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International Rice Research Institute

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[1]Left during the year.
[2]On study leave.
[3]Joined and left during the year.
[4]Joined during the year.
[5]Cooperative research staff.
[6]On project appointment.
[7]Transferred from Plant Pathology to International Rice Testing Program.
[8]Transferred from Pesticide Residue Laboratory to Training and Technology Transfer.
[9]Transferred from Training and Technology Transfer to Plant Breeding.
[10]Transferred from Statistics to Training and Technology Transfer.
[11]Died during the year.

About this report

This 25th annual report reviews research conducted by IRRI staff during 1986. Some experiments are summarized completely. Others are ongoing, and interim results are reported. In all cases, further information can be obtained from the departments identified in section and subsection headings, as this volume is necessarily abbreviated. 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 this collaboration, it is covered specifically in the Cooperative Programs section. Three programs that are predicated 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 under Cooperative Programs. Other sections that include a particularly strong international focus are Machinery Development and Testing, and Training Programs.

The volume of detail requires many abbreviations, which 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.

This 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. Deep water 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 at 14% moisture content, 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. Backcrosses are indicated by a superscript numeral.

Unless otherwise noted, scoring of morphological characters and of damage attributed to rice pests and physiochemical stresses is based on scales in the *Standard evaluation system for rice* (SES), 2d ed., 1980. Copies are available from the IRTP, 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
ABA = abscisic acid
AC = amylose content
ACC = 1-aminocyclopropane-1-carboxylic acid
ai = active ingredient
AIRAT = African Irrigated Rice Advanced Trial
AIRON = African Irrigated Rice Observational Nursery
AIRPSS = African Irrigated Rice Preliminary Screening Set
AN = ammoniacal nitrogen
AP = aminopeptidase
ARA = acetylene-reducing activity
ARSFN = Asian Rice Farming Systems Network
AURAT = African Upland Rice Advanced Trial
AURON = African Upland Rice Observational Nursery
AURPSS = African Upland Rice Preliminary Screening Set

BA = benzyladenine
BADC = Bangladesh Agricultural Development Corporation
Bak = bakanae
BARI = Bangladesh Agricultural Research Institute
BB = bacterial blight
BC = backcross
B:C = benefit-to-cost ratio
BGA = blue-green algae
B&I = broadcast and incorporated
Bl = blast
BLS = bacterial leaf streak
BPH = brown planthopper
BPI = Bureau of Plant Industry, Philippines
BR = broadcast seeded rice
BRP = brown rice protein
BRRI = Bangladesh Rice Research Institute
BS = best split
BSi = bush sitao
BWDB = Bangladesh Water Development Board

CAAS = Chinese Academy of Agricultural Sciences
CABO = Centre for Agrobiological Research, The Netherlands
CAI = cellulolysis adequacy index
CEC = cation exchange capacity
CFU = colony-forming unit
CGIAR = Consultative Group on International Agricultural Research
CGR = crop growth rate
CIMMYT = Centro Internacional de Mejoramiento de Maiz y Trigo
CIPR = Christmas Island phosphate rock
CIRAD = Centre International de Recherche Agronomique pour le Developpement, France
CMS = cytoplasmic male sterile
C:N = carbon-to-nitrogen ratio
CNRRI = China National Rice Research Institute
CP = cowpea

CRIFC = Central Research Institute for Food Crops, Indonesia
CSIRO = Commonwealth Scientific and Industrial Research Organization
CV = common variance, coefficient of variation
CW = caseworm
CY = crop year

DAD = days after draining
DAI = days after inoculation
DAP = days after planting
DAPI = days after panicle initiation
DAS = days after seeding, days after sowing
DBPI = days before panicle initiation
DBS = days before seeding, days before sowing
DBT = days before transplanting
DE = days after emergence
DF = days after flowering
dH = dehydrogenase
DH = days after heading
DM = dry matter
DMRT = Duncan's multiple range test
DP = deep placed, deep placement
DRRI = Dokri Rice Research Institute, Pakistan
DS = dry season
DT = days after transplanting
DWR = deepwater rice

EC = electrical conductivity
EI = efficiency index
ELISA = enzyme-linked immunosorbent assay
EPG = eggs per gram
EV = early variety

FAO = Food and Agriculture Organization
FAS = fluorescent-antibody staining
fb = followed by
FCC = Fertilizer Capability Classification
FFFIA = Father Farmer Irrigators Association, Philippines
FIA = farmers irrigators association
FMD = foot and mouth disease
FMP = fused magnesium phosphate
FOFIFA = National Center for Applied Research on Rural Development, Malagasy Republic
FR = farm reservoir
FTM = fertilizer testing model

GA_3 = gibberellic acid
GB = germplasm bank
GC = gel consistency
GCA = general combining ability
GEU = Genetic Evaluation and Utilization
GHC = green hairy caterpillar
G-K = Ganges-Kabodak Irrigation System, Bangladesh
GLH = green leafhopper
GSV = grassy stunt virus
GT = gelatinization temperature

HD = high density
HI = harvest index
HMB = higher mobility band
HRP = highly reactive rock phosphate

IAEA = International Atomic Energy Agency
IAP = ion activity product
IAS = Institute of Animal Science, UPLB
IBPGR = International Board for Plant Genetic Resources
ICAR = Indian Council of Agricultural Research
ICRISAT = International Crops Research Institute for the Semi-Arid Tropics
IDRC = International Development Research Centre, Canada
IDS = irrigated dry season
IFDC = International Fertilizer Development Center
IFRON = International Floating Rice Observational Nursery
IFST = Institute of Food Science and Technology, UPLB
IITA = International Institute of Tropical Agriculture
INSFFER = International Network on Soil Fertility and Fertilizer Evaluation for Rice
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
IRIS = Inarihan River Irrigation System, Philippines
IRON = International Rice Observational Nursery
IRRI = International Rice Research Institute
IRRSWON = International Rainfed Rice Shallow Water Observational Nursery
IRSATON = International Rice Salinity and Alkalinity Tolerance 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
ISF = irrigation service fee
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
IVDMD = in vitro dry matter digestibility
IVOMD = in vitro organic matter digestibility
IWS = irrigated wet season

LAI = leaf area index
LCPIS = Libmanan-Cabusao Pump Irrigation System, Philippines
LD_{50} = duration, in days, to 50% mortality

LER = land equivalent ratio
LF = leaffolder
lps = liters per second
LRP = less reactive rock phosphate
LSc = leaf scald
LSD = least significant difference
LSS = line source sprinkler
LWR = length-to-width ratio

M = maize
MAF = Ministry of Agriculture and Food, Philippines
MB = mungbean
MBCR = marginal benefit-cost ratio
MDW = medium deepwater and deepwater
MORIF = Maros Research Institute for Food Crops, Indonesia
MRM = multifertilizer response model
MRP = milled rice protein
MRR = marginal rate of return
MRRTC = Maligaya Rice Research and Training Center, Philippines
MV = modern variety
MVP = mean viability period

NAR = net assimilation rate
NBPT = N-(n-butyl) thiophosphoric triamide
NIA = National Irrigation Administration, Philippines
NIAS = National Institute of Animal Science, Denmark
NSKE = neem seed kernel extract

OC = organic carbon
OM = organic matter
OPV = open-pollinated variety
ORSTOM = Office de la Recherche Scientifique et Technique Outre-Mer, France
OTMS = Ottawa texture measuring system
OYT = observational yield trial

P = peanut
PAR = photosynthetically active radiance
PARC = Pakistan Agricultural Research Council
PB = phosphate buffer
PET = potential crop evapotranspiration
PI = panicle initiation
PP = pigeonpea
PPD = phenyl phosphorodiamidate
PPH = plants per hectare
PRIS = Pampanga River Irrigation System, Philippines
P/S = protein per seed
PU = prilled urea
P-V = pressure-volume

R = rice
RAVC = return above variable costs
RB = rice bug
RCBD = randomized complete block design
RDA = Rural Development Administration, Korea
RGA = rapid generation advance
RH = relative humidity

RRP = rough rice protein
RS = rapeseed
RSV = ragged stunt virus
RTBV = rice tungro bacilliform virus
RTSV = rice tungro spherical virus
RTV = rice tungro virus, tungro
RWM = rice whorl maggot
RYT = replicated yield trial

