projects with various institutions and universities in the United Kingdom with funding by the Overseas Development Administration. The projects in 1987 were

- Evaluation of rices for salinity tolerance
- Use of protoplast fusion techniques in rice
- Water-use efficiency in relation to abscisic acid
- Use of protoplast fusion for production of interspecific azolla species
- Water and nitrogen use by legumes following rice
- Azolla taxonomy
- Biological nitrogen fixation and algal growth in deepwater ricelands
- Determining mechanisms of resistance to brown planthopper
- Pheromones to forecast and control insect pests
- Pest management of deepwater rice
- Effect of nematodes on rice yields
- Farmer adaptation of technology over time
- Rice abstracts
- Training and professional development programs

Vietnam. The Government of Australia has, since 1985, supported IRRI's program of collaboration with Vietnam, with particular emphasis on human resource development.

To evaluate the progress of the IRRI-Vietnam Project and to identify future priorities, an IRRI mission visited Vietnam in July 1987. The IRRI mission met with leading scientists from Vietnam's main research institutes and universities concerned with rice research and development. A joint work plan was developed specifying areas of mutual interest in research as well as training needs in Vietnam.

In November 1987, the IRRI Director General led a second mission to Vietnam to prioritize further the IRRI-Vietnam Project, based on the Government's perceived priorities, IRRI's capacity to undertake collaboration, and the likely availability of extra-core funds.

West Africa. IRRI's activities in Africa have two broad thrusts. The first is IRRI's liaison and collaborative activities with other international organizations (such as IITA and WARDA) and with national agencies in the region. The second thrust is IRRI's support for IRTP-Africa, which was organized to provide a unified rice testing program and a more effective link among national and international rice improvement programs.

Sixty-seven superior varieties for both lowland and upland ecologies were identified from the IRTP-Africa nurseries in 1985 and 1986. Highlights of IRTP-Africa in 1987 were

- successful monitoring tour to the Ivory Coast, the Gambia, and Senegal;
- productive workshop in Saint Louis, Senegal; and
- publication of two reports, one on the 1985 and 1986 nursery results, and the other a summary report on the 1987 monitoring tour and workshop.

IRRI supports the activities of international agricultural research centers (IARCs) in Africa by sending staff to work at the IARCs, assisting in planning meetings, and training IARC staff.

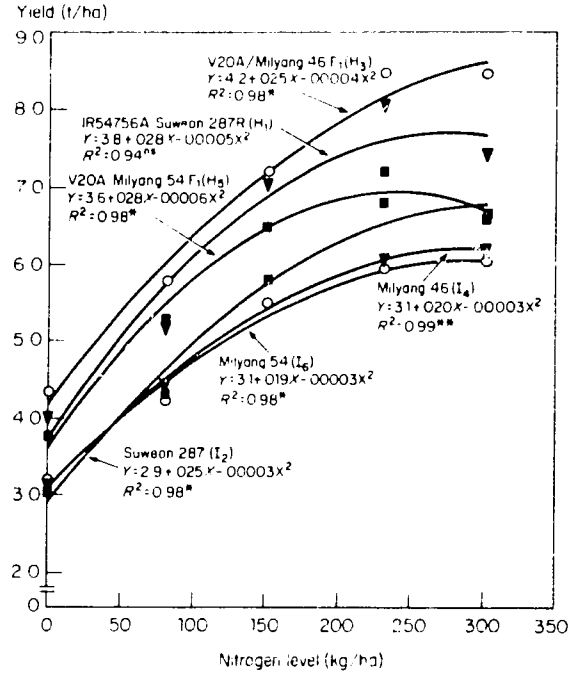
IRRI's role in Africa has produced visible results and has made considerable impact. At least three tangible results of these activities can be identified:

- There is a growing awareness of the impact and usefulness of IRTP-Africa. Consequently, it constitutes the core of many national breeding programs.
- There is increasing interest among African countries to send candidates to IRRI's various training programs. The number of Africans participating in IRRI training programs has grown considerably in the last 2 yr.
- There is increasing commitment of African countries, IITA, IRRI, and WARDA to work together as a team for IRTP-Africa. The program thus continues to make further progress.

EFFECT OF PLANT DENSITY AND NITROGEN LEVEL ON YIELDS OF F_1 HYBRIDS AND ELITE INBRED CULTIVARS

Plant Breeding Department

In a collaborative experiment with the Crops Experiment Station, Suweon, Korea, two hybrids, V20A Milyang 46R and IR54756A/Suweon 287R, yielded significantly higher than the best inbred cultivar, Suweon 287. Plant density levels did not significantly affect yields of hybrids and inbreds. Among N levels, 230 and 300 kg/ha gave significantly higher yields than did 80 or 150 kg/ha. Significant interactions were noted for N × plant density, N × variety, and N × plant density × variety. Variety × plant density interactions was nonsignificant. Two heterotic hybrids showed yield superiority over inbreds at all N levels (Fig. 1) due to higher total dry matter yield (TDMY) and higher harvest index (HI). HI was related to increased spikelet number per hill and 1,000-grain weight. The panicle number of rice hybrids and inbreds was identical. The ripening ratios of the hybrids were lower than that of the best inbred.



1. Yield responses of F_1 hybrids and elite inbred cultivars to N, Suweon, Korea, 1987.

Increasing N levels increased TDMY and panicle number, but decreased HI. The effect of N on spikelet number, 1,000-grain weight, and ripening ratio varied with the genotype.

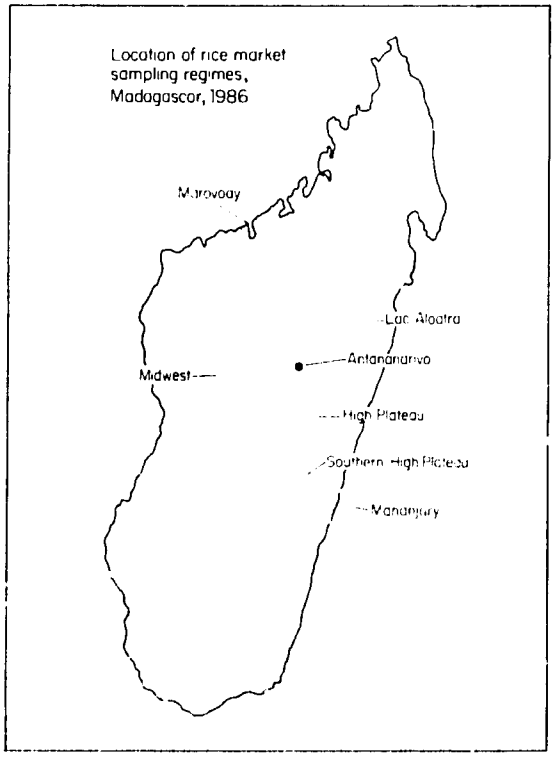
RICE QUALITY AND PRICES IN MADAGASCAR

Agricultural Economics and Cereal Chemistry Departments

An agricultural economist and plant breeders from FOFIFA, and IRRI scientists studied the grain quality of rice sold in Malagasy markets and how rice prices reflect quality differences. Two hundred twenty-five rice samples were purchased in retail markets covering a range of locations (Fig. 2).

Characteristics of samples. The average characteristics of the rice samples, and measures of their variability are reported in Table 4.

Factors contributing to low whiteness were undermilling, bran streaks, and red grains. Most of the samples fell in the range of 45-65% head rice values typical of hand-pounded rice or rice milled in small steel-huller type rice mills. Grain shape was generally medium (length:width = 2.6), with samples varying from bold (1.6) to slender (3.9) grains and exhibiting marked regional differences.



2. Location of rice market sampling regimes, Madagascar 1986.

Table 4. Average characteristics and variability of characteristics of 255 rice samples, Madagascar, 1986.

Grain characteristic	Mean value	Coefficient of variation (%)
Physical characteristics		
Whiteness (% pure white)	29.8	23
Head rice (% unbroken)	52.6	31
Length (mm)	6.2	9
Width (mm)	2.4	11
Length-width ratio	2.6	17
Translucency (% not chalky)	32.1	45
Chemical characteristics		
Amylose content (%)	24.5	8
Gel consistency[a] (mm)	36.4	33
Alkali spreading (mm)	6.2	12
Protein content (%)	7.7	15

[a]Av of gel length of 100 mg and 90 mg rice flour in 2 ml 0.2 N KOH.

Most of the samples had intermediate (20-25%) to high (25-30%) amylose content (AC).

There are sharp contrasts in varietal preferences between regions in Madagascar, as reflected in the types of rice offered for sale in the markets. On the High Plateau, including Antananarivo, red bold rices, known as Vary Rojo, are preferred. In the southern, lower portions of the High Plateau, white long-grained japonica rices, known as Vary Lava, are preferred. On the northern coastal plains, such as Marovoay, white rices, typified by Vary Tsipala, are preferred, while in the Lac Aloatra region, varieties such as Makalioka are preferred; these varieties are in general more slender than those preferred on the High Plateau.

The average grain quality values of three regions are given in Table 5. The average whiteness value for samples collected in the Marovoay/Lac Aloatra area was significantly higher than that of samples from the other regions, partly due to the lower percentage of red rices in the Marovoay/Lac Aloatra samples. Head rice recovery was significantly less in the Marovoay/Lac Aloatra samples than in the other samples, possibly because the former were generally more slender. The chemical characteristics of the samples other than the alkali spreading values did not differ markedly.

Table 5. Mean values[a] of grain quality characteristics by major region, Madagascar, 1986.

Grain characteristic	Marovoay/ Lac Aloatra (N = 63)	High Plateau (N = 122)	Southern High Plateau (N = 24)
Physical characteristics			
Whiteness (% pure white)	34.3 a	27.8 b	29.3 b
Redness (% red grains)	12.6 b	38.8 a	23.1 b
Translucency (% not chalky)	39.9 a	27.4 b	36.1 a
Head rice (% unbroken)	43.0 b	57.1 a	55.9 a
Length-width ratio	2.9 a	2.6 b	2.4 b
Chemical characteristics			
Amylose content (%)	24.9 a	24.5 ab	23.8 b
Gel consistency (mm)			
-- 100 mg	37.7 a	37.2 a	34.9 a
-- 90 mg	56.2 a	54.7 a	48.9 a
Alkali spreading (mm)	5.8 a	6.3 b	5.8 a
Protein content (%)	7.5 a	7.9 a	7.7 a

[a]In a row, means followed by a common letter do not differ at the 5% level by DMRT.

Prices and weights. Rice is sold in Madagascar by the tin or *kapoaka*. The net weight of a kapoaka of rice averaged 293 g (CV = 6%). Some variability is anticipated in the weight per kapoaka, as it is a volume measure, with the weight depending on the degree of hilling; weight will also depend on grain physical attributes such as moisture content, kernel density, and percentage of broken rice.

The mean price of rice samples was FMG143/kapoaka (FMG783= US$1) with a range of FMG75-190/kapoaka; this converts to FMG483/kg, with a range of FMG352-711/kg. The mean weight per kapoaka varied between regions (Table 6); it was highest in the Midwest followed by Marovoay, Mananjary, and Lac Aloatra and lowest in Antananarivo.

The mean price per kilogram differed significantly between regions. It was least in Antananarivo. Rice prices in the Midwest at the time of the survey averaged FMG443/kg, which was significantly less than in the producing region of Lac Aloatra and the Southern High Plateau in the area of Fianarantsoa. Rice prices were highest in the High Plateau.

Implicit prices. The implicit prices of quality attributes, following the procedure described in the Annual report for 1986, are derived from the ordinary least squares estimate of the following equation:

$$P = a + \sum_{j=1}^{n} b_j X_j + \sum_{k=1}^{m} d_k D_k + u$$

where P is the market price of the rice sample (FMG/kg),

X_j is the amount of grain characteristic j in that sample,

D_k is a vector of dummy variables to incorporate regional differences,

a is the intercept,

u is a random error with normal properties,

b_j is the implicit value estimated for characteristic j, and

d_k is the estimated price difference between regions when other factors are adjusted.

Estimates of implicit prices of the measured grain quality attributes, as specified by the equation, are listed in Table 7. All characteristics other than protein content and gel consistency (100 mg) were significant at the 10% level of probability or better. Consumers paid more for rice with higher percentages of head rice, slender grains, and white rice. Low AC was preferred to high AC, as judged

Table 6. Mean rice prices[a] and sample weights, by zone, Madagascar, 1986.

Region	Samples (no.)	Weight (g/kapoaka)	Price	
			FMG/kapoaka	FMG/kg
Marovoay	30	299 ab	124 d	414 e
Lac Aloatra	21	295 bc	139 c	471 c
Antananarivo	7	291 c	110 e	379 f
High Plateau	90	292 c	153 a	526 a
Southern High Plateau	22	292 c	143 b	491 b
Midwest	17	306 a	135 c	443 d
Mananjary	9	298 bc	125 d	420 e

[a]FMG 783 = US$1.

Table 7. Ordinary least squares estimates of the relationship between rice price, grain quality, and location, Madagascar, 1986.

Variable	Partial regression coefficient	Standard error	t-test significance level (%)
Head rice (%)	0.35	0.11	1
Protein content (%)	-2.54	1.74	15
Gel consistency (100 mg) (mm)	-0.15	0.15	30
Amylose content (%)	-2.37	1.23	6
Alkali spreading (mm)	-4.19	2.52	10
Length:width	17.95	3.92	1
Whiteness (%)	0.50	0.48	7
Mahitsy (D_1)	-136.74	7.78	1
Marovoay (D_2)	-120.78	5.38	1
Southern High Plateau (D_3)	-31.09	4.91	1
Lac Aloatra (D_4)	-57.36	5.62	1
Mananjary (D_5)	-106.70	6.99	1
Midwest (D_6)	81.99	5.56	1
Constant (FMG/kg)	555.16	–	–
Standard error of Y	19.32		
$\bar{R}^2$	0.86		
F ratio (13,182)	96.66		
Durbin Watson	1.57		

by the negative sign for this variable, i.e., there was a preference for intermediate- over high-AC rice; consumers prefer rice that cooks moist and tender and does not become hard when it cools after cooking. There was also a marked preference for rices with lower alkali spreading values (-4.2), which implies a preference for rices with intermediate alkali spreading values as opposed to low gelatinization temperature (alkali spreading values of 6-7).

The partial regression coefficients of the quality attributes represent the implicit prices and measure the change in rice price for a one unit change in the level of that characteristic. The dummy variables measure the difference in price, quality factors aside, between the zones specified in Table 6 and the Antananarivo-High Plateau rice price, which is taken as the base. The significant negative dummy variable for Marovoay, for example, implies that, quality factors aside, the price of rice was cheaper by about FMG137/kg than on the High Plateau. These differences are consistent with the between-region price differences reported in Table 6 and show that regional differences in prices are far stronger than price differences due to quality attributes.

JAPAN-IRRI COLLABORATIVE PROJECT ON BACTERIAL BLIGHT

Plant Breeding and Plant Pathology Departments

IRRI continued research on BB as part of the Low Input Cultivation Technology Under Irrigated Conditions Project in close collaboration with the Tropical Agriculture Research Center (TARC), Ministry of Agriculture, Forestry and Fisheries, Japan. The project is funded by the Government of Japan.

Development of international differentials for bacterial blight (*Plant Breeding and Plant Pathology*). Using BB races from the Philippines at IRRI and from other Asian countries at TARC, we are developing near-isogenic lines with single genes for BB resistance. After obtaining BC_4F_1 progenies of the developed lines, we compared plant types of the lines with three recurrent parents—IR24 (indica), Toyonishiki (japonica), and Milyang 23 (indica/japonica hybrid)—at both IRRI and TARC. We have developed near-isogenic lines that have been advanced to BC_4F_4 or later generations as shown in Table 8.

Near-isogenic lines carrying the resistance gene *xa-8*, with Toyonishiki or Milyang 23 in their background, are under final selection (BC_4F_3). Near-isogenic lines carrying the resistance genes of Te-tep are now being separated into lines carrying a few single genes including a new gene from an Indonesian isolate (BC_4F_5).