S = sorghum
SA = South Asia
SB = soybean, stem borer
SCU = sulfur-coated urea
SD = standard deviation
SEA = Southeast Asia
SES = *Standard evaluation system for rice*
ShB = sheath blight
ShR = sheath rot
SIDA = Swedish International Development Authority
SMT = soil moisture tension
SP = sweet potato
SRL = shallow rainfed
SSB = striped stem borer

TARC = Tropical Agriculture Research Center, Japan
TDMY = total dry matter yield
TDN = total digestible nutrients
TDRI = Tropical Development and Research Institute, England
TPR = transplanted rice
TSP = triple superphosphate

UPE = upland pan evaporation
UPLB = University of the Philippines at Los Baños
UR = upland rice
USAID = United States Agency for International Development
USG = urea supergranules

VAM = vesicular-arbuscular mycorrhizal fungi
VDW = very deepwater
VISCA = Visayas State College of Agriculture, Philippines
vol = volume

W = wheat
WA = wild aborted
WAI = weeks after inoculation
WARDA = West Africa Rice Development Association
WAS = weeks after seeding, weeks after sowing
WBPH = whitebacked planthopper
WIRFS = Women in Rice Farming Systems program
WS = wet season

Xco = bacterial blight caused by *Xanthomonas campestris* pv. *oryzae*

YSB = yellow stem borer

Genetic evaluation and utilization (GEU) program

Genetic resources program

International Rice Germplasm Center and Statistics Department

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FIELD COLLECTION AND SEED DEPOSITS

International Rice Germplasm Center (IRGC)

Direct collaboration with national centers in collecting indigenous rice germplasm was phased out in 1986 when the International Board for Plant Genetic Resources (IBPGR) ceased to fund such activities. On the other hand, the 12 participants in the Genetic Resources Conservation and Management Training Course were required to conduct 3-mo field collection activities in their home countries as part of their training. They brought to IRRI 984 seed samples as follows: 63 from Burma, 12 from China, 164 from Ghana, 317 from India, 96 from Indonesia, 50 from Malaysia, 125 from Sri Lanka, 91 from the Philippines, 50 from Vietnam, and 6 cultivars and 10 wild rices from Ethiopia.

Limited collection activities were implemented by local workers in India, the Philippines, and Thailand. About 870 seed samples were received from these and earlier collection missions.

Major donors of seed to the IRGC follow:

- Anhui, Jiangxi, Yunnan, and Sichuan Provinces of China — 1,002 samples
- Central Research Institute for Food Crops, Indonesia — 766 samples
- Pathum Thani and Prae Rice Research Centers, Thailand — 441 samples
- National Bureau of Plant Genetic Resources and the Shillong Research Complex of the Indian Council of Agricultural Research — 338 samples
- National Institute of Agrobiological Resources, Japan — 121 native and 48 improved varieties, plus 36 blast testers
- Vietnam Agricultural Science Institute, Hanoi — 200 samples
- IBPGR collection team working in Togo — 12 samples of *Oryza glaberrima* and 3 *O. sativa* cultivars

The International Rice Testing Program placed 232 promising entries in the IRGC collection. From many other small donations, 4,159 seed samples in all were received in 1986, an 11% increase over the average annual total of the past decade.

INVENTORY, CHARACTERIZATION, AND DATA PROCESSING

International Rice Germplasm Center and Statistics Department

At the end of the year, IRGC holdings consisted of 72,460 registered accessions of *O. sativa*, 2,983 strains of *O. glaberrima*, 2,268 populations of wild species, and 700 genetic testers and mutants. Planted in November and December were 3,391 recently arrived seed samples of *O. sativa*; another 192 remained to be planted.

For initial seed increase, 4,503 plots were planted; for field characterization, 4,751. Field and laboratory characterization were completed for 3,000 *O. sativa* accessions, resulting in 60,047 accessions completely characterized. Characterization of the African rices and wild species was continued, with the complete characterization of 1,311 African rices and 786 wild taxa.

Microcomputer files for IRRI-involved field collections were established for past collection missions, totaling 1,893 samples. Among the samples collected from unfavorable production areas, separate lists were set up for deepwater tolerance (803 accessions) and salinity tolerance (412 accessions). The IRGC computer now handles incoming entries, canned accessions, characterization data of wild species, and various files needed by the IRGC.

A micro-based Seed Inventory System developed by the Statistics Department was tested and implemented to speed up the recording of the canned (long- and medium-term preservation) accessions. The seed system allows interface with the centralized mainframe-based GEU database system; 55,996 records on 27,998 canned accessions were transferred from the mainframe to the IRGC microcomputer.

The Statistics Department and IRGC also collaborated in developing a generalized micro-based data management system that will aid national rice genebanks in processing their data. The system includes facilities for data entry, data editing, data update, report generation, and information retrieval.

SEED INCREASE, REJUVENATION, AND DISTRIBUTION

International Rice Germplasm Center

The total land area devoted to seed production both inside and outside IRRI totaled slightly under 30 ha, which was less than that of previous years because of reallocation of land use on the IRRI farm, use of space by the Genetic Resources Conservation and Management Training Course trainees, and severe Zn deficiency on part of the rented fields at Dayap, Laguna. Seed production from the field plantings outside IRRI was adversely affected by an unusually rainy wet season, frequent flooding, Zn deficiency, and high incidence of stem rot. A combination of these factors resulted in poor seed production, in spite of the slightly larger number of plots devoted to rejuvenation: 13,736 in 1986 vs 12,800 in 1985.

Seed distribution to IRRI researchers and rice scientists abroad showed an increase over the average amounts of the past decade. IRRI scientists and trainees obtained 39,135 seed samples of *O. sativa* under 327 requests; other researchers requested 9,897 samples on 187 occasions. The demands for nearly 2,850 samples of wild species and *O. glaberrima* more than doubled those of 1985. The bulk of requests for such exotic germplasm came from workers in biotechnology. The IRGC found it necessary to plan for an expansion of the screened nursery area to produce such difficult-to-grow germplasm.

Quality control of seed being distributed was strengthened. Every seed sample for rejuvenation, distribution, and preservation was checked against seeds stored in the seed file, and the morpho-agronomic data were consulted when necessary.

During the year, 361 wild species were multiplied in response to researcher requests in addition to 430 wild rices grown in late 1985 for both characterization and seed increase. However, the seed supply still lagged behind the recent surge in demand. Meanwhile, 660 African rices were grown for seed rejuvenation.

A 2-page leaflet was prepared to guide the users of IRGC services in obtaining correct seed and related information and in receiving the same accession for retesting. The guidelines are distributed to IRRI staff, scholars, foreign researchers, and national genebanks. For the proper care of difficult-to-grow wild species, we have been supplying a similar leaflet to users.

SEED PRESERVATION

International Rice Germplasm Center

In recent years, a large proportion of the incoming seed samples were collected by extension workers of national centers from farmers' fields. Some farmers prefer to keep a mixture of genotypes as seed, largely as insurance against adverse weather or changes in pest incidence. Such intentional mixtures have posed a serious problem to conservationists because nearly all breeders and affiliated researchers would like to receive purified seed. More stringent measures in seed purification were implemented in early 1986 by selecting panicles in the headhouse prior to threshing. The added operation has helped to purify the seed stocks to some extent, but it has also reduced the seed quantities and consumed much more staff time in the preservation phase.

With 3,946 accessions of *O. sativa* — about one-third of the samples grown for rejuvenation — selected, dried, and sealed in aluminum cans during 1986, the year-end total of canned accessions was 27,838. At year end, only one-third of the total collection of cultivars had been sealed in cans and deposited at a duplicate site (National Seed Storage Laboratory, Ft. Collins, Colorado, USA).

STUDIES ON SEED VIABILITY

International Rice Germplasm Center

The monitoring of the seed viability of 3 varieties during the past 23 years continued. The two tropical and dormant varieties, Siam and Peta, retained their germinability at 95 and 94%, respectively, at the end of the year, while Chianan 8 hovered between 10 and 40% in 2 semiannual tests. The longevity pattern was essentially the same as

that for 1985 (Annual report for 1985). This experiment is the longest continually monitored seed longevity study in crop science.