Inheritance of resistance (*Plant Breeding*). Two new genes for BB resistance have been identified. One was found in BJ1, which shows resistance to Philippine races 1-6. The result of the segregation of the F_2 populations indicated that BJ1 had two recessive genes, one identical to *xa-5* in IR1545-339 and the other a new recessive gene (Table 9). The new recessive gene was considered to carry resistance to Philippine race 6 and to have a complementary reaction with *xa-5* to Philippine race 4. Moreover, the new recessive gene might be linked with *xa-5*. We have designated this recessive gene *xa-13*.

The other new resistance gene was found in TN1, which showed a specific reaction to Philippine races: it resisted only race 5 (PXO 112). This kind of resistance to Philippine races was never found in any differentials or resistant varieties. Analysis of F_1 and F_2 populations from the crosses

Table 8. Near-isogenic lines with resistance gene for BB developed at IRRI and TARC, 1987.

Designation[a]	Resistant donor	Recurrent parent	Resistant gene
IR-BB1 (t)	Kogyoku	IR24	*Xa-1, Xa-12*
IR-BB101 (t)	Kogyoku	Toyonishiki	*Xa-1, Xa-12*
IR-BB201 (t)	Kogyoku	Milyang 23	*Xa-1, Xa-12*
IR-BB3	Chugoku 45	IR24	*Xa-3*
IR-BB103	Chugoku 45	Toyonishiki	*Xa-3*
IR-BB203	Chugoku 45	Milyang 23	*Xa-3*
IR-BB4	IR20	IR24	*Xa-4*
IR-BB104	IR20	Toyonishiki	*Xa-4*
IR-BB204	IR20	Milyang 23	*Xa-4*
IR-BB5	IR1545-339	IR24	*xa-5*
IR-BB105	IR1545-339	Toyonishiki	*xa-5*
IR-BB205	IR1545-339	Milyang 23	*xa-5*
IR-BB7	DV85	IR24	*Xa-7*
IR-BB107	DV85	Toyonishiki	*Xa-7*
IR-BB207	DV85	Milyang 23	*Xa-7*
IR-BB8	PI231129	IR24	*xa-8*
IR-BB10	Cas 209	IR24	*xa-10*
IR-BB110	Cas 209	Toyonishiki	*xa-10*
IR-BB210	Cas 209	Milyang 23	*xa-10*
IR-BB11	IR8	IR24	*xa-11*
IR-BB111	IR8	Toyonishiki	*xa-11*
IR-BB211	IR8	Milyang 23	*xa-11*
IR-BB3J	Java 14	IR24	*Xa-3*
IR-BB103J	Java 14	Toyonishiki	*Xa-3*
IR-BB203J	Java 14	Milyang 23	*Xa-3*
IR-BB3Z	Zenith	IR24	*Xa-3*
IR-BB103Z	Zenith	Toyonishiki	*Xa-3*
IR-BB203Z	Zenith	Milyang 23	*Xa-3*
IR-BB3S	Sateng	IR24	*Xa-3*
IR-BB103S	Sateng	Toyonishiki	*Xa-3*
IR-BB203S	Sateng	Milyang 23	*Xa-3*

[a](t) = tentative designation, because *Xa-1* and *Xa-12* were not yet established as identical or different.

of TN1 with three varieties indicated that TN1 has one dominant gene for resistance to Philippine race 5 (Table 10). Thus, we designated this gene *Xa-14*. From the genetic analysis for BB resistance for the past 5 yr, we standardized the BB resistance genes identified at both IRRI and TARC as shown in Table 11.

Rice varietal groups based on reaction to four races (*Plant Breeding*). We continued to evaluate resistant varieties against four Philippine BB races and to analyze the resistance genes by allele tests. We reconfirmed that there are four major varietal groups: Java 14 (*Xa-3*), TKM6 (*Xa-4*), DZ192 (*xa-5*), and Cas 209 (*Xa-10*). In addition, four small groups of varieties were identified. In summary, we grouped resistant varieties against four Philippine BB races as follows:

Java 14 (*Xa-3*) group
TKM6 (*Xa-4*) group
  Subgroup: Mod Ba (*Xa-4* + *Xa-10*)
DZ192 (*xa-5*) group
  Subgroup: BJ1 (*xa-5* + *xa-13*)
  Subgroup: DV85 (*xa-5* + *Xa-7*)
  Subgroup: Makhmal Mehi (*xa-5* + *Xa-4*)
Cas 209 (*Xa-10*) group

The result of isozyme analysis of BB-resistant varieties showed that the Java 14 group falls mainly into groups V and VI, TKM6 into group I, the DZ192 group into group II, and the Cas 209 group into group I in the Glaszmann classification.

Table 9. Reaction[a] of F_1 and F_2 populations from the crosses of IR24 or IR1545-339 and BJ1 group varieties to 4 BB races (1, 2, 4, and 6) at booting. IRRI, 1986-87.

Cross	Reaction of F_1	Reaction of F_2 plants				χ^2	P
		SSSS	RRMS	SSSR	RRRR		
						(9:3:3:1)	
IR24/BJ1	SSSS	164	27	29	31	34.215	0.001>
IR24/AC19-1-1	SSSS	117	35	37	16	1.177	0.7 -0.8
IR24/Chinsurah Boro II	SSSS	173	43	30	23	14.744	0.001>
IR24/Aus 274	SSSS	171	40	47	11	6.943	0.05-0.1
IR24/Kalimakri 77-5	SSSS	155	39	55	21	4.1000	0.2 -0.3
						(3:1)	
IR1545-339/BJ1	RRMS		184		78	3.193	0.05-0.1
IR1545-339/AC19-1-1	RRMS		192		67	0.104	0.7 -0.8
IR1545-339/Chinsurah Boro II	RRMS		184		69	0.697	0.3 -0.5
IR1545-339/Aus 274	RRMS		200		70	1.123	0.7 -0.8
IR1545-339/Kalimakri 77-5	RRMS		187		81	3.900	0.02-0.05

[a]R = resistant, M = moderately resistant, S = susceptible.

Table 10. Reaction[a] of F_1 and F_2 populations from the crosses of TN1 with 3 varieties to 4 races (1, 2, 4, and 5) of BB. IRRI, 1987.

Cross	Reaction of F_1	Reaction of F_2 plants		χ^2 (3:1)	P
		SSSR	SSSS		
Toyonishiki/TN1	SSSR	185	4	5.563	0.01-0.02
Milyang 23/TN1	SSSR	200	70	0.123	0.7 -0.8
TN1/Te-tep	SSSR	208	57	1.722	0.1 -0.2

[a]R = resistant, S = susceptible.

Table 11. Genes for BB resistance.

Standardized gene symbol[a]	Original designation	Representative varieties
Xa-1		Kogyoku
Xa-1^h (t)	*Xa-1*^{h}	IR28, IR29, IR30
Xa-2 (t)	*Xa-2*	Rantai Emas 2, Te-tep
Xa-3	*Xa-w*	Wase Aikoku 3, Chugoku 45
	Xa-4^b	Semora Mangga
	Xa-6	Zenith
	xa-9	Sateng
Xa-4	*Xa-4*	TKM6, IR20, IR22
	Xa-4^a	
xa-5		DZ192, IR1545-339
Xa-7		DV85
xa-8		PI231129
Xa-10		Cas 209
Xa-11	*Xa-pt*	RP9-3, IR8, Elwee
Xa-12 (t)	*Xa-kg*	Kogyoku
Xa-12^h (t)	*Xa-kg*^{h}	IR28, IR29, IR30
xa-13		BJ1, Chinsurah Boro II
Xa-14		TN1

[a](t) = tentative symbol pending confirmation.

This fact indicates that the differentiation of BB resistance genes in rice varieties coincides with varietal differentiation of rice groups.

RACE-SPECIFIC PARTIAL RESISTANCE TO BLAST IN JAPONICA RICES

Plant Pathology Department

As part of a collaborative project with the Rural Development Administration, Korea, breeding lines and recommended japonica (J) and indica-japonica (IJ) varieties from Korea are evaluated each year for Bl resistance from November to February at IRRI. However, little is known about how environment and pathogen differences affect the comparative responses of the materials in Korea at the Philippines.

The purpose of this work was 1) to compare the Bl resistance of Korean J and IJ germplasm as measured in nursery tests in the Philippines and in Korea, and 2) to determine if race-specific partial resistance affects the reactions of temperate J varieties when evaluated at IRRI.

Upland nursery experiments were done during 1986 in the Philippines at IRRI and in Korea and the Icheon Experiment Station. At each site, 53 J and 24 IJ varieties from Korea were tested. Daily maximum and minimum temperatures were taken at each site.

To test for differences in aggressiveness on J varieties, isolates of *P. oryzae* were sent from the Philippines and Korea for testing under uniform conditions by a collaborating scientist in the U.S. Three J varieties – Daechang, Nagdong, and Palgeum – were tested. The indica (I) variety CO 39 was included as a susceptible check.

In the nursery experiments, the IJ varieties tended to be completely resistant in Korea but susceptible in the Philippines (Table 12). The race pattern in a given region depends on the varieties grown there. Only I varieties are grown near IRRI, but mostly J varieties are grown near the Icheon site in Korea. Thus, the nursery experiment results show that, with respect to their Bl resistance, the Korean IJ varieties are more similar to the I rices than are the J rices.

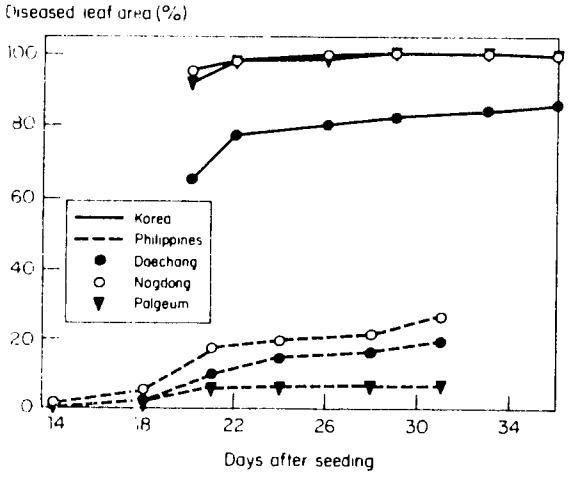
Many of the J varieties were qualitatively susceptible at both locations (Table 12). Of this group, most were more susceptible in Korea. The disease progress curves of Daechang, Nagdong, and Palgeum from the two sites illustrate this difference (Fig. 3). These three J varieties showed slow disease increase at IRRI, yet were highly susceptible in Icheon.

Environmental differences could have influenced the relative Bl susceptibility of the J cultivars at the

Table 12. Disease reactions of 53 japonica and 24 indica varieties in nursery tests in Korea and the Philippines.[a]

Variety group	Susceptible at both sites[b]			Resistant in Korea but susceptible in the Philippines	Susceptible in Korea but resistant in the Philippines	Resistant at both sites
	More susceptible in Korea	Equal	More susceptible in the Philippines			
Japonica	17	5	2	6	14	9
Indica-japonica[c]	0	0	2	19	0	3

[a]Considered qualitatively susceptible when typical spindle-shaped lesions occurred on most plants. [b]Combined analysis of variance was conducted using the area under the disease progress curve; varieties were grouped based on significant differences at 5% by LSD. [c]Derived from crosses between indica and japonica rices.



3. Blast disease progress in 3 japonica varieties in nursery plot trials in Korea and the Philippines, 1986.

Table 13. Disease scores for 4 rice varieties inoculated with isolates of *Pyricularia oryzae* from Korea and the Philippines.[a]

Variety	Isolate[b]		Difference[c]
	Korean	Philippine	
Nagdong	5.1	1.8	3.3**
Daechang	4.5	1.3	3.2**
Palgeum	4.8	1.3	3.5**
CO 39	4.9	4.5	0.4ns

[a]Mean of 3 replications; percent diseased leaf area rated as 0 = no infection, 1 = 0-10%, 2 = 11-25%, 3 = 26-50%, 4 = 51-75%, 5 = 76-90%, 6 = 91-100%. [b]3 isolates from each location tested. Location means are presented because of no significant isolate differences within location, [c]** = significant at the 1% level by LSD, ns = non-significant.

two locations. During the IRRI nursery test, the mean day temperature was 32.1 °C and the mean night temperature 23.1 °C. During the test in Icheon, the mean day temperature was 27.4 °C and the mean night temperature 19.2 °C. Night temperatures of about 20 °C are reported to favor Bl, and this temperature effect is reportedly more pronounced in J rices.

However, data from the inoculation experiments support the hypothesis that race specificity, and not environmental differences, was the primary cause of the greater susceptibility of the J varieties in the Korean tests. For each of the three isolates tested from each location, the Korean isolates caused more disease than the Philippine isolates on the three J varieties tested (Table 13). On the susceptible check CO 39, the isolates appeared to be equally aggressive.

Because of this race specificity, it is not possible to assess the relative partial resistance of the Korean J varieties in the Philippine tests. These tests have value primarily for revealing the high susceptibility of some IJ varieties or lines that are presently resistant in Korea.

The resistance of the J varieties to the Philippine isolates may be similar to the race-specific field resistance found in varieties Chugoku 31 and St 1 in Japan, which is monogenically controlled.

KOREA-IRRI COLLABORATIVE PROJECT

Plant Physiology and Plant Breeding Departments

At the rice cold tolerance screening nursery in Chuncheon, Korea, 969 entries were screened in plots with continuously flowing cold water with a temperature of 17 °C at the inlet and 21-25 °C at the outlet. In the pedigree nursery, with continuously flowing water at 20 °C, 63 F_2 populations, 10 F_5 lines, and 35 hybrid crosses were grown. The 1987 International Rice Cold Toler-

ance Nursery entries were grown in pots at 19 ± 1 °C during anthesis. Thirty-five entries were grown under normal farmers' field conditions with 200 kg N/ha in observational yield trials. For cold tolerance at the seedling stage, 15-d-old seedlings were subjected to 12 °C continuously flowing water for 10 d. And photoperiod-insensitive, salt-tolerant indica rices were screened. See the section on Adverse Temperature Tolerance for details.

IDENTIFICATION OF PROMISING F_1 RICE HYBRIDS IN KOREA, INDIA, INDONESIA, MALAYSIA, AND VIETNAM

Plant Breeding Department

Evaluations of experimental hybrids in 1986 and 1987 (Table 14) indicate that IRRI hybrids IR54752A/IR14753-120-3, IR54752A/IR46R, IR54752A/IR54R, IR54752A/IR13419-113-1R, IR54752A/ARC11353R, IR54752A/IR20933-68-21-1-2, IR54752A/IR19392-211-1, IR46828A/IR13524-21-2-3-3-2-2, and IR54752A/IR29512-81-2-1 yielded higher than the best local checks in the tropics. Promising hybrids for Korea were

Table 14. Yields of IRRI hybrids compared with those of local checks in India, Indonesia, Malaysia, Korea, and Vietnam, 1986-87.

Hybrid or variety	Growth duration (d)	Yield (t/ha)
Coimbatore, Tamil Nadu, India, 1986 WS		
IR54752A/IR14753-120-3	138	7.5
CO 43	138	6.4
University of Agricultural Sciences, Bangalore, India		
IR54752A/IR46R	148	11.0
IR54752A/IR54R	152	9.4
IR54752A/IR13419-113-1R	154	9.1
IR54752A/ARC11353R	149	8.9
Puspha	134	8.1
Jaya	154	4.0
Bangalore, India, 1987 WS		
IR54752A/IR54R	142	7.2
IR54752A/ARC11353R	140	6.9
Puspha	125	6.3
Mithapur, Patna, Bihar, India, 1986		
IR54752A/IR19392-211-1	–	6.2
IR54752A/IR20933-68-21-1-2	–	6.2
IR54752A/14753-120-3	–	5.8
IR54752A/IR54R	–	5.2
IR46828A/IR13524-21-2-3-3-2-2	–	5.2
IR64	–	3.7
Sita	–	4.0
Mahsuri	–	4.2

Table 14 continued.

Hybrid or variety	Growth duration (d)	Yield (t/ha)
Central Rice Research Institute, Cuttack, India, 1986 WS		
IR54752A/IR20933-68-2-1-1-2	142	5.5
IR54752A/IR54R	140	5.4
IR54752A/IR14753-120-3	141	5.3
IR46828A/IR13524-21-1-3-3-2-2	129	5.3
IR64	127	4.2
IR54	139	4.5
Ratna	122	4.5
LSD (5%)	–	0.4
Cuttack, 1987 WS		
IR54752A/IR54R	140	7.5
IR54752A/IR13419-113-1R	133	7.5
IR54 (local check)	139	7.0
MW10 (local check)	113	6.5
Ratna (local check)	120	6.2
Aduthurai, Tamil Nadu, India, 1986 WS		
IR46828A/IR13524-21-2-3-3-2-2	120	9.4
IR64	120	8.2
IR50	118	7.4
ADT36	127	8.4
TKM9	125	7.7
LSD (5%)	–	0.9
Sukamandi, Indonesia, 1986-87 WS		
IR54752A/IR29512-81-2-1	132	7.8
IR54752A/IR20933-68-21-1-2	128	5.7
IR54752A/IR54R	123	4.6
IR54	127	3.6
Cisadane	139	3.2
IR64	12[illegible]	2.7
Bumbong Lima, Malaysia, 1986 DS		
IR54752A/IR14753-120-3	128	5.0
IR64	114	3.0
Muda	135	3.9
Bumbong Lima, Malaysia, 1986-87 WS		
IR54752A/ARC11353R	129	3.1
IR64	116	2.8
Muda	137	1.6
MR84	138	2.1
Hau Giang, Vietnam, 1987 WS		
IR54752A/IR54R	123	6.9
IR54752A/ARC11353R	126	6.7
IR54752A/IR46R	126	6.4
IR64	120	5.7
LSD (5%)	–	1.0
Suweon, Korea, 1987		
IR54756A/Suweon 332	–	8.4
Suweon 287	–	7.8
IR54756A/Iri 361	–	9.4
IR54756A/Suweon 333	–	8.7
IR54756A/Iri 362	–	8.7
IR54756A/Suweon 294	–	8.5
Suweon 294	–	7.6
Suweon 287	–	7.3
Milyang, Korea, 1987		
IR54756A/Suweon 287	–	8.1
Iri 361	–	7.4
Milyang 54 (local check)	–	6.7

IR54756A/Suweon 332, IR54756A/Suweon 333, IR54756A/Iri 362, IR54756A/Suweon 294, and IR54756A/Suweon 287. These combinations were developed in the Korea-IRRI collaborative research program. No IRRI hybrid tested performed better than local checks in replicated yield trials during 1987 in Kapurthala, Punjab, India; Maros, South Sulawesi, Indonesia; and Iri, Korea.

RATOONING PERFORMANCE OF IRRI HYBRIDS IN BANGALORE, INDIA

Plant Breeding Department

Ten IRRI F_1 hybrids and three local checks were ratooned in Bangalore in July 1987 after harvesting the 1987 dry season (DS) crop. IR4752A/ARC11353R, IR54752A/IR13419-113-1, and IR54752A/IR54 ratooned well and produced high total (main and ratoon crop) yields (Table 15). In total yield, IR54752A/IR46R was also promising. These results indicate the importance of considering hybrid ratooning ability.

GROWTH BEHAVIOR OF A 2,4-D-RESISTANT WEED

Agronomy Department

Gooseweed (*Sphenochlea zeylanica* Gaertn.), a common annual weed in lowland rice, was usually controlled in the 1970s with 2,4-D applied preemergence (3-5 d after transplanting [DT]) or postemergence (17-20 DT). Ten years later, a 2,4-D-tolerant strain of gooseweed was observed in Bulacan. To date, a susceptible strain has been collected from Pangasinan and Ilocos, a moderately susceptible strain from Los Baños, and a tolerant strain from Bulacan. These differential responses may be due to the degree of 2,4-D used in each area.

To evaluate the differential tolerance of these strains to 2,4-D, their germination, growth behavior, and leaf morphology were compared in the greenhouse in a collaborative experiment with the National Crop Protection Center and the UPLB Agronomy Department. Germination did not differ. Stem elongation, leaf production, and TDMY of the susceptible and moderately susceptible strains were higher than those of the tolerant strain when 60 kg N/ha was applied; these differences were apparent at 5 wk after emergence. Without N, these growth factors did not differ.

The tolerant strain had thicker leaf cuticles starting at the 8- to 10-leaf stage, when it exhibited tolerance for 2,4-D. Thus, a thick cuticle may limit 2,4-D absorption.

Adding a surfactant (wetter) to the spray solution of 0.8 kg 2,4-D/ha nullified the tolerant strain's response. The wetter may have enhanced 2,4-D absorption, overcoming the barrier presented by the thick cuticle.

The results demonstrate the potential threat of a 2,4-D-tolerant strain of gooseweed. The susceptible strain grew where 2,4-D has never been used, and the tolerant strain where 2,4-D was applied every season for the last 10 yr; therefore herbicide use may have created the tolerance. Herbicide rotation will help avoid buildup of tolerance. If 2,4-D is used, it should be applied preemergence or early postemergence (but not later than the 8- to 10-leaf stage).

Table 15. Ratoon (1987 WS) and main crop (1987 DS) yields (t/ha) of IRRI F_1 hybrids and local checks, Bangalore, India.

Hybrid or check	Main crop, 1987 DS	Ratoon crop, 1987 WS	Total
IR54752A/IR46R	11.0	1.4	12.4
IR54752A/IR54R	9.4	3.1	12.5
IR54752A/IR13419-113-1	9.1	3.3	12.4
IR54752A/ARC11353R	8.9	4.5	13.4
IR46828A/IR13524-21-2-3-3-2-2	8.5	0.9	9.4
IR54752A/IR27315	8.4	1.1	9.5
IR46830A/IR50R	7.5	0.7	8.2
IR54752A/IR29723-143-3-2-1R	7.0	0.7	7.7
IR54752A/IR4422	4.8	0.3	5.1
Checks			
Pushpa	8.1	0.8	8.9
Mangla	5.5	0.3	5.8
Jaya	4.0	0.3	4.3
LSD (5%)	1.3	0.54	
CV (%)		33	

PHOSPHORUS NUTRITION OF RICE FOR SUSTAINABLE FARMING

Agronomy Department

A collaborative project in Thailand, Indonesia, Bangladesh, and China is evaluating the short- and long-term effects of highly soluble, partially soluble, and relatively insoluble P sources in acid

and acid sulfate lowland soils. Trials involve irrigated rice in Indonesia, Bangladesh, and China, and rainfed lowland rice in Northeast Thailand.

Results show that partially acidulated phosphate rock with 30% acidulation is as good as triple superphosphate and potentially less expensive.

DEEPWATER RICE FOR HERBAGE

Plant Physiology Department

DWRs usually take more than 200 d from germination to maturity. The long growth duration produces TDMY as high as 19 t/ha. Unfortunately, most farmers burn the DWR biomass after harvest. If cut before flowering, this biomass could be used to feed livestock where natural pasture is limited.

A collaborative experiment with the Rice Research Institute, Thailand, examined the effect of leaf cutting on the growth, development, and yield of DWR at the Huntra Rice Experiment Station, Ayutthaya, Thailand. DWR variety Pin Gaew 56 was planted under natural deepwater conditions. Seed at 120 kg/ha was sown on 10 Jun, late because heavy rains delayed land preparation. Ammonium phosphate (16:20.0) at 90 kg/ha was applied at 55 d after emergence (DE). The upland field was naturally flooded on 15 Aug, when the rice was 60 d old. Plants were pruned 0-3 cm above the water at 100 DE, when the water level was about 77 cm.

Leaf regrowth. Removing leaves reduces photosynthesis; however, new leaves started growing 1 d after cutting. Leaf emergence and internode elongation occurred simultaneously. It took 7 d to develop 1 new leaf, almost 1 mo to have 4 fully developed leaves, and 56 d to have the same number of green leaves as the control. Therefore, to avoid competition between leaf regrowth and spikelet formation, the last pruning should be at least 6 wk before the start of the reproductive phase.

Plant height and internode elongation. Pin Gaew 56, a tall variety, generally lodges during the reproductive phase. When leaves were cut at 100 DE, plant height decreased by 39 cm. Plant height at flowering was markedly reduced in cut plants, the result of reduced internode elongation. The number of elongated internodes was not greatly affected by cutting, but the total length of the elongated internodes was reduced.

Herbage yield, grain yield, and yield components. Herbage yield was 0.57 t/ha when cutting was at 100 DE. It could be increased by planting earlier or by cutting more often. Herbage yields of 0.5-3.2 t/ha have been obtained in irrigated transplanted rice.

Cut and uncut plots did not differ in grain yield, probably because the long growth duration of DWR enabled it to recover before the reproductive phase had begun.

Cutting increased panicles per unit area but reduced spikelets per panicle. It did not affect percentage fertility or 1,000-grain weight.

Herbage quality. Rice herbage from plantings in Thailand and at IRRI was sent to the Dairy Training and Research Institute at UPLB for feeding studies. The rice herbage was high in crude protein and in vitro true dry matter digestibility (IVTDMD) (Table 16). The rice herbage from Pin Gaew 56 had lower crude protein than B4259 but was better in quality than that of rice straw. The crude protein of B4259 cut at different dates and at 15 and 30 cm plant height ranged from 9.3 to 19.8%, similar to that of very young improved tropical grasses. The high IVTDMD values indicate high potential as ruminant feed. Feeding trials

Table 16. Crude protein and in vitro true dry matter digestibility (IVTDMD) of rice herbage from varieties B4259 and PG56. IRRI, 1987.

Cutting time[a]	Cutting height (cm)	Dry matter basis crude protein (%)	IVTDMD (%)
		B4259	
40 DT	15	15.9	71
	30	19.8	70
50 DT	15	13.5	72
	30	15.2	72
60 DT	15	9.3	76
	30	12.4	78
70 DT	15	9.8	72
	30	12.0	66
80 DT	15	9.3	67
	30	10.9	59
		PG56	
14-15 WAS	3	7.9	69

[a]DT = days after transplanting, pruned at 15 and 30 cm aboveground. WAS = weeks after seeding, pruned at 3 cm above water surface (depth 60 cm).

of rice herbage from B4259 showed high palatability of rice forage silage with high crude protein digestibility and positive N balance.

The results support the use of rice herbage for animal feed. In Thailand, beef and dairy cattle in DWR areas are fed rice straw with concentrate supplement. The herbage quality and grain yield maintenance for Pin Gaew 56 encourage more research.

Rice forage as goat *Capra hircus* feed. *Chemical composition.* The chemical composition of rice forage hay (RFH), rice forage silage (RFS), and rice straw are shown in Table 17. Both RFH and RFS contain much higher crude protein and lower cell wall fractions than rice straw, indicating that RFH and RFS are better roughage.

Intake and digestibility. Although RFH and RFS have similar nutrient composition, in the digestion study using goats, RFS showed higher dry matter intake and digestibility. RFH showed lower dry matter intake as percentage of body weight than RFS. Feed textures and structures differ. RFH is sharper and hairier than RFS, reducing its palatability. RFH gave low nutrient digestibility, nutrient intake, and negative N retention. Supplementing RFH with 25% stargrass or adding 50% RFS to rice straw would provide higher digestibility, intake, and N retention.

Table 17. Chemical composition (dry matter basis of the basal diet used in the feeding experiment) of rice forage hay, rice forage silage, and rice straw, IRRI, 1987.

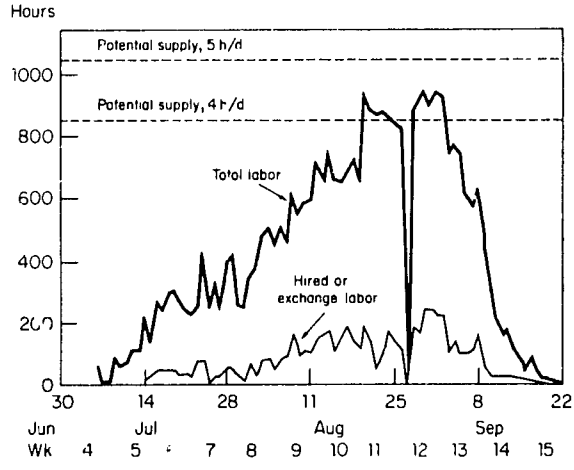
Component	Rice forage hay	Rice forage silage	Rice straw
Dry matter (%)	84.0	34.0	84.9
Organic matter (%)	81.3	81.9	78.1
Crude protein (%)	10.4	10.9	6.3
Neutral detergent fiber (%)	64.1	62.3	70.6
Acid detergent fiber (%)	44.6	44.2	56.5
Hemicellulose (%)	19.5	18.1	14.1
Cellulose (%)	30.1	29.9	32.5
Lignin (%)	3.4	3.4	6.0
Acid insoluble ash (%)	11.2	10.9	18.0
Ash (%)	18.7	18.1	21.9
Energy (kcal)	3390.0	3440.0	3352.0

ECONOMIC CONSTRAINTS ON TURNAROUND TIME IN BANGLADESH

Agricultural Economics Department

A collaborative project with BRRI was conducted to identify resource constraints on turnaround time between the two major rice crops, aus and transplanted aman. The introduction of modern varieties (MVs) has increased pressure on farmers during this period. Modern aus varieties are harvested later, while modern aman varieties must be transplanted earlier to flower before low temperatures reduce yields. The objective was to determine whether shortages of labor and draft power limit the area under MVs.

Resource constraints. The results were based on a random sample of 110 farms in the BRRI project area, which represents the rainfed, shallow-flooded rice environment of eastern Bangladesh. They indicate the existence of a draft power constraint on the area under modern aus. Figure 4 shows the distribution of animal labor during turnaround. The dip in the graph was caused by the Islamic holiday of Id-ul-Azha on 26 Aug. Demand peaked in week 11 (19-25 Aug), when 7,131 h of animal labor were used. This was 77% of the potential supply if animals worked at their full capacity of 6.25 h/d. Discounting the Id-ul-Azha holiday would bring hours worked up to 83% of potential supply. Since data on hours worked were probably underrecorded and some slack has to be built into the system to allow for adjustments when the unexpected occurs, the evidence suggests that



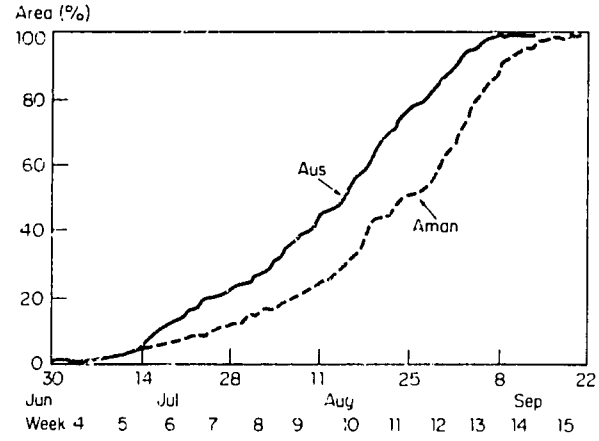
4. Hours of animal labor during turnaround between aus and aman, Joydebpur, Bangladesh, 1985.

supply and demand for draft power are in equilibrium and there is no "surplus" draft power available during the peak period for land preparation.

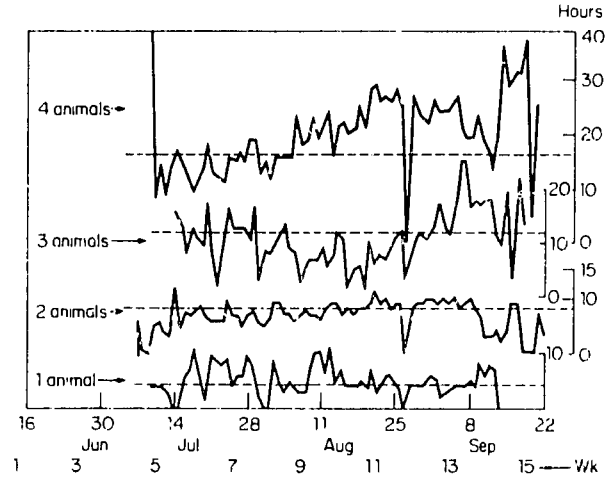
Draft power was not a constraint on the area under modern aman. Figure 5 shows the cumulative percentage frequency of aus harvested and aman transplanted by date over the turnaround period. Turnaround time is measured by the horizontal space between the lines on the graph. Figure 5 shows that 64% of the aman area was transplanted by 31 Aug, the latest date for transplanting modern aman under rainfed conditions. Since only 12% of the aman area was under MVs, a shortage of draft power was not the reason for low adoption.