We also monitored seed viability levels of remnant seeds stored in the fumigated short-term storeroom (19 °C, 50% relative humidity [RH], and 10% seed moisture content) before we discarded the seeds so as to make room for newly harvested seeds. The viability levels of 59 accessions from 7 countries after 5-6 yr of storage were compared with those of seeds stored for 3½ yr and tested in 1979. The 1980-81 harvested seeds had markedly higher viability levels than those harvested in 1975 (Table 1), mainly because the seed production fields had been moved from pest-ridden fields on the old IRRI farm in the 1970s to the upland farm in 1980 and to an off-station field in 1983. This marked improvement in seed longevity is more obvious in temperate-zone varieties of China, Japan, and Italy, which are highly susceptible to virus diseases. Tropical varieties having strong grain dormancy have retained their germinability better than the nondormant accessions from temperate and tropical countries.

TRAINING OF GENEBANK MANAGERS FOR NATIONAL CENTERS

International Rice Germplasm Center and Statistics Department

IRRI's first Genetic Resources Conservation and Management Training Course, which had begun in October 1985, was completed at the end of September. Twelve participants from 8 Asian and 2 African nations implemented a 3-mo field collection in their home countries during late 1985, completed the 2-wk rice production course and the 3½-mo Genetic Evaluation and Utilization Course, and acquired 5 mo of intensive training in the scientific knowledge of and practical skills in genetic conservation. The participants also planted, characterized, harvested, and processed their collected seed samples for preservation. At the end of the course, the participants were awarded the Associate of IRRI Diploma, the first of its kind.

The intensive course is unique in combining a complete array of academic lectures with the hands-on practices of a genebank in a crop-oriented research institute. With the participation of lecturers from other conservation-oriented institutions, especially the University of the Philippines at Los Baños, the trainees also acquired knowledge of other crops. Field and laboratory exercises occupied a major portion of the time the trainees spent in Los Baños (Table 2).

This unique training course was funded by the Italian Ministry of External Affairs and the IBPGR. Foreign lecturers came from the Nordic and Bari genebanks and the IBPGR.

Table 1. Mean viability of seeds of different national origins in the short-term storeroom from 1975 and 1980-81 harvests, IRRI, 1986.

Country of origin	1975 (3½-yr storage)		1980-81 (5-6 yr storage)	
	Mean viability (%)	Accessions tested (no.)	Mean viability (%)	Accessions tested (no.)
China	30	8	97	8
India	72	13	87	14
Indonesia	75	12	92	6
Italy	2	4	80	3
Japan	16	16	61	6
Sri Lanka	90	7	91	8
Thailand	80	7	81	14

TECHNICAL ASSISTANCE TO NATIONAL AND STATE CENTERS

International Rice Germplasm Center

The IRGC extended to genebanks in China and India technical assistance on genebank design and choice of laboratory equipment. Construction of the National Crop Germplasm Resources Storage Center of China in Beijing was completed in October with scientific inputs from the IRGC. Laboratory technicians and engineers of the Chinese genebank also received training at IRRI.

The agricultural research station of the Andhra Pradesh Agricultural University at Maruteru and the Agricultural Research Institute at Patna, Bihar, in India requested the return of seed samples of their entire rice collections deposited earlier with IRRI and received 98 and 63 accessions, respectively.

Table 2. Time spent on topics in class, laboratory, and field, Genetic Resources Conservation and Management Training Course, IRRI, 1985-86.

Topic	Time (h)	
	Lectures	Laboratory and field exercises
Field collection in participant's home country	9.5 at IRRI	320+ (2 mo)
Principles of biosystematics	6	7.5
Plant geography	1.5	6
Crop evolution and history	7.5	8
Population genetics	11	6
Quantitative genetics	11	6
Seed physiology	8	12
Morphology and physiology of the rice plant	4.5	6
The genus *Oryza* (including wild rices)	6	20.5 and 1-d field trip
Evolution of cultivated rices	4.5	8
Systematic characterization	3	21
Genebank operations: registration, seed processing, and quality control	13	31.5
Seed preservation	8	20.5
Seed viability and monitoring	4.5	21.5
Refrigeration and dehumidification equipment	4.5	3
Design and management of genebanks	9.5	17
Seed health	4	5.5
Evaluation and use of exotic germplasm	4.5	(under GEU training course)
Documentation	6	20
Biostatistics	13.5	8
Use of microcomputers	16	16
In vitro and in situ conservation	3	9.5
Availability of crop germplasm and related politico-socio-economic issues	6	–
Participation in IRGC activities	–	51
Special project: Seed increase and characterization of the collected rice samples	–	243.5
Communication process, scientific communication, and miniseminars:	10.5	74.5
Field collection		
Country report on rice germplasm		
Wild species		
GEU traits		
Genetic resources and conservation of crops other than rice	13	6

In December, 752 traditional wetland varieties of the Philippines were grown for seed increase. The multiplied seed will be turned over to the Philippine Ministry of Agriculture and Food in 1987 for further seed increase and distribution so that Filipino farmers who want these difficult-to-obtain varieties may have access to the seed.

A brochure on traditional Philippine varieties preserved in IRGC was prepared.

Genetic evaluation and utilization (GEU) program

Agronomic and physiological characteristics

Agronomy, Plant Physiology, and Multiple Cropping Departments

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MAXIMUM YIELD EXPERIMENT

Agronomy Department

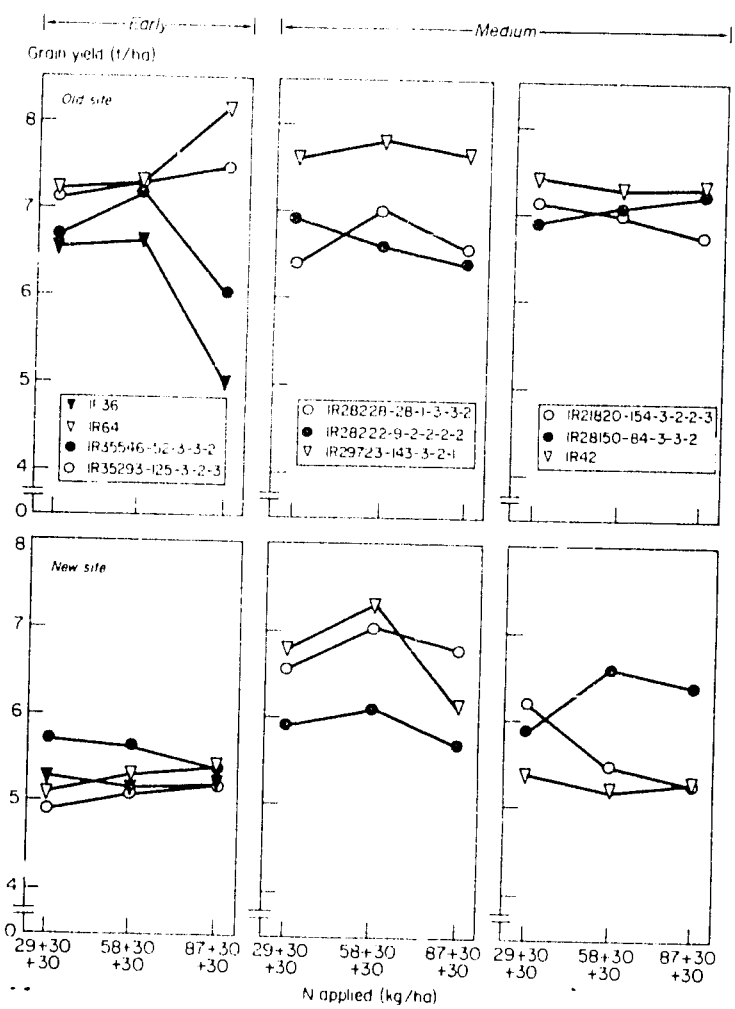
IRRI. Ten early- and medium-maturing rices received varying N rates. Urea supergranules were deep-placed, followed by topdressing of prilled urea at the desired growth stage. Planting dates were staggered for uniform ripening at two IRRI sites.

In the dry season (DS), IR64 yielded the highest (8.1 t/ha) among the early-maturing and IR29723-143-3-2-1 (7.8 t/ha) among the medium-maturing rices at the old site (Fig. 1). Yields at the new site were generally lower because of more severe lodging, especially at the highest N rate. Except for IR64 at the old site, no significant yield response to increasing N rate was observed.

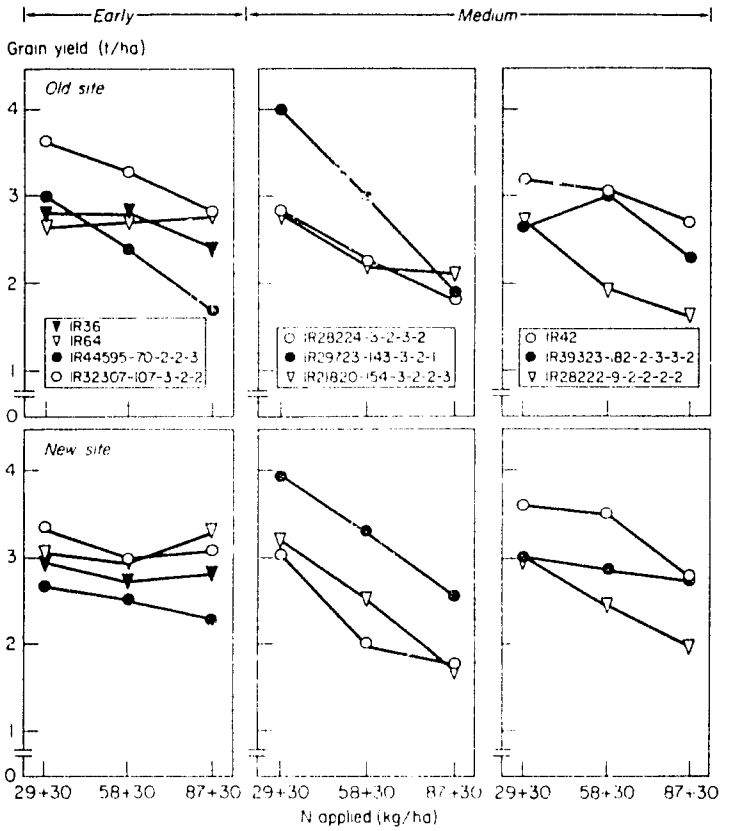
In the wet season (WS), the medium-maturing IR29723-143-3-2-1 and early-maturing IR32307-107-3-2-2 consistently gave highest yields in their maturity groups at both sites (Fig. 2). In general, there was a negative yield response to increasing N rate.

Low yields in DS were attributed mostly to lodging. In WS, stem borer, sheath blight, leaf scald, bacterial leaf streak (LS), and lodging were the major causes of yield reduction.

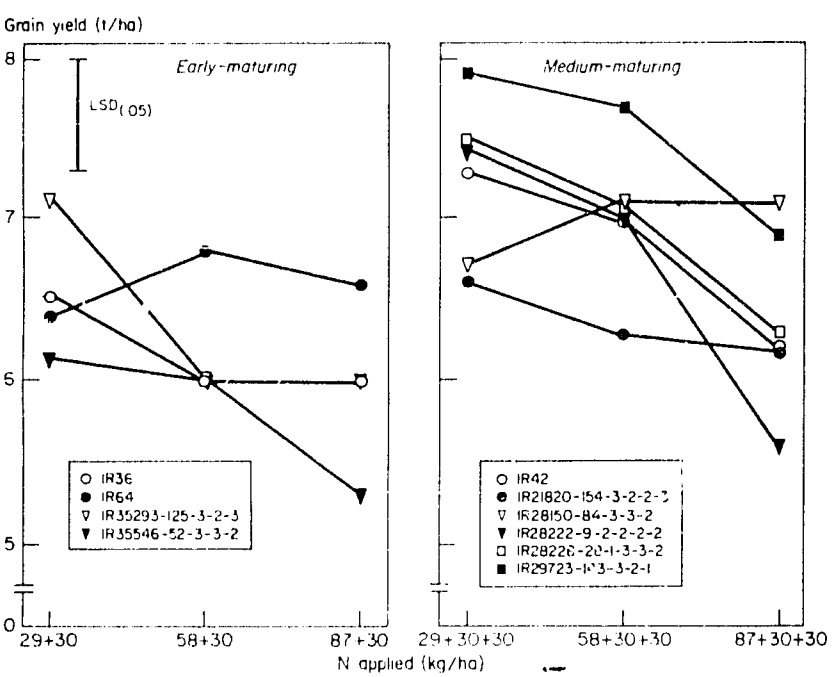
Farmer's field. In DS, most of the test rices attained a maximum yield at the lowest level of applied N. Only the yields of early-maturing IR64 and medium-maturing IR28150-84-3-3-2 increased with an increase in N application rate (Fig. 3). IR29723-143-3-2-1 yielded the highest with 7.9 t/ha. This medium-maturing cultivar has given the



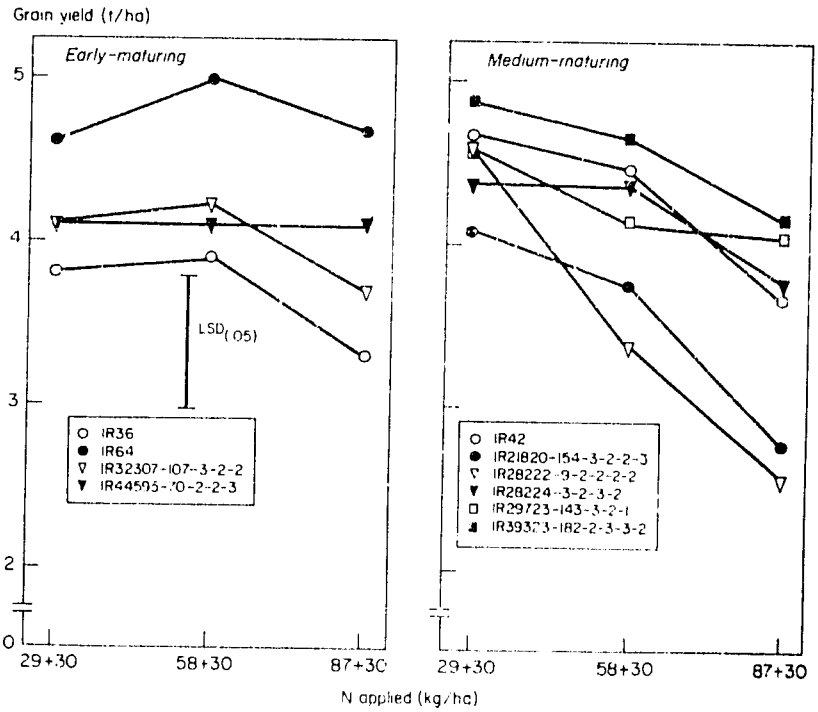
1. N response and grain yield of early- and medium-maturing rices at 2 sites, IRRI, 1986 DS.



2. N response and grain yield of early- and medium-maturing rices at 2 sites. IRRI, 1986 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. 1986 DS.



4. Yields of rices as affected by N application rate in the maximum yield trial in a farmer's field. Talavera, Nueva Ecija, Philippines, 1986 WS.

Table 1. Yields of hybrid rices, their high-yielding parents, and selected IR varieties at 3 N levels on an irrigated farm. IRRI, 1986 DS.

Entry	Yield[a] (t/ha)			
	No N	75 kg N/ha	150 kg N/ha	Mean
Wei You 64[b]	2.0	3.5	3.2	2.9
IR21845-90-3A/IR54R	4.1	5.7	4.0[c]	4.6
IR21845-90-3A/IR29512-81-2-1	5.1	6.1	6.3	5.8
IR21845-90-3A/IR19392-211-1	5.2	7.3	7.0	6.5
IR21845-90-3A/IR20933-68-21-1-2	4.1	5.7	5.0	4.9
IR21845-90-3A/IR4422-480-2-3-3	4.9	5.4	3.9[c]	4.7
IR46830A/IR50	3.3	5.3	5.5	4.7
V20B[d]	0.9	1.2	1.3	1.1
IR9761-19-1	3.5	5.5	5.9	5.0
IR21845B	4.9	4.8	4.7	4.8
IR54R	5.1	5.9	6.3	5.7
IR29512-81-2-1	4.4	5.4	4.7[e]	4.8
IR19392-211-1	4.3	5.9	4.9[f]	5.0
IR20933-68-21-1-2	3.4	3.9	3.3[e]	3.5
IR4422-480-2-3-3	4.1	4.9	4.4	4.4
IR46530B	2.4	4.3	5.0	3.9
IR50	4.4	5.2	5.4	5.0
IR64 (check)	3.8	6.0	6.6	5.5
IR58 (check)	2.6	4.7	4.6	3.9
IR28150-84-3-3-2 (check)	4.0	5.6	5.0[f]	4.9

[a]Av of 2 replications. To compare 2 N means for the same or different rice entries, LSD (.05) = 1.0 t/ha or LSD (.01) = 1.5 t/ha. To compare 2 variety means for the same N entry, LSD (.05) = 0.9 t/ha or LSD (.01) = 1.2 t/ha. CV = 13% for N and 10% for variety. [b]Damaged by brown planthopper (BPH). [c]Severely lodged in both replications. [d]Affected by tungro and BPH. [e]Damaged by leaffolder (LF) in both replications. [f]Damaged by LF in 1 replication.

highest yields in many seasons.