At the farm level, farmers who did not own a pair of draft animals did not face a constraint. There was no significant difference in turnaround time after modern aus between farmers owning different numbers of draft animals (Fig. 6), because farmers with fewer than two animals hired animals, timed operations differently, and worked animals harder. Farmers with four draft animals were found to work their animals intensively for long periods.

Programming solutions. A linear programming model of resource use was developed to compare the impact of different strategies to reduce labor and draft power constraints. The basic model accurately reproduced the existing cropping patterns and correctly identified the draft power constraint on the area under modern aus. Seven strategies were evaluated, and several conclusions emerged. First, all the individual strategies increased the area under modern aus except an extension program to increase the area under the pattern modern aus - modern aman (BR1 - BR11). This confirmed an earlier finding of a draft power constraint on modern aus. Second, the model demonstrated the importance of new varieties to overcome resource constraints. In particular, a shorter-duration modern aus, a direct-seeded modern aus, and a photoperiod-insensitive, IR50-type modern aman that can be transplanted up to mid-September would increase the area under MVs by spreading the demand for resources during turnaround. Finally, to overcome the draft power constraint, it will be necessary to introduce minimum tillage or power tillers, which the model suggests are equally effective in increasing the area under modern aus.



5. Mean cumulative area harvested and transplanted for rainfed aus and aman in 6 villages, Joydebpur, Bangladesh, 1985.



6. Average hours per day worked by 1-4 animals, Joydebpur, Bangladesh, 1985.

ECONOMICS OF HYBRID RICE IN CHINA

Agricultural Economics Department

A joint project was pursued with CAAS, involving several components.

Rice yields and resource use in hybrid and conventional rices. Interviews of 90 farmers growing hybrid (H) rices and 86 farmers growing conventional rices in Jiangsu Province, China,

revealed that the mean yield of H (7.8 t/ha) was significantly higher than that of japonica (J) rices (6.8 t/ha) by 15%. H outyielded indica (I) rices by 0.9 t/ha, or 15%. J dominated in the southern part and I in the northern part of Jiangsu Province.

The seed rate of H (21 kg/ha in the south and 27 kg/ha in the north) was significantly less than for J (56 kg/ha) and I (100 kg/ha), largely because H was transplanted at 1 seedling/hill compared with 3-4 for I and J. All farmers applied pesticides, mainly insecticides. Pesticide use averaged significantly higher for H (39 kg/ha) than for J (22 kg/ha) in the southern counties; however, in the northern counties, both H and I farmers used 9 kg/ha. Total N (260 kg/ha in the south and 210 kg/ha in the north) from organic and inorganic sources did not differ significantly from amounts applied to J and I. Labor for J was significantly higher than for H because of greater seedbed and transplanting time. Labor for H and I did not differ significantly. Irrigation expenses were similar.

In summary, seed rate was the only significant input difference between H and J and between H and I.

Comparative benefits. Adoption of new technology strongly depends on its comparative economic benefits. Enterprise budgets prepared for H, J, and I appear in Table 18.

Hybrid versus japonica rice. In the southern counties, neither total returns (grain and straw) nor net returns differed significantly between H ($1,040/ha and $492/ha) and J ($1,052/ha and $498/ha).

Farmers received higher prices for J but had higher yield with H. H has a shorter duration, giving farmers more flexibility in establishing winter crops.

Hybrid versus indica rice. The gross return from

Table 18. Costs and returns ($/ha) by county and rice type,[a] Jiangsu Province, China, 1984.

Item	Southern counties			Northern counties		
	H (n = 45)	J (n = 44)	Difference	H (n = 45)	I (n = 42)	Difference
Gross returns						
Grain	925	952	-27^{ns}	849	723	126**
Straw	115	100	15**	106	92	14**
Subtotal	1040	1052	-12^{ns}	955	815	140**
Input costs						
Labor						
Land preparation	17	18	-1^{ns}	16	19	-3^{ns}
Establishment	92	110	-18*	90	97	-7^{ns}
Management	88	88	0^{ns}	79	80	-1^{ns}
Harvest/postharvest	68	74	-6^{+}	60	54	6^{+}
Subtotal	265	290	-25**	245	250	-5^{ns}
Nonlabor						
Seed	29	15	14**	37	17	20**
Organic fertilizers	62	66	-4^{ns}	42	46	-4^{ns}
Chemical fertilizers	69	72	-3^{ns}	81	74	7^{ns}
Pesticides	23	16	7**	13	11	2^{ns}
Irrigation	22	23	-1^{ns}	19	21	-2^{ns}
Electricity	4	3	1^{ns}	2	2	0^{ns}
Added capital for seedbed above main field	15	14	1^{ns}	14	16	-2^{+}
Tractor or draft animal	26	23	3^{ns}	24	24	0^{ns}
Machine thresher	5	4	1^{ns}	8	6	2^{ns}
Indirect costs	28	28	0	26	26	0
Subtotal	283	264	19*	266	243	23**
Total costs	548	554	-6*	511	493	18*
Net returns	492	498	-6^{ns}	444	322	122*

[a]H = hybrid rice, J = japonica rice, I = indica rice. [b]** = significant at the 1% level by t-test, * = 5% level, + = 10% level, ns = nonsignificant.

H ($955 ha) was significantly higher than from I ($815 ha). H had significantly higher grain and straw yields, and H and I were similarly priced.

The net return was $444 ha for H and $322 ha for I, a clear advantage for H in the northern counties at current official prices.

Returns to variable inputs. Value ($) and productivity (kg) indices were calculated for labor and nonlabor costs.

Hybrid versus japonica rice. In the southern counties, the returns to labor ($ $) were $2.86 d for H and $2.71 d for J, and returns per labor day were $2.78 and $2.65, neither difference being significant. Returns to nonlabor costs and to total costs did not differ. Farmers made a 90% return on variable costs when all inputs were valued at official prices.

Labor productivity (measured in both kg per d and $ per d) was significantly higher for H than for J. However, the productivity of nonlabor inputs was significantly higher for J. In consequence, total productivity did not differ significantly between H and J.

Hybrid versus indica rice. H was significantly more profitable than I on all measures. H earned a significantly higher return to labor ($2.81 $ of labor cost) than I ($2.23 $ of labor cost). Similarly, returns per labor day were significantly higher for H ($2.36 d) than for I ($1.93 d). Net returns to total cost for H were $0.87, and for I, $0.65, again reflecting the higher returns per $ invested in H compared with I.

The productivity indices for labor and nonlabor inputs and for total productivity were similarly higher for H than for I, giving H a production advantage in northern Jiangsu Province at current official prices.

Economics of hybrid rice seed production. A survey of 8 male sterile seed producers and 21 hybrid seed producers in Jiangsu Province provided data on seed production. This province is a major hybrid rice region, with a well-established seed industry.

The economics of cytoplasmic male sterile (CMS) A-line seed multiplication, and F_1 hybrid seed production were compared with H and conventional (C) rice production.

A-line multiplication. Total labor to grow a hectare of CMS A-line averaged nearly 400 d across Jiangsu Province (Table 19), compared with less than 300 d ha for H or C. Substantial labor was required for transplanting (67 d ha), activities to ensure a good seed set (69 d ha), and harvesting and threshing (70 d ha). The male parent is often transplanted 2 or 3 times to ensure synchrony of flowering. Growers ensure good seed set by spraying gibberellic growth stimulants, clipping flag leaves to increase panicle exsertion, and dragging a rope across the field to transfer pollen.

Nonlabor inputs for CMS A-line production appear in Table 20. All growers used pesticides, mainly insecticides. Total N applied exceeded 250 kg N ha.

The average yield of the CMS A-line was 1.4 t ha, with a range of 0.9-2.0 t ha. Maintainer (B) line yield averaged 1.2 t ha, with a range of 0.6-1.5 t ha.

F_1 hybrid seed. Labor to produce a hectare of F_1 hybrid seed was 376 d (Table 19), almost as much as for CMS lines, but 75 d ha higher than for H or C production.

In nonlabor inputs (Table 20), pesticide use averaged 46 kg ha. Total N averaged nearly 290 kg ha.

The average yield of F_1 hybrid seed was 1.7 t ha with a range of 1.4-2.3 t ha.

Costs of and returns to seed production. The profitabilities of CMS A-line multiplication and F_1 hybrid seed production were calculated using

Table 19. Means and coefficients of variation (in parentheses) of labor inputs (d/ha) for cytoplasmic male sterile (A-line) seed multiplication and for F_1 hybrid seed production, Jiangsu Province, China, 1984.

Item	A-line (n = 8)	F_1 hybrid (n = 21)
Land preparation	31 (45)	18 (28)
Seed selection and preparation	3 (33)	2 (21)
Seed preparation and care	15 (25)	14 (40)
Transplanting	67 (16)	59 (19)
Organic fertilizer application	32 (85)	13 (70)
Chemical fertilizer application	13 (44)	14 (28)
Water control	28 (48)	25 (23)
Disease and insect control	15 (34)	20 (43)
Weed control	17 (54)	21 (40)
Activities to ensure seed set	69 (40)	85 (26)
Harvest and postharvest	70 (27)	70 (17)
Others	39 (48)	30 (30)
Total labor days	399 (8)	376 (7)

Table 20. Means and coefficients of variation (in parentheses) of nonlabor and recurrent inputs for cytoplasmic male sterile A-line seed multiplication, and for F_1 hybrid seed production, Jiangsu Province, China, 1984.

Item	A-line product		F_1 hybrid seed	
	% users	Mean values/ha (n = 8)	% users	Mean values/ha (n = 21)
Purchased inputs				
Pesticides	100	15 kg (58)	100	46 kg (82)
Organic fertilizer	88	47 t (128)	100	33 t (79)
Inorganic fertilizer: N	100	99 kg (52)	100	150 kg (37)
P	75	39 kg (25)	81	53 kg (40)
K	38	3 kg (30)	29	47 kg (87)
Total N	100	268 kg (103)	100	288 kg (46)
Seed, female parent (A-line)	100	30 kg (26)	100	35 kg (13)
Seed, male parent (B/R)	100	11 kg (40)	100	9 kg (26)
Machinery inputs[a]				
Power tiller	100	32 $ (47)	100	25 $ (41)
Machine thresher	63	9 $ (121)	86	13 $ (20)
Irrigation costs	100	23 $ (35)	100	21 $ (30)

[a]Exchange rate in 1984: ¥2.70 = US$1.

official prices for rice and labor in Jiangsu Province in 1984.

Prices and wage rates. The Jiangsu provincial government sets rice seed prices. Farmers bought F_1 hybrid seed from county seed companies for $1,375/t, on average. The county seed companies bought A-line seed and F_1 seed from seed producers at $1,281/t. The proportional price was $119/t for H and $116/t for I, B, and R-lines, by products of hybrid seed production. Straw value was $14.80/t. The average government-declared wage rate, $0.86/d, was used as a proxy for family labor costs.

Because the State owns the land, land value is not included, nor is cost of money (interest rate) invested in seed multiplication.

A-line multiplication. Gross returns to A-line multiplication are derived from the A-line, the maintainer seed, and the straw. Gross returns averaged $1,992/ha (Table 21). The imputed cost of labor ($374/ha) and of nonlabor inputs ($353/ha) were similar. The largest cash costs were for transplanting labor and inorganic fertilizer. The average net return to A-line multiplication was $1,264/ha.

F_1 seed production. Gross returns to F_1 seed production included the values of F_1 seed, CR restorer seed, and straw, averaging $2,488. Labor costs averaged $338, and nonlabor inputs $385/ha.

Table 21. Profitability of producing hybrid seed, male sterile seed, and hybrid rice, Jiangsu Province, China, 1984.

Item	Hybrid seed (n = 21)	Male sterile seed (n = 8)	Hybrid rice (n = 90)
Gross margins			
Gross returns ($/ha)	2488	1992	997
Input costs			
Labor costs	338	374	255
Nonlabor costs	385	353	273
Total costs	723	727	528
Net returns ($/ha)	1765	1264	469
Returns to			
Labor ($/$)	6.22	4.38	2.84
Labor ($/d)	5.61	4.13	2.56
Nonlabor ($/$)	5.59	4.58	2.71
Total costs	2.44	1.74	0.88

The net return to F_1 seed production averaged $1,765/ha.

Comparative profitability. Net returns per hectare were highest for F_1 seed production ($1,765/ha) and lowest for H production ($469), with A-line multiplication in between at $1,264/ha.

Returns to production factors are listed in Table 21. Returns to labor, to nonlabor inputs, and to total costs were consistently highest for F_1 seed production, intermediate for A-line multiplication, and lowest for H production.

RICE PRODUCTION SYSTEMS OF THE MAROVOAY PLAINS, MADAGASCAR

Agricultural Economics Department

The Rice Program of FOFIFA, in collaboration with IRRI, conducted a farming systems study in 1987 in the Marovoay Plains, a major coastal rice-growing region of Madagascar. Researchers represented three FOFIFA departments and six disciplines.

Participants reviewed past research, surveyed the region, and studied 127 rice farming households. The farm survey is summarized here. A full report, in French, is available from FOFIFA.

Rice environments. Seasonal flooding and irrigation provide two major rice seasons in the Marovoay Plains: *vary asara* in WS on hydromorphic soils not seasonally flooded, and *vary jeby* in DS in irrigated areas. A third rice type is *vary atriaty* (intermediate rice) grown on fringes and higher elevations of the floodplain. Jeby (47%) and asara (37%) dominate.

Farm households. A typical household consisted of seven persons. Adult males averaged 4 yr of schooling and adult females 2 yr. In one-third of the households, members worked off-farm, usually as agricultural laborers, being employed an average of 2 mo/yr. Off-farm work declined as farm size increased.

In addition to growing rice, most households farmed upland areas, growing maize, cassava, beans, peanut, and fruit trees. Farms averaged 2 ha of rice and 0.5 ha of upland crops. The distribution of ricelands among households was skewed, with 20% of households farming more than half the ricelands.

The family work-force per hectare of riceland averaged 3.3 persons, but was strongly skewed, with 50% of the households having fewer than 2.5 persons/ha. Thus, family labor per hectare was low, suggesting a need to increase labor productivity.

Although cattle are important in Marovoay farming, less than two-thirds of the households owned a pair of draft cattle, and less than 50% owned herd cattle. A typical herd consisted of 10-15 animals.

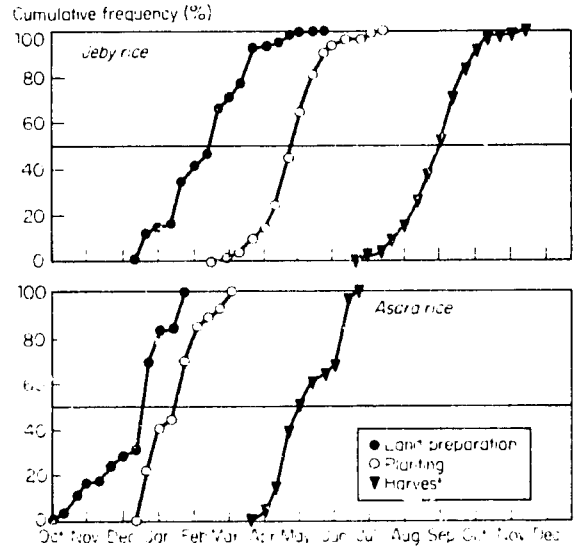
Rice production systems. The timings of land preparation, transplanting, and harvest of jeby and asara rice are shown in Figure 7. Labor-intensive, traditional methods of land preparation are used. Typically, the luxuriant biomass of weeds is removed, by hand, before the field is puddled using animals. It takes about 40 animal days to puddle 1 ha, with 8-10 men driving the animals.

Farmers grew a local variety, Tsipala, on 70% of the rice area. Seedlings, averaging 25-35 d, were randomly transplanted. No respondent applied fertilizer, herbicide, or insecticide on rice. Most farmers (91%) weeded jeby rice once; less than half (48%) weeded asara rice.

The labor input averaged 180-190 d/ha. For jeby rice, labor was equally divided among land preparation, crop establishment, crop care, and harvest and postharvest activities. For asara rice, land preparation absorbed one-third of the labor, with the remaining equally spread among the other three categories. Men prepare land, and women transplant and weed. Both men and women harvest; men thresh, and women winnow.

Mean yields of jeby rice (2.2 t/ha) were significantly higher than those of asara rice (1.1 t/ha) in 1987.

Rice production constraints. Farmers identified factors limiting yield (Table 22). In jeby rice, farmers said that insects (*Marasmia separatella* and *Hispa gestroi*), rats, and water shortages



7. Timing of land preparation, transplanting, and harvest of jeby and asara rice, Marovoay Plains, Madagascar, 1987.

Table 22. Farmer-identified problems limiting rice yields by season, Marovoay Plains, Madagascar, 1987.

Constraint	Jeby rice		Asara rice	
	Problem important	Most important problem	Problem important	Most important problem
Varieties not suited	9	3	3	3
Late planting	48	28	38	24
Flooding	17	8	28	21
Water shortage	60	45	76	66
No fertilizer	6	2	7	0
Insects	67	55	83	76
Weeds	57	25	41	28
Soil problem	40	20	31	28
Strong winds	49	27	24	10
Lodging	31	3	24	0
Rats	63	51	14	0
Birds	55	28	38	17

limited yields. In asara rice, insects (*M. separatella*), weeds, and water shortages were the principal constraints reported. Soil-related problems (salinity) were identified in both rice types. Lack of fertilizer and lack of access to higher yielding varieties were not perceived as problems.

Production costs and crop disposal. The production cost of jeby rice was about FMG225,000/ha, and for asara rice, FMG200,000/ha. Labor costs dominated production costs, accounting for 84% of jeby costs and 78% of asara costs. The average cost to produce jeby rice was about FMG100/kg; for asara rice it was FMG175/kg. Thus, the higher yields in jeby season more than compensated for its higher cost.

Twenty percent of the respondents reported that they consumed all the rice they produced. Those who sold rice kept more than half of their yield for consumption. Many rice-farming households in the Marovoay Plains are on the border of subsistence agriculture.

International collaboration

Technology sharing

Various departments

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COMMUNICATION AND PUBLICATIONS

Communication and Publications Department

Publications. At least 102,000 copies of major IRRI publications were distributed during 1987. Of these, 57,000 were in English; the others were translations generated through our copublication program.

Of the English publications, 38% were distributed free, mostly to key Third World libraries. Almost all translations were sold or sponsored by donor funds.

Fourteen books in English were released. An additional eight translations of IRRI publications were copublished by national programs. The section on Publications and Seminars has a full listing.

Four issues of the *IRRI reporter*, 6 issues of the *International rice research newsletter* (IRRN), and the IRRN *Subject index* for 1986 were distributed to 16,500 rice workers and 3,050 libraries in 151 countries. Two issues of the *International azolla newsletter*, three of the *Hybrid rice newsletter*, and two of the *Integrated pest management newsletter* were published. Eight issues of the *IRRI research paper series* came out.

Thirty news releases were written and distributed, and the IRRI information brochure was published in French.

Seven issues of *Rice abstracts*, which IRRI began publishing jointly with CAB International in 1986, were distributed. The Asian Development Bank has provided a grant to support 1,000 *Rice abstracts* subscriptions for key agricultural libraries in the Third World for 3 yr.

Editing and Publication training courses. The fourth and the fifth Editing and Publication (EdPub) training courses, sponsored by IRRI and the International Development Research Centre (IDRC) of Canada, were held in 1987. Nineteen men and women from 14 countries of Asia, Africa, and South America received intensive training in the principles and practices of their profession. Each trainee produced an individual printed project, and as a group each course produced an alumni newsletter and a slide tape show on a publishing-related topic.

A 2-wk EdPub course for 25 editors was held in June in Beijing at the invitation of the Chinese Academy of Agricultural Sciences. A second 2-wk course for 20 participants was held in November in Nairobi, Kenya. The course was organized by the International Centre of Insect Physiology and Ecology and sponsored by IDRC.

Research on *A farmer's primer* among women farmers. In a 1985 survey among Filipino farmers in Negros and Cavite on the effectiveness of *A farmer's primer on growing rice*, we learned that the wives of many farmer-respondents read the Primer as comprehensively as did their husbands; others read the entire book to husbands who were illiterate or lacked the time to read.

Thus, we extended our study to determine the effectiveness of the Primer among women farmers, using the 1985 methodology.

Although 74% of the women farmers scored low initially, high scorers increased more than 3 times after exposure to the Primer. The mean scores of the women farmers increased significantly, from 33 to 44 points. The highest post-test score was 59 81% of the highest possible score. Knowledge gain was highest on the topic carbohydrate production the topic on which knowledge gain was lowest among male farmers. The women farmers who had more media exposure and training were more interested in technical topics such as carbohydrates and fertilizers. Our previous study showed that male farmers avoided the more technical subjects.

The group of women who did not finish reading the book had more high scorers in the pretest than the males who did not finish it. The women who read the entire book also had higher knowledge gain than the males who finished it.

COOPERATIVES AND NETWORKS

Rice Genetic Engineering Network. We continued to participate in the Rice Genetic Engineering Network organized and supported by the Rockefeller Foundation. The network aims at generating the knowledge and technology needed to apply advances in molecular and cellular biology to the genetic improvement of rice. The network supports research at 35 collaborating institutions in Australia, Belgium, China, Colombia, France, Federal Republic of Germany, Japan, Republic of Korea, Netherlands, Philippines, United Kingdom, and United States.

Besides the fundamental investigations on rice molecular genetics, major emphasis is on the

development of techniques for genetic transformation of rice. Protoplast regeneration was achieved in rice, and methods for gene transfer are being investigated. Several laboratories are identifying, characterizing, and cloning useful genes. These will be utilized for transformation studies. Various protocols for transformation such as agrobacterium-mediated DNA transfer, electropolation, and microinjection are being investigated. Basic work on rice genetics has been intensified. Linkage maps have been associated with respective chromosomes, and new markers are being added to linkage groups. Eighteen of the 25 isozymes have been located on 8 of the 12 chromosomes. A restriction fragment length polymorphism map consisting of 120 DNA markers was completed through a collaborative project between Cornell University and IRRI. Through the wide hybridization program we have transferred useful genes for resistance to brown planthopper and whitebacked planthopper. Studies on the genetics of pathogenicity and the establishment of suitable techniques for race identification in blast and bacterial blight are under way.

Participants in this research cooperative meet once a year. The 1989 meeting will be held at IRRI in January.

Rice Genetics Cooperative. The Rice Genetics Cooperative aims to foster cooperative research on all aspects of rice genetics. It has a coordinating committee with its secretariat at IRRI. Its four standing committees attend to various aspects of coordination and international cooperation. The committee on gene symbolization and nomenclature has prepared a set of rules for symbolizing genes and monitors the application of these rules in assigning symbols to new genes. The committee on genetic stocks has prepared lists of marker stocks being maintained at two Rice Genetic Stock Centers. The committee on genetic engineering is monitoring progress in various aspects of genetic transformation in rice. Volume 4 of the *Rice genetics newsletter* was published in December 1987. A meeting of the coordinating committee of the Rice Genetics Cooperative was held at IRRI on 22-24 Oct 1987. It was decided to hold the second International Rice Genetics Symposium at IRRI, 14-18 May 1990.

Integrated Pest Management Project. The development of integrated pest management (IPM) programs for rice requires information on the ecology of pests and of beneficial organisms in the rice ecosystem, yield loss assessment and action thresholds, management strategies, and the socioeconomics of on-farm decisionmaking. IRRI has been collaborating with the Food and Agriculture Organization Intercountry Program for Integrated Pest Control in Rice in South and Southeast Asia in developing training and extension materials and on-farm decision aids for implementation. The collaborative program emphasizes

- training of farmers to acquaint them with the concepts of need-based pesticide applications and the role of natural enemies; with these skills, farmers can become better managers of their own fields; and
- regional pest surveillance to enhance the decisionmaking skills of national agricultural policymakers.

During 1987 we developed a methodology for surveys to determine multiple pest infestations in farmers' fields, economic thresholds for combined infestations of stem borers and leaffolders, computer-based disease management expert systems for interactive training, and coupled pest-crop models for determining the basis of yield losses. In the future, IRRI will emphasize environment-neutral research to provide practical decision tools for IPM.

Cooperative for Research on Problem Soils. Research activities of the Cooperative for Research on Problem Soils began during 1987 with the identification of cooperating institutions and scientists in India, Indonesia, Pakistan, Sri Lanka, and Thailand. Preliminary experiments were also conducted. For details, see the sections on Adverse Soils Tolerance and Integrated GEU Program.

Members of the Cooperative met at the Central Soil Salinity Research Institute, Karnal, India, on 14-18 Sep 1987, and planned a long-term research program with special emphasis on breeding, to begin in 1988. The meeting strongly emphasized the participation of plant physiologists in the cooperative and the exchange of breeding materials among members.

CONFERENCES, WORKSHOPS, AND MEETINGS

The following conferences, workshops, and meetings were held in 1987.

January

12-13 Training Workshop on Systems Analysis and Simulation for Rice Production

26-27 Conference on Comparative Food Pricing Policy in Asia

26-28 IFAD-IDRC/RF/GTZ/ADAB Consultation on Strengthening National Agricultural Research Systems (Italy)

31-3 Feb International Symposium on Rice Farming Systems: New Directions (Egypt)

February

6-9 Climate and Food Security Symposium (India)

23-2 Mar Internal Program Review

March

3-10 Country Visits of External Management Review Panel (Asia and Africa)

9-14 Workshop on Research and Training Needs in the Field on Integrated Vector-borne Disease Control in Riceland Agroecosystems of Developing Countries

16-20 International Workshop on Rice Seed Health

23-25 Workshop on Differential Effects of Modern Rice Technology on Favorable and Unfavorable Production Environments

30-3 Apr Korea-IRRI Planning Session (Korea)

April

9-10 IIMI-IRRI Collaborative Planning Meeting

9-12 Hunger Project Board Meeting

May

18-28 Varietal Improvement Monitoring Tour (Sri Lanka and Indonesia)

25-29 Workshop on Sustainable Agriculture: The Role of Green Manure Crops in Rice Farming Systems

June

5-6 DA-IRRI Technology Transfer Workshop

10-12 IRRI-France Collaborative Research Planning Meeting

22-23 Workshop on Rice Grain Quality in Domestic and International Markets

July

24-1 Aug Symposium on The Improvement of Tropical and Subtropical Crops at the International Botanical Congress (Federal Republic of Germany)

28-29 Integrated Pest Management and Nutrient Management in Rice Workshop

August

30-4 Sep 18th Asian Rice Farming Systems Working Group Meeting

September

14-18 Second Meeting of the Cooperative for Research on Problem Soils (India)

20-1 Oct INSFFER Site Visit Tour and Planning Meeting with ICAR (India)

21-25 International Rice Research Conference (Irrigated Rice) (China)

28-10 Oct Crop-Livestock Monitoring Tour (China and Philippines)

October

1-2 DA-IRRI Technology Transfer Workshop

10-25 Deepwater Rice Monitoring Tour (Thailand, Bangladesh, and India)

11-17 International Workshop on Crop Loss Assessment to Improve Pest Management in Rice and Rice-Based Farming Systems in South and Southeast Asia

12-14 IRTP-Africa Workshop (Senegal)

22-24 Rice Genetics Committee Meeting

26-30 Deepwater Rice Workshop (Thailand)

27 IRRI-IIMI Meeting

November

18-26 Second Differential Impact Study Workshop (Thailand and Indonesia)

December

1-4 Expert Consultation for Identifying Issues and Developing Methodologies for Measuring the Environmental, Socioeconomic, and Interactive Impacts of New Rice Technology

5-7 INSURF Planning Workshop

10-12 IRRI-Bhutan Workplan Meeting

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LIBRARY AND DOCUMENTATION CENTER

The 1986 supplement to the International bibliography of rice research was released in 1987. The 808-page volume contains 8,011 bibliographic citations on rice literature. Also included is a list of rice literature translations acquired during 1986. An additional 84 serial titles were scanned for the compilation. The bibliography is arranged according to subject matter, with author and keyword indexes.

At the end of 1987, the Rice Literature Search System, which became operational in 1985, had rice literature entries covering the years to 1987. All the original documents representing these citations are in the library's book and periodical collection and are being utilized to reply to worldwide requests for rice information.

The following publications were also issued in 1987:

- Theses and dissertations on rice available in the library of the International Rice Research Institute, 1987 supplement
- 12 issues of Library list of recent accessions (January to December 1987)

All the above publications were distributed, free, by the library to more than 600 libraries and documentation centers in the rice-producing world. A large number were also sold to subscribers.

There was a marked increase in the number of requests for information, particularly from India, Bangladesh, and Indonesia. Assistance in library organization and management, and in the selection and processing of special materials such as microforms, maps, pamphlets, and ephemera, was also given.

During 1987, the library provided in-service training to a librarian from the Bangladesh Rice Research Institute.

Lectures in literature searching and library use, and library tours were given to IRRI scholars, trainees, and visitors. The library also handled computer literature searches, textbook purchasing, thesis and dissertation binding, and provision of certificate folders.

Researchers and students from the Los Baños community, Metro Manila, and Central Luzon used the library facilities. The requests were not for rice literature alone, but for other disciplines as well.

At the close of 1987, the monograph collection (books, pamphlets, reprints, and translations) totaled 83,954. Serial titles reached a maximum of 3,474 during the year, but a few were excluded at year's end. Maps and microforms were also added.

To keep the scientists informed of the latest publications on rice, the library continued circulating tables of contents of newly received journals within IRRI and to several stations in Indonesia, Bangladesh, and Africa. The library also forwarded to the Commonwealth Agricultural Bureaux International (CABI) citations of Japanese and Chinese publications for inclusion in the CABI database, and the original documents for abstracting. The library was also a test site for the CABI CD-ROM Project.

During the year, the library sent input sheets of its serial holdings to the International Crops Research Institute for the Semi-Arid Tropics for the preparation of a union catalog of serials of the Consultative Group on International Agricultural Research (CGIAR) Center libraries. Likewise, to improve access to the knowledge base of the CGIAR centers, the library forwarded copies of "nonconventional" IRRI literature to CGIAR for inclusion in its Preservation and Dissemination Project.

EXPERIMENTAL FARM

During 1987, the Experimental Farm planted only 27.6 ha for seed multiplication and for rice for IRRI employees at Christmas. The following varieties and selections were planted: IR20, IR62, IR64, IR65, IR66, IR442, IR841, IR28224, IR28228-12-3-1-1-2, and IR42029-38-3-3-2. Cover crops like sesbania and crotalaria were also multiplied to supply the needs of the research departments.

A total of 25,497 rats were killed in IRRI fields during the year.

A total of $246,994 was paid for contract labor for land preparation (carabao and landmaster) ($30,718), planting and weeding ($68,935), and bird watching ($147,341); 59.7% of the amount was spent for bird watching.

Farm income for 1987 was $56,438 (Table 1).

As of year's end, we had in our seedroom 10,930 kg of seed valued at $3,551, and 15,528 kg of rough rice valued at $2,259.

Table 1. Farm income, IRRI, 1987.

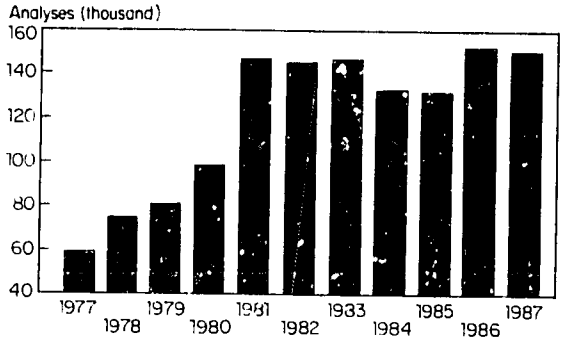
Item	Quantity (kg)	Value (US$)
Seed		
IR36	636	139
IR42	385	84
IR43	10	2
IR48	264	58
IR50	108	22
IR52	444	38
IR54	77	17
IR56	24	5
IR60	339	76
IR62	257	56
IR64	10,784	1,966
IR65	186	134
IR66	15,060	5,067
IR841	44	10
IR28224-3-2-3-2	110	36
IR28228-1-3-1-1-2	66	21
Rice for milling	66,932	9,277
Milled rice (IR64 and mixed varieties)		33,333
Milled rice (IR841)		910
Glutinous rice		3,787
Flint maize		32
Rejected maize		14
Green supersweet maize		1,018
Rice bran		62
Soybean		78
Sesbania crotalaria		194
Total		56,438

ANALYTICAL SERVICE LABORATORIES

Output, staff, and budget. The Analytical Service Laboratories (ASL) ran 151,556 analyses on 81,747 samples for 71 parameters in 1987. As in the past years, the number of analyses performed was close to the 150,000 mark, the apparent maximum capability of ASL with current space, equipment, and personnel (Fig. 1).