In WS, increasing N application rate in medium-maturing rices resulted in yield decline (Fig. 4). In the early-maturing rices, maximum yield was attained by IR64 (5.0 t/ha) with 88 kg N/ha.

YIELD PERFORMANCE OF HYBRID RICE

Agronomy Department

IRRI. *Nitrogen response.* In 1986 DS, six hybrid rices from IRRI and their high-yielding parents were tested at three N rates. Two other hybrid rices from cooperating countries and three check cultivars were also studied.

Among the test rices, IR21845-90-3A/IR19392-211-1 yielded the highest with 7.3 t/ha at 75 kg N/ha (Table 1). Among the check varieties, IR64 yielded the highest with 6.6 t/ha at 150 kg N/ha.

Without applied N, hybrid rices IR21845-90-3A/IR29512-81-2-1 and IR21845-90-3A/IR19392-211-1 yielded more than 5.0 t/ha. Their yields were statistically similar to those of IR21845-90-3A/IR4422-480-2-3-3, IR21845B, IR29512-81-2-1, IR19392-211-1, and IR50.

With 75 kg N/ha, optimum yield was obtained for hybrid rices and check varieties. Four high-yielding IR parents gave optimum yields, while the remaining five gave no significant increase with N application. Wei You 64, damaged by brown planthopper, and V20B, infected with tungro virus (RTV), gave low yields.

In WS, IR46830A/IR50R was retained and four hybrids were replaced with new entries. IR58, IR64, and IR28150-84-3-3-2 were included as checks. N fertilizer was lower than in DS.

Without N fertilizer, yields of two hybrids and three high-yielding parents were higher than that of any check variety or line (Table 2).

At 60 kg N/ha, IR46828/IR13524-21-2-3-3-2-2 and the same hybrids that yielded highly without N yielded half a ton more than the check varieties and their parents. Increasing N to 120 kg/ha did not significantly increase yield. Sterile panicles of IR54752A/IR19392-211-1 caused its low yield.

Plant spacing. In 1986 DS, seven hybrid rices and three check varieties were tested at four planting densities. N fertilizer was applied at 150 kg N/ha.

Table 2. Yields of hybrid rices, their high-yielding parents, and selected IR varieties at 3 N levels on an irrigated farm. IRRI, 1986 WS.

Entry	Yield[a] (t/ha)		
	No N	60 kg N/ha	120 kg N/ha
IR54752A/IR19392-211-1	2.5	3.5	2.9
IR46830A/IR13292-5-3	3.1	4.4	4.2
IR46830A/IR50R	2.8	3.8	4.1
IR46828/IR13524-21-2-3-3-2-2	3.1	4.5	4.7
IR46830A/IR13524-21-2-3-3-2-2	2.9	4.4	4.5
IR54752B	2.9	3.3	3.4
IR46830B	2.8	4.0	4.1
IR46828B	2.2	2.7	3.0
IR19392-211-1	3.3	3.9	3.9
IR13292-5-3	2.6	3.3	3.0
IR13524-21-2-3-3-2-2	3.3	3.7	4.0
IR50R	3.2	3.2	3.4
IR64 (check)	2.9	3.6	4.3
IR58 (check)	2.6	3.9	4.0
IR28150-84-3-3-2 (check)	2.8	3.4	3.4

[a] To compare 2 N means for the same or different varieties, LSD (.05) = 0.7 t/ha. To compare 2 variety means at the same N level, LSD = 0.6 t/ha. CV = 8% for N and 9% for variety.

IR46830A/IR50 yielded the highest with 6.6 t/ha when spaced at 20 × 20 cm (Table 3). Except for IR46830A/IR50 and IR21845-90-3A/IR4422-480-2-3-3, all hybrid rices yielded similarly at any plant spacing.

The yield of IR50 decreased with an increase in plant spacing: that of IR64 declined only when planted 30 × 30 cm apart. IR21845-90-3A/IR19392-211-1, a hybrid that yielded highest in the N response trial, had a high percentage of sterile grains and hence low yields at all planting densities.

In WS, three hybrid rices, their high-yielding parents, and check variety IR64 were evaluated at 4 plant spacings with N at 60 kg/ha.

A 20- × 20-cm spacing appeared to be optimum for the high-yielding entries. IR46830A/IR50R yielded 4.3 t/ha, as did IR64 (Table 4). The yield of both rices declined, however, at wider spacing.

Among the high-yielding parents, IR19392-211-1 yielded high at all plant spacings. Wider plant spacing significantly reduced the yield of IR46830B and IR19392-211-1. IR54752A/IR50R and IR54752A/IR19392-211-1 had a high percentage of sterile panicles.

Table 3. Yields of hybrid rices and selected IR varieties with 150 kg N/ha at 4 plant spacings on an irrigated farm, IRRI, 1986 DS.

Entry	Yield[a] (t/ha)				
	20 X 20 cm	20 X 25 cm	25 X 25 cm	30 X 30 cm	Mean
IR46830A/IR50	6.6 a	5.9 b	5.9 b	5.1 c	5.9
IR21845-90-3A/IR29512-81-2-1	5.9 a	5.7 ab	5.4 b	5.5 ab	5.6
IR21845-90-3A/IR19392-211-1[b]	3.5 a	3.8 a	3.6 a	3.5 a	3.6
IR21845-90-3A/IR20933-68-21-1-2	5.2 a	5.5 a	5.1 a	5.1 a	5.2
IR21845-90-3A/IR14753-120-3	4.7 a	4.7 a	4.8 a	4.8 a	4.7
IR21845-90-3A/IR4422-480-2-3-3	5.5 ab	5.7 a	5.2 bc	5.0 c	5.3
IR21845-90-3A/IR54R	6.4 a	6.2 ab	5.9 b	6.1 ab	6.1
IR64 (check)	6.2 a	6.0 a	6.2 a	5.5 b	6.0
IR54R (check)	5.7 a	5.4 a	5.7 a	5.3 a	5.5
IR50 (check)	6.0 a	5.3 b	5.4 b	4.8 c	5.4
Mean	5.6	5.4	5.3	5.1	

[a]Av of 3 replications. In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. CV = 12% for variety and 5% for spacing. [b]High percentage of sterile grains.

Table 4. Yields of hybrid rices and their parents with 60 kg N/ha at 4 plant spacings on an irrigated farm, IRRI, 1986 WS.

Entry	Yield[a] (t/ha)				
	20 X 20 cm	20 X 25 cm	25 X 25 cm	30 X 30 cm	Mean
IR46830A/IR50R	4.3 a	3.8 b	3.9 b	3.6 b	3.9
IR54752A/IR50R	4.2 a	4.1 a	4.1 a	4.0 a	4.1
IR54752A/IR19392-211-1	4.0 a	4.1 a	3.9 a	4.0 a	4.0
IR46830B	3.9 a	3.9 a	3.7 ab	3.4 b	3.7
IR54752B	3.5 a	3.5 a	3.4 a	3.3 a	3.4
IR54R	3.9 a	3.9 a	3.9 a	3.7 a	3.8
IR19392-211-1	4.3 a	4.2 ab	4.1 ab	3.9 b	4.1
IR50R	3.6 a	3.6 a	3.6 a	3.4 a	3.5
IR64 (check)	4.3 a	4.0 ab	3.8 b	3.7 b	3.9

[a]Av of 3 replications. In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. CV = 6% for variety and 5% for spacing.

Maligaya. The potential yield of 13 hybrids was compared with those of 5 check cultivars in Nueva Ecija, Philippines. In DS, NPK was applied at 150-26-50 kg/ha. Most hybrids produced 6.0 t/ha or more (Table 5). Two very promising ones, IR54752A/IR19392-211-1, and IR54752A/IR29723-143-3-2-1, yielded more than 7.0 t/ha, but this was not significantly different from the highest yield among the check varieties (6.5 t/ha). With the exception of Wei You 64, the hybrids showed varying degrees of sterility. The sterility rating for IRRI-developed hybrids ranged from 5 to 14%. Sterility varied widely within individual hybrids (CV = 94%); hence the sterility rating among hybrids did not vary significantly.