ASL was operated by a staff of 23, consisting of the manager, 6 research assistants, 1 research aide, 1 secretary, and 14 technicians and laborers. With 4,700 labor-hours of overtime and about 5,800 labor-hours of emergency hired help, ASL averaged nearly 3 analyses labor-hour, or about 21 min analysis.

Initial funding for the year was $6,000 for supplies, hourly help, and overtime. ASL earned nearly $120,000 on the charge-back system. Additional funding of $10,000 for equipment at year's end was used for 2 microcomputer systems and a microwave digester.



1. Output of the Analytical Service Laboratories, IRRI, 1977-87.

Research. The search for safe extraction methods and for rapid and reliable methods of analysis was continued.

Inductively coupled argon plasma (ICAP) spectrometer. The ICAP is a high-speed, automated system for multi-element analysis. Using an ICAP is faster than using an atomic absorption spectrophotometer (AAS) because the ICAP has a linear dynamic range and allows simultaneous analysis with a single aspiration of sample. Since the Model 3510 ARL ICAP was acquired, the following have been done preparatory to its adoption for routine analysis:

- Standardization
  - Scanning to identify the optimum wavelength
  - Correction for background continuum emission
  - Preparation of calibration standards suitable for plant and soil samples (root mean square error < 2%)
- Test runs
  - Na, Ca, and Mg analyses have been successfully done in ammonium acetate extracts of soil samples. Analyses of Ca and Mg in the ICAP do not require expensive lanthanum oxide required in atomic absorption spectrophotometry.
  - P, Fe, and Mn have been successfully analyzed in wet ashing digests in plant samples. P determination by ICAP spectrometry is faster than the colorimetric method presently employed.
  - Zn and Cu values in plant samples extracted with 1 N HCl are comparable to those obtained by AAS.

- Further tests need to be run to refine K and Al analyses.

Simultaneous ammonium-N and urea-N analysis. Floodwater samples submitted for analysis commonly require the determination of both NH_4^+-N and urea-N. The existing procedure analyzes these constituents in two separate Technicon Autoanalyzer I systems. A hybrid manifold for simultaneous analysis of NH_4^+-N and urea-N using Technicon Autoanalyzer II systems has been designed. The new procedure showed improved resolution and detection limit for both analyses.

Carbon and nitrogen analyses. The following modifications have been made in the use of the Perkin Elmer Model 240C elemental analyzer:

- changing the copper tubing of the O_2 and He inlet systems to polytetrafluoroethylene tubing to facilitate checking for leaks in the gas lines; and
- running two blank runs daily to prevent deterioration of the valves and to maintain the instrument at "run-ready" condition.

PESTICIDE RESIDUE LABORATORY

Sample load. The Pesticide Residue Laboratory (PRL) received 1,128 samples for complete analysis in 1987. Of these, 809 were water samples to be tested for residues of regularly applied organophosphates and carbamates as part of the Experimental Farm waterways monitoring project for pesticide runoff. The Entomology Department submitted 116 formulations of various pesticides as it wound up storage degradation studies it had started in 1984; another 55 samples were submitted for carbofuran, carbosulfan, and CGA 73102 residue analyses. PRL also determined monocrotophos levels in 123 gauze patch tests for the Safety Office's authorized pesticide applicator program. The Agronomy Department turned in 16 samples for paraquat analysis. The remainder were samples from the Plant Physiology and Soil Microbiology Departments. A total of 7,558 analyses were done on these 1,128 samples (Table 2).

The Cereal Chemistry Department sent in 29 samples and the International Rice Testing Program 18 samples for fatty acid methyl ester analysis.

Table 2. Analyses performed by the Pesticide Residue Laboratory, IRRI, 1987.

Test	Complete analyses	GLC[a] injections only
Carbofuran	864	
Diazinon	838	
Isoprocarb	838	
Monocrotophos	838	
Butachlor	809	
BPMC	809	
Acephate	809	
Carbaryl	809	
Chlorpyrifos	809	
Carbosulfan	55	
CGA 73102	55	
Paraquat	16	
Others	9	47
Total	7558	47

[a]Gas liquid chromatography.

Experimental Farm waterways monitoring project. The Pesticide Residue Laboratory has been monitoring IRRI farm waterways for residues of the pesticides commonly applied by IRRI researchers and of those pesticides on which Philippine Government regulatory agencies have set limits.

The water samples taken from IRRI waterways from the 1986 dry season (DS) to 1987 DS show that organophosphates and carbamates constitute the bulk of intact pesticides in IRRI runoff. No organochlorine pesticides were detected in any of the samples. The levels of total organophosphates and carbamates were at the 1 ppb level on the average, ranging as high as 20 ppb on occasion. These levels fall within the limits set by the Laguna Lake Development Authority and the National Pollution Control Commission of the Philippines.

PHYTOTRON

Fifty-seven research projects of 11 departments were conducted in the phytotron from January to October, and 1 project through December 1987. Of these projects, 43 were new and 15 were continuing experiments from 1985 and 1986. The users were senior staff, visiting scientists, postdoctoral fellows, and scholars.

Among the growth rooms, the artificially lighted cabinet (Koitotron HNL) had the highest oc-

cupancy rate (95%), followed by the glasshouses and the Conviron (92%). The HNL cabinet was used throughout the year for growing azolla germplasm collections. The occupancy levels of other rooms ranged from 80 to 88%. Most of the experiments lasted from 3 to 10 mo.

As in the past, the drying oven and cold room facilities were heavily used. The aeroponic equipment in the glasshouse room was used regularly for screening root characters. Fifty-nine requests were accepted for the use of the oven, cold room, and leaf area meter.

The phytotron spent $172,121 for electricity and $2,145 for diesel fuel in 1987. These expenditures included the cost of energy used by the Mass Spectrometry Laboratory, Personnel/Scientific Supply Store Building, Soils Laboratory, and Plant Physiology Department (formerly Tissue Culture Facility). Fifteen scheduled and unscheduled power interruptions were recorded, a total of over 148 h. During interruptions, the two generators were used.

Forty-four facilities were serviced and tested for standard performance in November and December. A new boiler was operated for water distillation.

SEED HEALTH UNIT

The Seed Health Unit (SHU) processed 810 requests for phytosanitary certification during 1987. These consisted of 97,991 seed lots from 1,550 sets of IRTP nurseries, and 40,749 from all other departments, including International Rice Germplasm Center (IRGC) material and breeding lines a total of 138,740 seed lots. Samples were drawn from 5,645 untreated seed lots and 5,633 treated seed lots for routine seed health tests (RSHTs). Based on RSHT results and specific requirements of the importing country, seeds were subjected to phytosanitary treatments of hot water (52-57 °C, 15 min) or mancozeb and benomyl seed dressing applied at 0.3% by weight. All materials were fumigated with aluminum phosphide prior to dispatching.

A total of 12,733 seed lots from 26 countries (63 shipments) were received by SHU for postentry quarantine clearing. Of these, 36% had been treated and 64% were untreated. RSHTs were carried out on 959 treated and 4,328 untreated seed lots. Eleven incoming seed lots were rejected due to severe seed infection with *Aphelenchoides besseyi*. Standard SHU treatments were administered to all incoming seeds.

SHU conducted crop health inspection on 3,866 entries planted during DS and 1,376 entries during the wet season in the seed increase plots of IRTP, IRGC, the Plant Breeding Department, and other IRRI departments. The entries inspected included incoming seeds. Significant diseases were sheath rot and narrow brown leaf spot. Rice tungro, ragged stunt, and grassy stunt viruses were not observed.

Three researchers from Laos, Thailand, and Vietnam attending the GEU Seed Production Program and Hybrid Rice Training Program spent 1 wk training in seed health tests and quarantine methods for rice in the SHU.

COMPUTER SERVICES

During 1987, response times and user service maintained high levels (response average 0.13 s; resource availability index 74% and decreasing; system availability 98.78%), even though 16 additional ports were made available to bring the total to 56.

The IRRI microcomputer population grew to around 300 during the year. Many of these were also used for data storage and analysis, relieving the load on the mainframe. However, many data have yet to be added to the central databases, and the present system will be unable to store the larger databases of GEU, the Soils Department, the Agricultural Economics Department, and others for on-line processing. At present most data processing is run in batch mode.

At the end of 1987, the Computer Center was reorganized. Following the recommendations of the External Management Review, the Center began to plan for the near and long-term future. Four items stand out:

- First is the plan to fill an urgent need for a general database to give scientists ready access to the vast amount of information at IRRI that is not easily available to them for the design and management of research. This step will also remove the direction and control of a

user department from IRRI's database, since it limits access by others. Under the aegis and management of the reorganized Computer Services, access by all will be assured.

- The second is the plan to fill another major need for specialized computer programs for the design, conduct, and analysis of experiments. Over and above their need for a common database, scientists must be able to simulate experiments and explore options.
- The third major item in the plan is to computerize administrative functions at IRRI, since all such functions have lagged far behind the research departments in computerization.
- The fourth and very critical area is computerization of project budgeting and control — the interface between science and administration. As IRRI moves into program management in 1988, each project needs to be budgeted and monitored continuously.

To implement these activities, an additional VAX 8350 computer was installed together with 16 terminals connected via an "Ethernet" network using fiber-optics cabling. For the ongoing need to store, process, and disseminate data, the Computer Center commenced projects to expand IRRI's computer network, identify suitable database management systems, and improve voice and data communication to facilitate the dissemination of information stored in IRRI's databases.

COMMUNICATION SUPPORT

The Communication and Publications Department (CPD), in addition to its editorial, information, distribution, and research functions, provides in-house communication support services to IRRI programs. These include typesetting, art and design, printing, and audio-visual services.

CPD printed 24 millions pages, in house, in 1987 (not including the printing of books and major periodicals, which are contracted out). About 120,000 slides were produced, 80% in color. About 6,000 pieces of black-and-white artwork were drawn, and about 10,000 black-and-white photos were developed.

Publications and seminars

PUBLICATIONS

Under Institute publications are listed the 17 major books produced by the Communication and Publications Department, 4 of which were copublished in 9 multilanguage editions; 8 monographs in the IRRI Research Paper Series on a variety of topics; and 7 periodicals. Subsequent sections list the output of individual scientists by department and additional bibliographies produced by the Library and Documentation Center.

Institute publications

Major publications

World rice statistics 1985. 276 p.
Global aspects of food production. 460 p.
Physical measurements in flooded rice soils: the Japanese methodologies. 69 p.
Strengthening national wheat and rice research systems. 55 p. (produced for the International Fund for Agricultural Development)
Upland rice: a global perspective. 364 p.
Efficiency of nitrogen fertilizers for rice. 260 p.
Weather and rice. 323 p.
Azolla utilization. 303 p.
A farmer's primer on growing soybean on riceland, by R. K. Pandey. 216 p. (jointly with IITA)
A farmer's primer on growing cowpea on riceland, by R. K. Pandey. 218 p. (jointly with IITA)
Annual report for 1986. 639 p.
IRRI highlights for 1986. 90 p.
A farmer's primer on growing rice (Lao edition), by B. S. Vergara. 221 p.
Insights of outstanding farmers (Tagalog edition). 114 p.
Helpful insects, spiders, and pathogens — friends of the rice farmer (English, French, Iloko, and Tagalog editions), by B. M. Shepard, A. T. Barrion, and J. A. Litsinger. 136 p.
Field problems of tropical rice (Sinhala, Malagasy, and Khmer editions). 172 p.
International bibliography of rice research: 1986 supplement. 808 p.

Research Paper Series

123. Upland rice insect pests: their ecology, importance, and control, by J. A. Litsinger, A. T. Barrion, and Dandi Soekarna. 41 p.
124. A review of agronomic wheat research at the International Rice Research Institute, by P. K. Aggarwal, S. P. Liboon, and R. A. Morris. 12 p.
125. Source-sink relationships in crop plants, by B. Venkateswarlu and R. M. Visperas. 19 p.
126. The effectiveness of language: a study of two rice extension publications in English and Cebuano among English-speaking change agents in the Philippines, by M. M. Haque, T. R. Hargrove, and P. L. Esteban. 6 p.
127. The effectiveness among farmers of *A farmer's primer on growing rice* in two Philippine dialects, by V. L. Cabanilla and T. R. Hargrove. 11 p.
128. Evaluation of 12 insecticides against green leafhopper for preventing rice tungro virus disease, by R. F. Macatula, S. L. Valencia, and O. Mochida. 9 p.
129. Solar radiation and rice productivity, by B. Venkateswarlu and R. M. Visperas. 22 p.
130. A model of resource constraints on turnaround time in Bangladesh, by A. Orr and N. Magor. 15 p.

Periodicals

International rice research newsletter, Vol. 12, nos. 1-6, plus Subject index
International azolla newsletter, Vol. 3, nos. 1-2
Deepwater rice, No. 12
Hybrid rice newsletter, Vol. 1, nos. 1-3
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Training and Technology Transfer

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SEMINARS

Thursday seminars and special seminars cover a wide range of topics. Saturday seminars report ongoing IRRI research. Unless otherwise stated, the speakers were IRRI staff members.

Thursday seminars

IRRI's research agenda in the context of global rice scenario. Dr. M. S. Swaminathan.

Current activities of chemical control group at the Department of Entomology. Dr. O. Mochida.

Raising the yield potential of rice. Dr. B. S. Vergara.

Self-reliance in the Philippine Livelihood Program. R. G. David, chief of staff, New Movement for Livelihood and Development, Manila.

Use of land for production and conservation. Dr. W. E. Larson, professor and head, Department of Soil Science, University of Minnesota, USA.

FRENTS housing technology. Mr. S. G. Aquino, Jr., president and general manager, FRENTS Housing Settlement, Inc., Manila.

Preparing to fly and actually flying basic travel and airline procedures. Ms. L. C. Gutierrez, manager, Thomas Cook, IRRI Sub-office.

Environmental management for disease vector control. Dr. R. Bos, scientist, Planning Management and Operations, Division of Vector Biology and Control, WHO, Geneva.

An underwater and archival search for the original towns of Tanauan and Lipa in Lake Taal, Philippines. Dr. T. R. Hargrove.

Rice research and production in Burma. Dr. P. B. Escuro, professor emeritus, University of the Philippines at Los Baños, College, Laguna.

Ending hunger: creating an idea whose time has come. Ms. Joan Holmes, global executive coordinator, The Hunger Project, USA.

Functional education for development. Dr. W. S. Griffith, project consultant, SEAMEO CIDA Project, SEARCA, College, Laguna.

Rice culture in Northern Queensland. I. Kay, senior entomologist, Department of Primary Industries, Queensland, Australia.

Recent irrigation developments in Sri Lanka a challenge to a third world economy. Dr. N. Ranaweera, visiting scientist, Agricultural Economics Department.

Interdisciplinary crop research: challenge for simulation modeling. Dr. F. W. T. Penning de Vries, visiting scientist, Multiple Cropping Department.

Inheritance of plant and internode elongation ability in rice (*Oryza sativa* L.). Dr. R. Thakur, visiting scientist and Dr. D. HilleRisLambers, plant breeder, Plant Breeding Department.

The occurrence of sulfur deficiency and the sulfur-demand relationship in Asian agriculture. Dr. G. J. Blair, Department of Agronomy and Soil Science, University of New England, Armidale, N. S. W., Australia.

The effectiveness among farmers of *A farmer's primer on growing rice* in two Philippine dialects. Ms. V. Cabanilla.

Problems and prospects in delivering IPM to farmers. Dr. P. E. Kenmore, regional programme coordinator, FAO UNDP.

The new communication technologies: some utilization trends. Dr. F. Librero, chairman, Department of Development Communication, UPLB, College, Laguna.

Approaches to rural extension: emphasis on linking research and extension. Dr. C. F. Azucena, director of extension, UPLB, College, Laguna.

IRRI beyond the external program and management reviews. Dr. M. S. Swaminathan.

Can research creativity be managed? Dr. R. V. Cuyno, director, Research Management Center, UPLB, College, Laguna.

Modeling the ricefield rat. Dr. E. Benigno, postdoctoral fellow, Entomology Department.

Deepwater rice in West Africa: some progress and constraints. Dr. F. J. Bangura, postdoctoral fellow, Plant Breeding Department.

New approaches to integrated pest management in the tropics. Prof. T. R. Odhiambo, director, International Center for Insect Physiology and Ecology (ICIPE), Nairobi, Kenya.

Management of crop residue to maximize asymbiotic nitrogen fixation in tropical agriculture. Dr. D. G. Patriquin, soil biologist, Dalhousie University, Halifax, Canada.

Department of Agriculture's thrusts and policies. Atty. D. Barbosa, undersecretary of agriculture, Department of Agriculture, Philippines.

Can Southeast Asia produce wheat? Potential and constraints in rice-based cropping systems. Dr. P. K. Aggarwal, visiting research fellow, Multiple Cropping Department.

Floral biology of rice in relation to hybrid rice seed production. Dr. H. Namai, associate professor, Institute of Agriculture and Forestry, University of Tsukuba, Sakuramura, Ibaraki-ken 305, Japan.

Physical edaphology of lowland rice soils and tillage for rice-based cropping systems. Dr. B. Mambani, postdoctoral scientist, Agronomy Department.

The sustainability of rehabilitation in rice-based irrigation systems: a comparative analysis of selected systems in the Philippines. Mr. C. Wensley, research fellow, Water Management Department.

Surviving, prospering, and the IRRI timepiece. Dr. D. J. Greenland, former deputy director-general, IRRI, and director for scientific services, CAB-International, Wallingford, Oxon OX10 8 DE, UK.

How insect ecology can solve rice farmers' pest problems. Dr. K. L. Heong, senior research officer, Central Research Laboratories, Malaysian Agricultural Research Development Institute, Serdang, P.O. Box 12301, 50774 Kuala Lumpur, Malaysia.

International dialogue on plant genetic resources: a plant breeder's view. Dr. J. Hardon, IRRI Board of Trustee, Centre for Genetic Resources, P.O. Box 224, 6700 AE Wageningen, The Netherlands.

Tilapia genetics and aquaculture development: a new research perspective. Dr. R. S. V. Pullin, director, Aquaculture Program, International Center for Living Aquatic Resources Management (ICLARM), Makati, Manila.

Developing ecological models to predict the performance of rhizobium in tropical soils. Dr. P. Singleton, NifTAL Project and MIRCEN, Department of Agronomy and Soil Science, University of Hawaii, P.O. Box 0, PAIA, Maui, HI 96779, USA.

Soil structure and water stability of aggregates measurement and modeling. Dr. G. Voss, collaborative research scientist, Soils Department.

Rice improvement for rainfed environments in Bihar, India. Dr. B. N. Singh, visiting scientist, Plant Breeding Department.

Causes of low rice yields in a predominantly rainfed region in India. Dr. M. D. Pathak.

The new paradigm for agricultural research with resource poor farmers: the opportunity and challenge for IRRI. Dr. R. Chambers, Institute of Development Studies, University of Sussex, Brighton, England.

The Kampuchea rice economy: an overview. Dr. P. L. Pingali.

Strengthening IRRI's international programs. Dr. F. A. Bernardo.

Saturday seminars

Evaluation of twelve insecticides for green leafhopper *Nephotettix virescens* (Distant) (Homoptera: Cicadellidae) control for preventing rice tungro virus disease. Mr. R. F. Macatula, Mr. S. L. Valencia, and Dr. O. Mochida.

Physiology of short-term varieties. Mr. P. Sta. Cruz, Mr. D. Aragones, and Dr. G. Wada.

Raising the yield potential of rice. Dr. B. S. Vergara, plant physiologist and head; Dr. B. Venkateswarlu,

visiting scientist; and Dr. J. K. Ahn, research fellow, Plant Physiology Department.

Farming systems research: the Khon Kaen University approach. T. Charoenwatana, Plant Science Department, Khon Kaen University, Khon Kaen, Thailand.

A socioeconomic perspective of an upland, acid rice environment, Claveria, Misamis Oriental. Mr. A. Mandac and Dr. J. C. Flinn.

Women in rice farming systems: a preliminary report of an action research project in Sta. Barbara, Pangasinan. Ms. T. Paris and Mr. B. Duff.

Differential impact of technical change in rural labor markets in favorable and unfavorable areas. Mr. E. Bautista and Dr. C. C. David.

An investigation of power requirement of the IRRI axial-flow thresher. Mr. B. Ramos, research scholar, Agricultural Engineering Department.

Computer application in agricultural engineering. Mr. E. Calilung and Mr. A. Mazaredo.

Isozymes in rice breeding. Dr. J. C. Glaszmann.

Combining ability and heterosis over environment in relation to hybrid rice breeding. Dr. Young Jubao, research fellow; and Dr. S. S. Virmani, plant breeder, Plant Breeding Department.

Genetic and associated studies on rice seed protein. Dr. V. V. Shenoy, research fellow; and Dr. D. V. Seshu, global coordinator, IRTP.

Rice and mungbean pest control practices in a drought and flood prone rainfed wetland environment, Solana, Cagayan, Philippines. Mr. B. Canapi, Dr. J. A. Litsinger, and Mr. A. T. Barrion.

Studies on some selected plant derivatives as paddy/rice protectants against stored grain insects. Dr. G. Jilani, postdoctoral scientist; and Dr. R. C. Saxena, entomologist, Entomology Department.

Sampling rice insect. Ms. E. Ferrer and Dr. B. M. Shepard.

N and P content of azolla collected from the Philippines. Ms. C. Ramirez.

Economical way of applying P to azolla. Ms. M. T. Lapis.

Chemical environments of aerobic soil in rice growth. Mr. D. K. Kundu, research fellow; and Dr. H. U. Neue, soil chemist and head, Soils Department.

Influence of soil drying on the chemical changes of flooded soils and rice growth. Mr. P. K. Patra, research fellow; and Dr. H. U. Neue, soil chemist and head, Soils Department.

Nonwaxy rice from *tapuy* (rice wine) production (a cooperative study). Dr. P. C. Sanchez, associate professor, Institute of Food Science and Technology, UPLB.

Food grain forage legume intercropping in rice-based farming systems. Mr. P. Tengco.

Landform, surface hydrology, and rainfed rice adaptation. Mr. P. Agustin.

Studies on breaking seed dormancy in *Sesbania rostrata* (Brem. and Oberm.). Mr. Md. Ruhul Amin, research scholar; Dr. D. P. Garrity, associate agronomist, Multiple Cropping Department; and Dr. R. C. Mabesa, assistant professor, Department of Horticulture, UPLB.

Sustainability of cropping systems in an acid upland environment. Mr. R. Magbanua and Dr. D. P. Garrity.

Adaptation to seedling age and hydrology in medium deepwater rice. Mr. V. Quimsing and Dr. D. P. Garrity.

Farm-level management systems for green manure crops in different rice environments. Dr. D. P. Garrity and Dr. J. C. Flinn.

The IRGC's role and services: germplasm conservation, seed dissemination, and technical assistance to national rice research systems. Dr. D. A. Vaughan and Dr. T. T. Chang.

Herbage production in a rice crop under natural deepwater conditions. T. Kupkanchanakul, Huntra Rice Experiment Station, Ayutthaya, Thailand; Dr. B. S. Vergara, plant physiologist and head, Plant Physiology Department; and Dr. A. Y. Robles, Dairy Training and Research Institute, College, Laguna.

Genetic analysis and virulence in the blast fungus, *Magnaporthe grisea*. Mr. E. Borromeo.

Effect of tungro-associated viruses on rice symptoms and yield. Dr. A. Hasamuddin, research fellow, Plant Pathology Department.

Effects of water deficit on rice blast disease development. Mr. L. M. Sanchez, research assistant; Dr. M. A. Gill, research scholar; Ms. A. Mackill, research assistant; and Dr. J. M. Bonman, associate plant pathologist, Plant Pathology Department.

Trichoderma—a potential biological control agent in rice-based cropping systems. Dr. A. Nagamani, postdoctoral fellow; and Dr. T. W. Mew, plant pathologist and head, Plant Pathology Department.

Seasonal changes of yield determining process of early maturing cultivars. Mr. F. T. Parao and Dr. S. Akita.

Growth and yield of monthly planted IR cultivars. Mr. F. T. Parao and Dr. S. Akita.

Relationship between nitrogen absorption and yield of paddy plants. Dr. G. Wada.

Characterization, quantification, isolation and conservation of N_2-fixing BGA from rice soils. Ms. S. Santiago-Ardales and Dr. P. A. Roger.

Evaluation of mineral solubility relations in flooded soils. Ms. J. B. Aduna, research assistant; Mr. E. B. Zarate, research assistant; Mr. D. K. Kundu, research fellow; Dr. P. R. Bloom, visiting scientist; and Dr. H. U. Neue, soil chemist and head, Soils Department.

Soil water retention: determination and application. Mr. P. Tolentino, Ms. M. L. Razal, and Dr. G. Voss.

Relationship between nitrogen, photosynthesis, and grain yield as affected by timing and method of nitrogen application in transplanted and direct seeded lowland rice. Dr. H. F. Schnier, collaborative research fellow; M. Dingkuhn, collaborative research fellow; Mr. J. E. Faronilo, research assistant; Ms. C. B. Javellana, research aide; Ms. E. P. Marqueses, research assistant, Mr. J. E. R. Wijangco, research assistant; and Dr. S. K. De Datta, principal scientist and head, Agronomy Department.

Effect of nitrogen timing and water deficit on nitrogen dynamics and growth of rice. Mr. E. Castillo, research assistant; Mr. J. Siopongco, research assistant; Dr. R. J. Buresh, visiting scientist; Dr. K. T. Ingram, associate agronomist; and Dr. S. K. De Datta, principal scientist and head, Agronomy Department.

The effect of transplanting *Echinochloa glabrescens* with rice and possible control methods. Dr. A. N. Rao, postdoctoral scientist; and Dr. K. Moody, agronomist, Agronomy Department.

Physical and management determinants of effective farm reservoir use in rainfed rice areas. Mr. P. G. Watson, collaborative research fellow; Mr. L. C. Guerra, research assistant; and Dr. S. I. Bhuiyan, agricultural engineer and head, Water Management Department

Water management for improving farm productivity in a coastal irrigation system Ms. M. A. Lantican, Mr. A. R. Sumayao, Mr. D. F. Tabbal, and Dr. S. I. Bhuiyan.

A progress report on pesticide levels in IRRI waterways 1986-87. Mr. R. A. R. Natividad, Mr. A. R. Sumayao, Dr. B. O. Juliano, and Dr. S. I. Bhuiyan.

Fate and efficiency of ^{15}N-labeled *Sesbania rostrata* green manure and urea in lowland rice. Mr. T. K. Biswas and Dr. S. K. De Datta.

Special seminars

Synthetic plant growth regulators. Dr. M. Halmann, The Wiezmann Institute of Science, Rehovot, Israel.

Quality of Hewlett-Packard (HP). V. Ang, managing director, Hewlett-Packard (ASEAN).

Modeling the climate-genetic interactions in rice. Dr. J. T. Ritchie, professor, Department of Crop and Soil Sciences, Michigan State University, USA.

Interparticle bonding and soil permeability. Dr. W. W. Emerson, CSIRO Division of Soils, Adelaide, South Australia.

The management of Laguna Lake and its watershed. M. D. Lopez, member, Presidential Committee for Laguna Lake.

A database management system for GFU. Dr. B. M. Octavio, postdoctoral fellow, Department of Statistics.

Soybean germplasm pools biochemical, structural, and physiological evaluations. Dr. D. A. Vaughan, The Land Institute, Solina, Kansas.

Global food policy issues and agricultural research priorities. Mr. J. W. Mellor, director, International Food Policy Research Institute, Washington, D.C., USA.

Physiological criteria in selection for salinity tolerance. Dr. A. R. Yeo, Sussex University, U.K.

Carl Zeiss microscopy seminar.

New discoveries concerning carbonate chemistry in wet and flooded soils and implications for crop management. Dr. P. R. Bloom, visiting scientist, Soils Department.

The Food and Fertilizer Technology Center in perspective. Prof. C. H. Huang, director, Food and Fertilizer Technology Center (FFTC), Taipei, Taiwan, R. O. C.

Azolla: the second arisen sun. M. Asfia, manager, Azolla Research Project, Iranian Research Organization for Science and Technology, No. 71, Forsat St., Enghelab Avenue, Tehran, Iran.

Dialogue with Los Baños Integrated National Police and barangay officials on security measures.

Complexation models and the absorption of ions on the surface of a variable charge system (soil:root). Dr L. Charlet, EAWAG (Swiss Federal Institute for Water Resources and Water Pollution Control), Switzerland.

Agroecosystems analysis. Dr. G. Conway, director, Centre for Environmental Technology, Imperial College of Science and Technology, London SW7 2AZ, England.

Seed vigor and associated studies in rice. Dr. V. Krishnasamy, postdoctoral scientist, IRTP.

Research and development on rice at Instituto de Agroquimica y Tecnologia de Alimentos (IATA). Dr. C. Benedito de Barber, Valencia, Spain.

Handling of statistical data in agricultural research. Dr. D. J. Finney, director, International Statistical Institute Research Centre, The Netherlands.

Durable disease resistance as an objective for plant breeders. R. Johnson, Plant Breeding Institute, Cambridge, England.

Socio-economic impact of plant diseases. Dr. K. Maramorosch, professor of entomology, Department of Entomology and Economic Zoology, The State University of New Jersey, Rutgers, Cook College, P.O. Box 231, New Brunswick, New Jersey 08903, USA.

Maturing of the Green Revolution: implication for the world rice market. Dr. D. O. Mitchel, senior economist, International Economics Department, World Bank, Washington, D.C., USA.

The unlimited potentials of the human mind. J. T. Licauco, head, The Human Resources Division, Andres Soriano Corporation.

CGIAR and IRRI's future. Dr. M. S. Swaminathan.

Recombinant DNA experiments and guidelines. Prof. B. Holloway, chairman, Department of Genetics, Morash University, Clayton, Victoria 3168, Australia.

Genetics of resistance to brown planthopper. Dr. R. Ikeda, plant breeder, National Tohoku Agricultural Experiment Station, Japan.

Staff changes

January

Dr. Osamu Mochida, entomologist, Entomology Department, left IRRI to join the Tropical Agriculture Research Center in Japan upon termination of his deputation period.

Dr. V. Pal Singh joined the Institute as consultant in the Asian Development Bank-funded IRRI Special Project on Adverse Soils, Soils Department.

Dr. W. W. Emerson, Commonwealth Scientific and Industrial Research Organization, Australia, arrived to work as consultant in the Soils Department for 1 mo.

Dr. K. Alluri, agronomist plant breeder, International Institute of Tropical Agriculture, and joint coordinator for International Rice Testing Program-Africa, joined as interim IRRI liaison scientist for West Africa.

February

Dr. George J. Moridis, agricultural engineer, Texas A&M University, joined the Institute as associate agricultural engineer in the Water Management Department.

Dr. Emmanuel Guiderdoni, Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT) Centre International de Recherche Agronomique pour le Developpement, joined the Institute as visiting scientist in the Plant Breeding Department.

Dr. E. A. Siddiq, plant breeder, IRRI-Egypt Collaborative Project, rejoined the Indian Council of Agricultural Research (ICAR) upon termination of the project.

Dr. Jack M. Swagerty, seed specialist, IRRI-Egypt Collaborative Project, left upon termination of the project.

Dr. W. W. Emerson, consultant, Soils Department, left after completing his assignment.

March

Dr. Z. R. Khan, collaborative research scientist, IRRI-International Centre of Insect Physiology and Ecology Project, was appointed associate entomologist in the same project, attached to the Entomology Department.