In WS, only 6 of the 13 hybrids tested earlier were retained. N application was reduced to 90 kg N/ha, while P and K rates were maintained. The highest yield was obtained from the check cultivar IR28150-84-3-3-2. Among the hybrids, only IR54752A/IR54R and IR54752A/IR14753-120-3 gave comparably high yields of about 5.0 t/ha.

YIELD PERFORMANCE AND NITROGEN RESPONSE OF VARIETIES AND BREEDING LINES

Agronomy Department

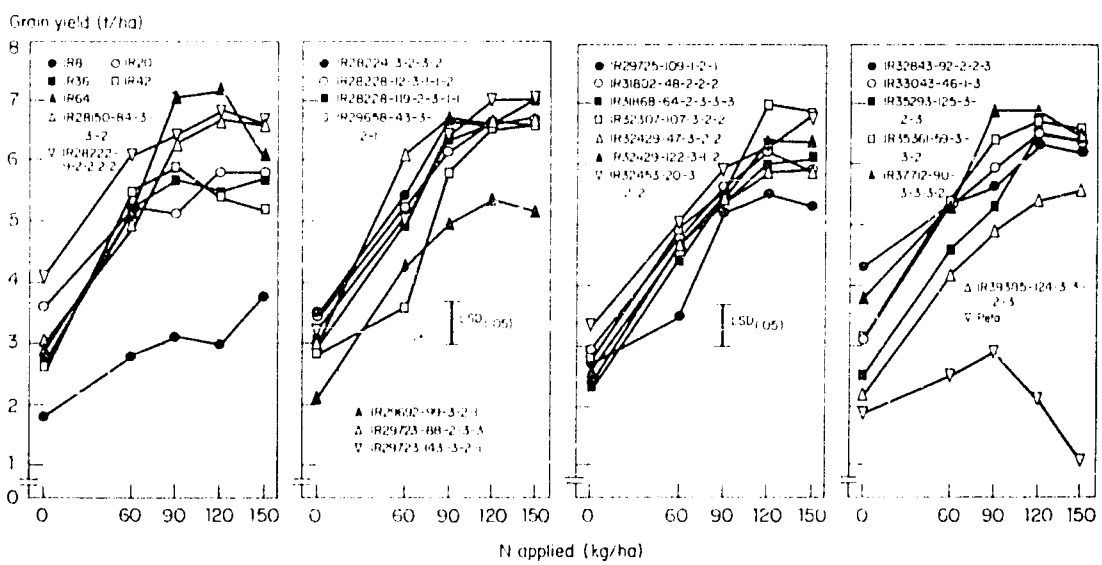
Irrigated rice. The yield performance of promising breeding lines was compared with that of the outstanding check varieties at four N levels in a farmer's field; five N levels were compared at IRRI; and six N levels were tested at three Philippine Bureau of Plant Industry (BPI) stations. N rates were higher during DS than during WS.

Table 5. Yield of hybrid rices and check varieties. Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines, 1986.

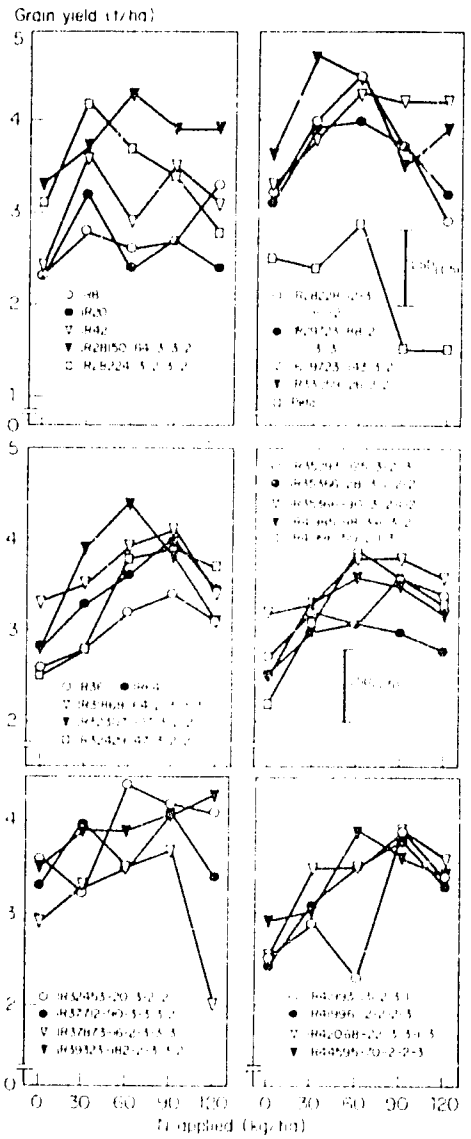
Cultivar	Grain yield[a] (t/ha)		Duration (DAS)[b]	Visual sterility rating[c] (%)
	DS	WS		
Wei You 64	6.4	3.2	98	0
IR[illegible]830A/IR50	6.6	3.2	108	14
IR46830A/IR9761-19-1	6.5	–	116	9
IR54752A/IR54R	6.6	5.2	123	4
IR54752A/IR29512-81-2-1	5.8	–	128	14
IR54752A/IR19392-211-1	7.2	3.6	123	8
IR54752A/IR20933-68-21-1-2	5.7	–	120	14
IR54752A/IR14753-120-3	6.4	4.8	128	13
IR54752A/IR15847-215-2-1	4.2	–	130	6
IR54752A/IR4422-480-2-3-3	6.3	3.6	133	14
IR54752A/IR13146-243-2-3	4.6	–	133	5
IR54752A/IR29723-143-3-2-1	7.4	–	130	12
IR46830A/IR29723-143-3-2-1	6.8	–	112	12
IR58 (check)	5.7	3.3	112	0
IR36 (check)	6.2	2.8	112	0
IR54 (check)	6.1	5.2	116	0
IR64 (check)	6.5	3.8	116	0
IR28150-84-3-3-2 (check)	5.5	5.4	128	0
LSD (.05)	1.6	0.6		11

[a]N at 150 kg/ha during DS and 90 kg/ha during WS, with 26 kg P and 50 kg K/ha. CV = 16% in DS and 9% in WS. [b]DAS = d after seeding. [c]Av of 3 replications. CV = 94%.

IRRI. In DS, IR64 yielded the highest (7.2 t/ha) at 120 kg N/ha among the 28 test rices (Fig. 5). Without N application, IR32843-92-2-2-3 outyielded the other test rices. Yields of five promising breeding lines (IR28228-12-3-1-1-2, IR31868-64-2-3-3-3, IR32429-122-3-1-2, IR32453-20-3-2-2, and IR39385-124-3-3-2-3) increased even at the highest N level. Most of the cultivars gave maximum yields with [illegible] or 120 kg N. Increasing the N rate further resulted in a decline or leveling off of yield



5. Yield of rices at 5 N rates. IRRI, 1986 DS.



6. Yield of rices at 5 N rates, IRRI, 1986 WS.

response. In IR8, severe RTV infection caused low yields. The traditional variety Peta was outyielded by most modern varieties and promising breeding lines at all N levels.

In WS, storms during the reproductive phase considerably reduced the grain yields of the 28 test rices. IR33059-26-2-2 gave the highest yield of 4.7 t/ha with 30 kg N/ha (Fig. 6) and, along with IR28228-12-3-1-1-2 and IR32307-107-3-2-2, showed the best yield performance. IR8, IR20, IR42, and Peta were adversely affected by virus diseases, hence the erratic yield response to varying N levels.

Farmer's field. In 1986 DS, IR42 yielded the highest (5.2 t/ha) in plots with no N fertilizer. Except for IR8, which gave the lowest yield, the other test rices yielded 4.0 t/ha or more (Table 6). With N application, the highest yields were from the promising breeding lines IR28150-84-3-3-2 and IR29723-143-3-2-1, which had outyielded the other test rices in the same field in 1985 DS. However, yields obtained in 1986 DS were lower than those in 1985.