Dr. Frank W. Sheppard, Jr., research systems specialist IRRI representative in Bangladesh, retired.

Dr. Robert E. Huke, visiting scientist, Agricultural Economics Department, left after completing his assignment.

Dr. Gregor J. Wells joined as consultant in the Training and Technology Transfer Department.

April

Dr. Prabhu L. Pingali, economist (consultant), Agriculture and Rural Development Department, World Bank, joined as associate economist in the Agricultural Economics Department.

Dr. Paul S. Teng, associate professor, Department of Plant Pathology, University of Minnesota, joined as plant pathologist in the Plant Pathology Department.

Dr. Alastair W. Orr, visiting associate economist, Agricultural Economics Department, left after completing his assignment.

May

Dr. Kissen Kanungo, consultant, Director General's office, left after completing his assignment.

Mr. Ramesh D. Sharma, chief editor, Kheti, ICAR, India, joined as visiting editor for 6 mo in the Communication and Publications Department.

Dr. J. Samuel Fujisaka, visiting scientist, University of the Philippines at Los Baños, was appointed associate visiting scientist in the Agricultural Economics Department.

June

Dr. Jean-Christophe Glaszmann, visiting associate scientist, IRRI-IRAT Collaborative Project, left after completing his assignment.

Dr. Amir U. Khan, agricultural engineer and head, Agricultural Engineering Department, left to join Winrock International in Cairo, Egypt.

July

Dr. Robert E. Stickney, agricultural engineer, Agricultural Engineering Department, left the Institute.

Mr. Paul A. Cooper, director, Budget and Accounts, left the Institute.

Dr. Dennis J. Greenland, deputy director general, left to join the Commonwealth Agricultural Bureaux International (CABI), United Kingdom.

Dr. Paul R. Bloom, visiting scientist, Soils Department, left after completing his assignment.

Dr. Sang-Won Ahn, visiting associate plant pathologist, IRTP, was appointed associate plant pathologist, IRTP.

Mr. Sean E. O'Connor, consultant, Computer Center, was appointed computer hardware coordinator and acting head, Computer Center.

Dr. Duncan A. Vaughan, postdoctoral fellow at the Land Institute, Salina, Kansas, joined as associate geneticist in the International Rice Germplasm Center.

Dr. Bert J. Hoff, associate professor, Louisiana State University, joined as visiting scientist in the Plant Breeding Department.

Mr. Khin Win, managing director, Agriculture Corporation, Ministry of Agriculture and Forest, Rangoon, Burma, joined as visiting scientist to work with Dr. M. D. Pathak.

Dr. K. Takahashi, associate professor, Tohoku University, joined as visiting scientist in the Plant Pathology Department.

Ms. Jill Marie Sullivan, language consultant, World Health Organization, joined as consultant in the Training and Technology Transfer Department.

August

Dr. Fernando A. Bernardo, director, Southeast Asian Regional Center for Graduate Study and Research in Agriculture, joined as deputy director general of the Institute.

Mr. Joseph K. Campbell, professor, New York State College of Agriculture and Life Sciences, Cornell University, joined as visiting agricultural engineer in the Agricultural Engineering Department.

Dr Andrew Dua, honorary research scientist, Multiple Cropping Department, was appointed consultant in IRTP.

Mr. Edward N. Sayegh, financial controller and treasurer, International Center for Agricultural Research in the Dry Areas, joined as director, Finance Department.

Dr. Nicolas Mateo, senior program officer – crops, International Development Research Centre – Latin America, joined as associate visiting scientist in the Rice Farming Systems Program.

September

Mr. Devinder Sharma, development correspondent, Indian Express, India, joined as consultant in the Communication and Publications Department.

Dr. Dennis J. Greenland, director for scientific service, CABI, joined as special consultant to the director general.

Dr. Darshan Singh Brar, professor of tissue culture, Department of Plant Breeding, Punjab Agricultural University, joined as associate plant breeder in the Plant Breeding Department.

November

Mr. R. D. Sharma, visiting editor in the Communication and Publications Department, left after completing his assignment.

Dr. Edward D. Spratt, principal consultant of Agronomics International, Saskatoon, Canada, joined as project manager for the IRRI-Egypt Collaborative Project.

Dr. George C. Krajcsik, regional director of Computer Services and Information Centers, Cadbury Schweppes, Stamford, Connecticut, joined as software coordinator and head, Computer Services Department.

Dr. Dennis J. Greenland, director for scientific service, CABI, left after completing his assignment.

December

Dr. Yong-Won Jeon, associate agricultural engineer, Agricultural Engineering Department, left the Institute.

Dr. Gregor J. Wells, consultant in the Training and Technology Transfer Department, left after completing his assignment.

Dr. John M. Wilson, University College of North Wales, joined as visiting scientist in the Plant Physiology Department.

Dr. Robert E. Huke, professor of Geography, Darmouth College, joined as visiting scientist for 3 mo in the Agricultural Economics Department.

Finances

Summary of financial support to IRRI core and to special and collaborative projects received in 1987.[a]

	Amount (US$)			
	Core		Special and collaborative project	Total
	Unrestricted	Restricted		
Details of sources of support from grants				
International Bank for Reconstruction and Development	2,100,000			2,100,000
Japanese Government		5,586,934	994,182	6,581,116
Overseas Development Administration United Kingdom	1,389,113			1,389,113
Canadian International Development Agency	1,351,440			1,351,440
United States Agency for International Development		4,050,140	1,447,235	5,497,375
Asian Development Bank			664,600	664,600
Federal Republic of Germany	708,738		195,818	904,556
United Nations Development Programme		2,289,300	6,075	2,295,375
European Economic Community		2,044,292		2,044,292
Australian Government	646,185		390,711	1,036,896
International Development Research Centre		58,047	562,167	620,214
Government of Sweden	502,358			502,358
Government of Denmark	370,112		63,122	433,234
Swiss Development Cooperation		250,000	50,000	300,000
Rockefeller Foundation		355,400	343,000	698,400
Ford Foundation	**300,000**	**80,000**	244,000	624,000
Government of The Netherlands		**297,754**	200,897	492,651
Government of India	**246,782**			246,782
Government of Finland	233,481			233,481
Government of Norway	116,669			116,669
Organization of Petroleum Exporting Countries			154,329	154,329
Government of France		130,760		130,760
Office of Rural Development, Korea			98,000	98,000
Government of the Islamic Republic of Iran			83,030	83,030
Government of the Philippines	53,530		29,132	82,662
People's Republic of China	50,000			50,000
Government of Spain	30,000			30,000
Government of Mexico	**19,446**			19,446
Government of New Zealand	15,025			15,025
Miscellaneous research grants			48,611	48,611
Funds reimbursed under collaborative research program				
International Food Policy Research Institute			89,441	89,441
International Centre of Insect Physiology and Ecology		**81,637**		81,637
Resources Management International, Indonesia			65,107	65,107
University of Giessen			62,712	62,712
Istituto per la Chimica Del Terreno			50,000	50,000
International Fertilizer Development Center			45,514	45,514
International Center for Living Aquatic Resources Management			33,845	33,845
University of Hamburg			21,163	21,163
Consortium for International Crop Protection			16,553	16,553
International Institute of Tropical Agriculture			15,642	15,642
USDA University of Minnesota			13,814	13,814
Total	8,132,879	15,218,264	5,988,700	29,339,843

[a]Receipts are accounted for on a cash basis. Amounts shown in boldface differ from 1987 pledges by grantors in that they may reflect 1986 or 1988 pledges received in 1987 or may not reflect the full amount of 1987 pledges that are anticipated to be received in 1988. Also, the Government of France (through the research organizations ORSTOM and IRAT) provided IRRI the services of three resident scientists, the value of their services cannot be quantified.

Weather summary

The 1987 annual rainfall totals were 1,660 mm for the dryland (upland) site and 1,577 mm for the wetland (lowland) site (Table 1). These values were 414 mm lower than normal for the dryland site and 445 mm lower than normal for the wetland site. A 4-mo dry period occurred from January to April 1987 (Fig. 1). The longest dry spell experienced was 20 d (14 Jan to 2 Feb). The longest wet spell, 12 d, occurred between 31 Aug and 11 Sep at the wetland site. In summary, 1987 was dry compared to normal, with fewer tropical storms.

The average solar radiation was 16.6 MJ/m^2 per d at the dryland site and 16.8 MJ/m^2 per d at the wetland site (Table 1). Solar radiation was highest in May (21.7 MJ/m^2 per d) at the dryland site and in April (22.2 MJ/m^2 per d) at the wetland site (Fig. 2). Lowest solar radiation was in December (11.4 MJ/m^2 per d) at both sites. Bright sunshine at the wetland site was highest from March to May (9.4, 9.3, 9.4 h) and lowest in December (3.9 h).

The average daily temperatures were 31.9 °C maximum and 23.5 °C minimum at the dryland site, and 30.9 °C maximum and 23.2 °C minimum at the wetland site. The average maximum temperature was lowest at the dryland site in December, at 28.9 °C, and in January at the wetland site, at 28.0 °C; it was highest at the dryland site in May, at 35.5 °C, and at the wetland site also in May, at 34.0 °C (Fig. 3). The minimum temperature averages were lowest in February, with 21.2 °C at the dryland site and 20.1 °C at the wetland site.

Windspeed measured at 2 m above the ground was highest in February, with 2.1 m/s at the dryland site and 2.0 m/s at the wetland site; it was lowest at the dryland site in October, with 1.2 m/s, and at the wetland site in September, with 1.1 m/s (Table 1).

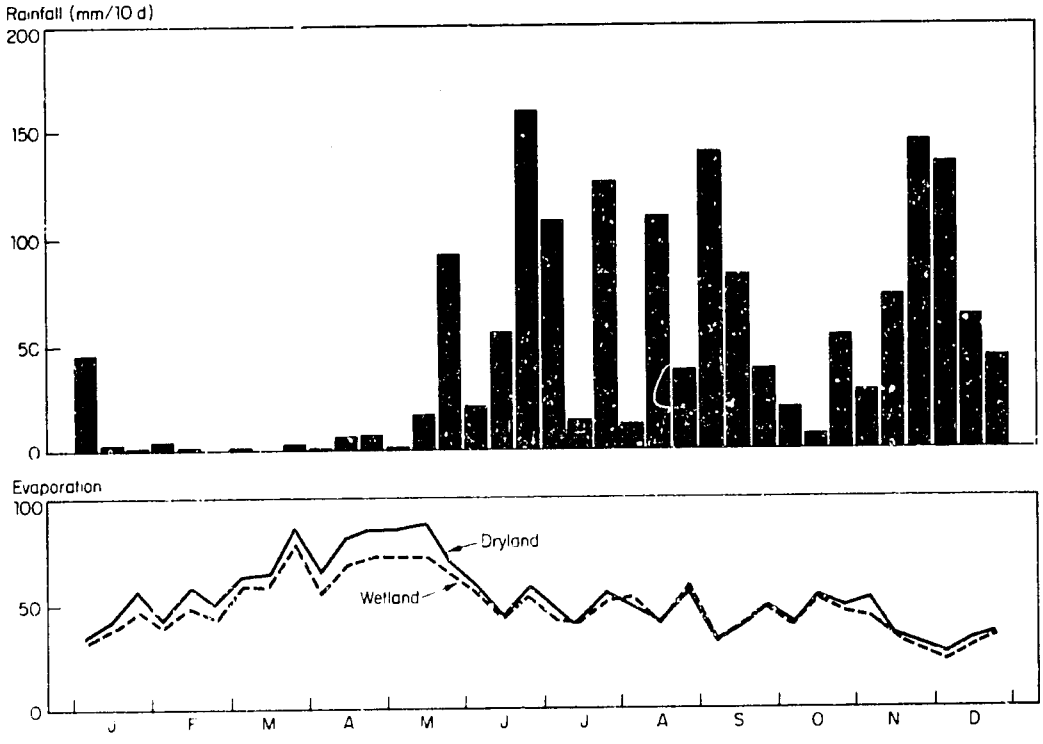
Total evaporation from the class A pan was higher at the dryland site (1,896 mm) than at the wetland site (1,742mm) (Table 1, Fig. 1).

Of the 16 tropical cyclones that passed through the Philippine area of responsibility during 1987, 9 affected Los Baños, although not directly, bringing forth intensified rain and winds.

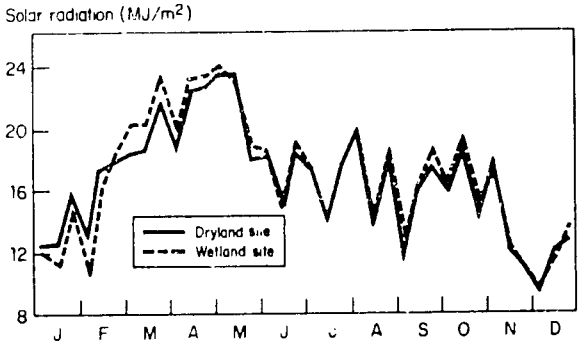
Table 1. Monthly weather data at IRRI dryland site (14°13'N, 121°15'E) and wetland site (14°11'N, 121°15'E), Los Baños, Laguna, Philippines, 1987.

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total or daily average
Dryland site													
Rainfall (mm/mo)	51	6	4	16	111	238	247	160	260	82	243	242	1660
Av solar radiation (MJ/m^2)	13.6	16.1	19.5	21.3	21.7	17.3	16.2	17.1	15.0	16.2	13.5	11.4	16.6
Av maximum temperature (°C)	29.2	29.7	32.5	34.6	35.5	33.2	31.9	32.2	31.6	32.6	30.9	28.9	31.9
Av minimum temperature (°C)	21.3	21.2	22.4	24.1	24.5	24.9	24.0	24.3	24.2	24.0	23.8	23.0	23.5
Windspeed (m/s)	1.9	2.1	1.9	1.8	1.4	1.6	1.5	1.6	1.4	1.2	1.9	1.7	1.7
Total evaporation (mm/mo)	135	152	215	232	245	164	139	143	118	141	118	94	1896
Wetland site													
Rainfall (mm/mo)	40	4	5	17	79	289	117	145	274	74	257	276	1577
Av solar radiation (MJ/m^2)	12.8	15.3	21.4	22.2	22.0	17.5	15.1	17.3	15.8	16.9	13.5	11.4	16.8
Av maximum temperature (°C)	28.0	28.1	30.7	32.3	34.0	32.7	31.6	31.7	31.3	31.7	30.1	28.5	30.9
Av minimum temperature (°C)	20.4	20.1	21.1	22.7	24.1	25.1	24.5	24.6	24.4	24.1	23.9	23.1	23.2
Windspeed (m/s)	1.8	2.0	1.9	1.6	1.3	1.3	1.2	1.5	1.1	1.2	1.4	1.5	1.5
Wind direction[a]	VRBL	ENE	ENE	ENE	E	VRBL	SSE	VRBL	VRBL	SSE	ENE	ESE	
Bright sunshine (h/d)	6.2	7.5	9.4	9.3	9.1	6.1	4.5	5.7	4.7	6.6	5.2	3.9	6.5
Total evaporation (mm/mo)	120	134	197	197	208	153	136	149	120	137	104	87	1742

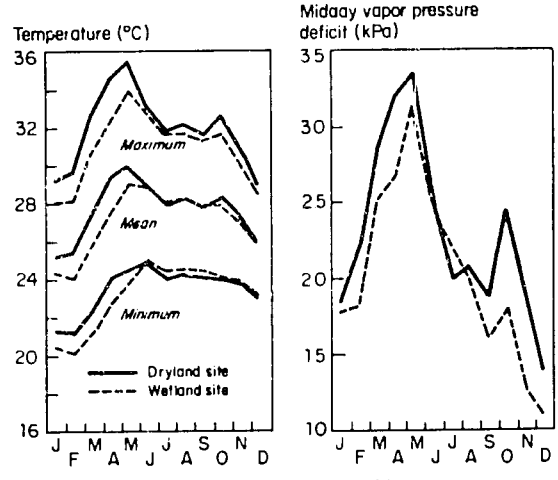
[a]VRBL = variable.



1. Rainfall and evaporation by 10-d period. IRRI, 1987.



2. Solar radiation by 10-d period. IRRI, 1987.



3. Average monthly temperature and midday vapor pressure deficit. IRRI, 1987.