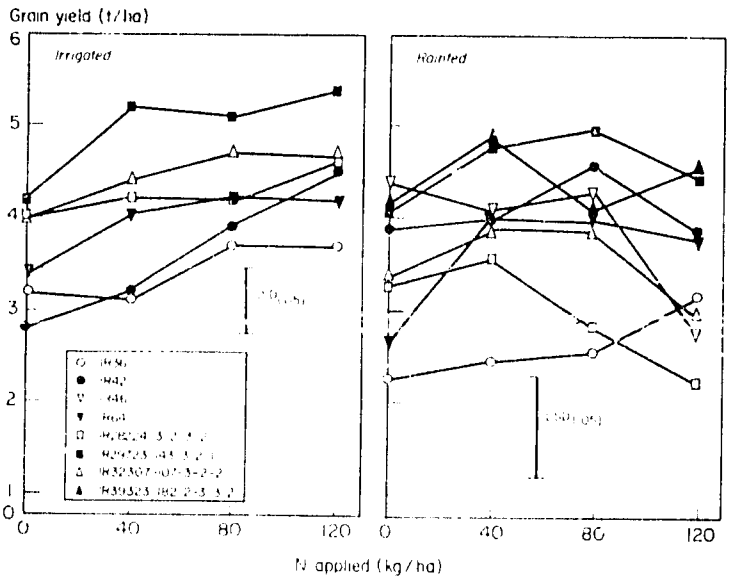
In WS, the promising breeding line IR29723-143-3-2-1, which had outyielded the other test rices in the same field during the 1984 and 1985 croppings, gave the highest yield at all N levels (Fig. 7). The same line also performed well at a rainfed site. Maximum yields, however, were lower than those previously observed.

BPI stations. At the Maligaya Rice Research and Training Center (MRRTC) in Nueva Ecija, 10 of 17 IRRI-developed rices responded positively to increasing N application rate in DS (Fig. 8). IR29723-143-3-2-1 and IR32453-20-3-2-2 produced more than 8.0 t/ha. When N fertilizer

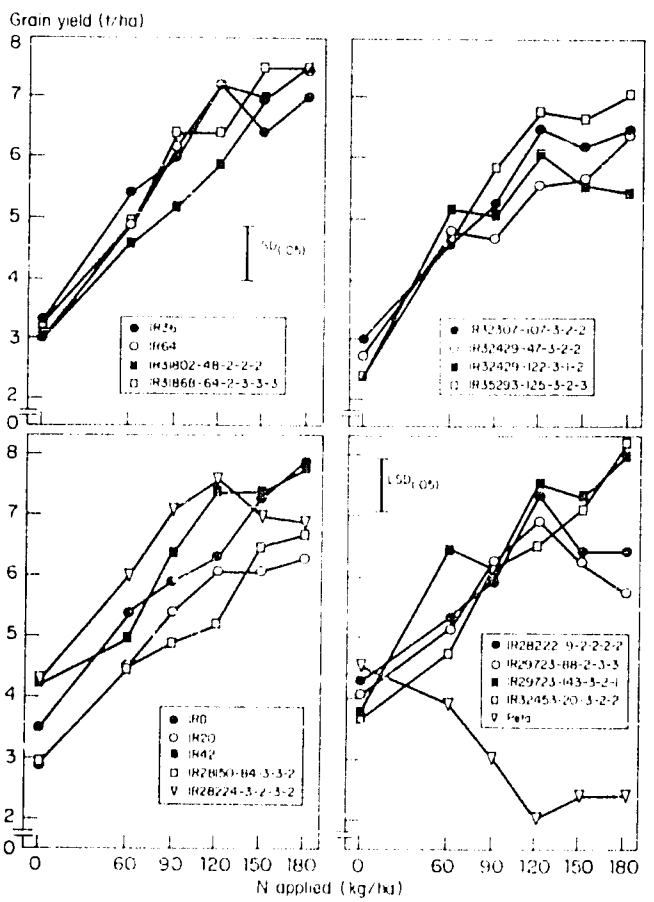
Table 6. Yields of IR varieties and promising breeding lines at 4 N levels in an irrigated farmer's field, Cabuyao, Laguna, Philippines, 1986 DS.

Variety or line	Duration (d)	Grain yield[a] (t/ha)			
		No N	50 kg N/ha	100 kg N/ha	150 kg N/ha
IR8	134	3.9	6.3	5.2	6.6
IR36	112	4.0	5.2	5.6	6.5
IR42	122	5.2	5.3	6.2	6.8
IR64	119	4.5	6.0	6.5	6.8
IR28150-84-3-3-2	128	4.8	6.4	7.4	8.2
IR29723-143-3-2-1	142	5.0	6.8	7.2	7.1
IR32843-92-2-2-3	119	4.5	6.0	6.9	6.6
IR35293-125-3-2-3	119	4.0	5.7	5.9	6.8

[a]Av of 3 replications. CV for variety = 7%. LSD (.05) = 0.7 t/ha.



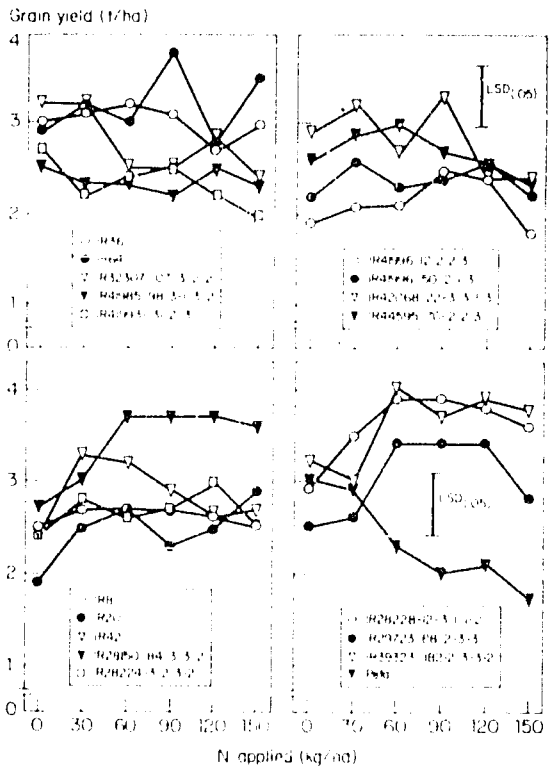
7. Yield of rices at 4 N rates in an irrigated and a rainfed farmer's field. Cabuyao, Laguna, Philippines, 1985 WS.



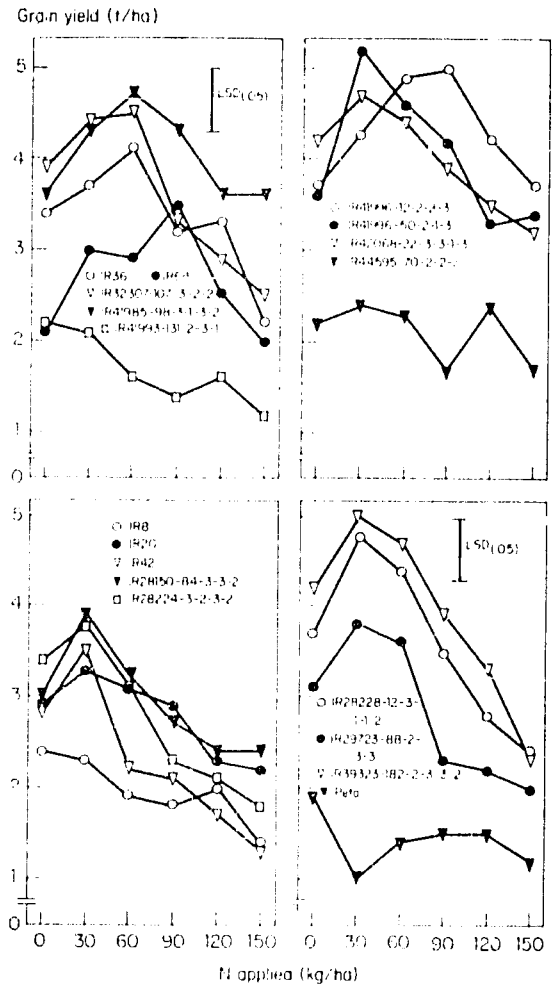
8. Yield of rices at 6 N rates. Maligaya Rice Research and Training Center (MRRTC), Nueva Ecija, Philippines, 1986 DS.

was not applied, Peta yielded the highest, but not significantly higher than IR28222-9-2-2-2-2 and IR29723-88-2-3-3.

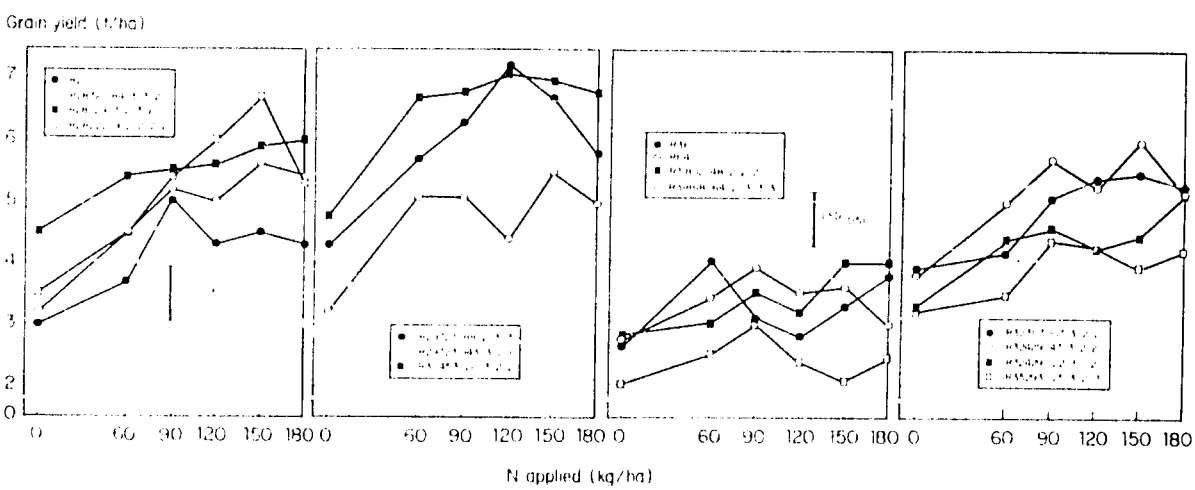
In WS, rice yields were lower than those on the IRRI farm (Fig. 9) because of storms at the



9. Yield of rices at 6 N rates, MRRTC, Nueva Ecija, Philippines, 1986 WS.



11. Yield of rices at 6 N rates, Bicol Experiment Station, Pili, Camarines Sur, Philippines, 1986 WS.



10. Yield of rices at 6 N rates, Bicol Experiment Station, Pili, Camarines Sur, Philippines, 1986 DS.

reproductive phase. None of the test rices yielded more than 4.0 t/ha. Rat damage, LS, and bacterial blight (BB) infection also contributed to low yields in early-maturing rices.

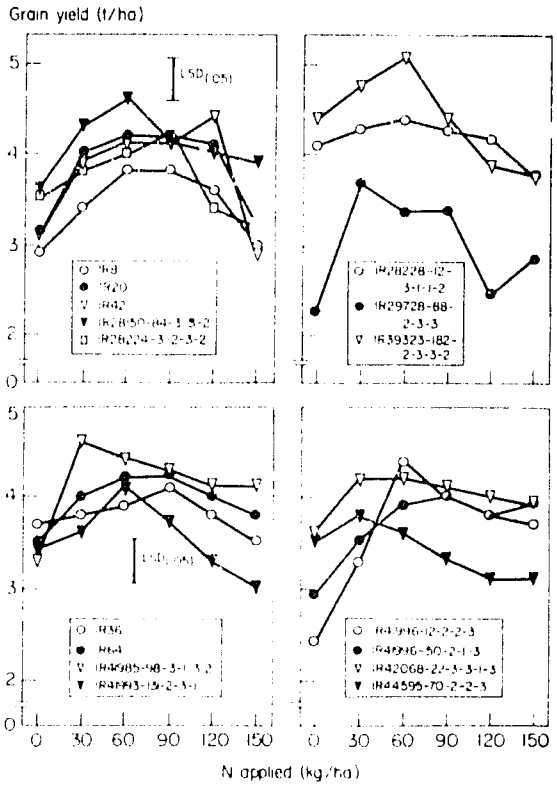
In Bicol during DS, insufficient water supply seriously affected the grain yield of the early-maturing rices. The medium- to late-maturing rices, however, had better yields even without applied N. Yields of IR28224-3-2-3-2, IR29723-88-2-3-3, and IR32453-20-3-2-2 were highly promising with low N application (Fig. 10). Viral infections, which had reached endemic proportions in Bicol, damaged IR8, IR42, IR64, and even the traditional variety Peta.

In WS, N application beyond 30 kg/ha reduced yield in most rices. IR41996-50-2-1-3 gave the highest yield of 5.2 t/ha (Fig. 11). IR39323-182-2-3-3-2 at 30 kg N/ha and IR41996-12-2-2-3 at 90 kg N/ha also yielded 5.0 t/ha. Rice lodged heavily and was infected with BB.

As in Bicol, water shortage at the reproductive phase was a problem in DS in the Visayas. Rice yields were generally lower than those on the IRRI farm and at MRRTC (Fig. 12). IR32307-107-3-2-2 was outstanding in yield performance, producing 6.6 t/ha at 90 kg N/ha.

In WS, IR39323-182-2-3-3-2 yielded the highest (5.1 t/ha). In the no-N plots, this line, along with IR28228-12-3-1-1-2, produced more than 4.0 t/ha (Fig. 13). Stem borer infestation was noted among the early-maturing rices.

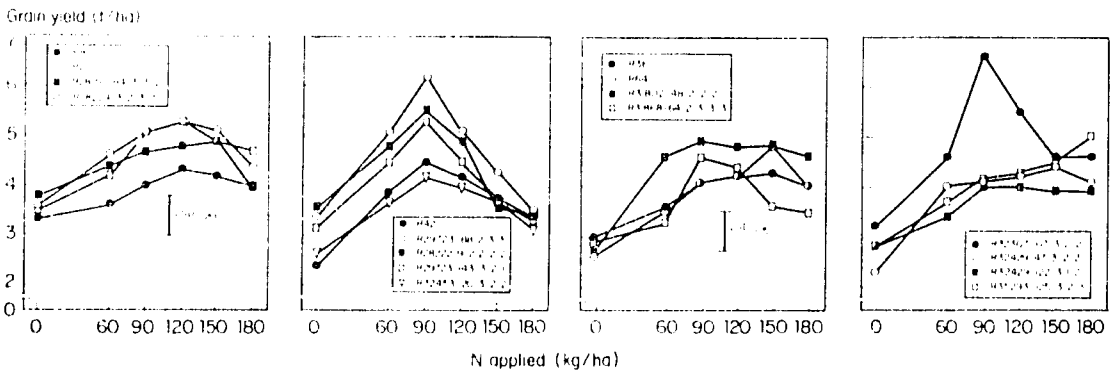
Rainfed rice. *IRRI.* Yields of 4 varieties and 8 lines ranged from 2.3 to 4.4 t/ha, and none showed a response to N. IR39323-182-2-3-3-2 yielded marginally higher than the check variety IR64.



13. Yield of rices at 6 N rates, Visayas Experiment Station, Iloilo, Philipines, 1986 WS.

IR32307-107-3-2-2 was a promising rainfed variety, yielding the highest (4.4 t/ha) at 90 kg N/ha.

Farmer's field. The highest yield of 5.0 t/ha was obtained from IR29723-143-3-2-1 at 80 kg N/ha (Fig. 7). This line, along with IR46 and the breeding line IR39323-182-2-3-3-2, produced more



12. Yield of rices at 6 N rates, Visayas Experiment Station, Iloilo, Philippines, 1986 DS.

than 4.0 t/ha in the no-N plots. IR39323-182-2-3-3-2 likewise performed well at all N levels.

AGRONOMIC CHARACTERISTICS AND YIELDS OF BROADCAST SEEDED RICE

Agronomy Department

In 1986 DS, the agronomic characteristics and yields of broadcast seeded, flooded, and transplanted rices were compared. Pot studies were conducted to determine seedling growth characteristics of the entries.

Among the 6 test rices, IR36 emerged fastest, and hence was tallest at 3 d after seeding (DAS). After seedling emergence, IR58 and IR29723-143-3-2-1 showed the fastest seedling growth, while IR42 and IR32429-47-3-2-2 were slowest (Fig. 14) with or without applied N. Seedlings at 3 DAS were significantly shorter at 150 kg N/ha than at no N (Table 7).

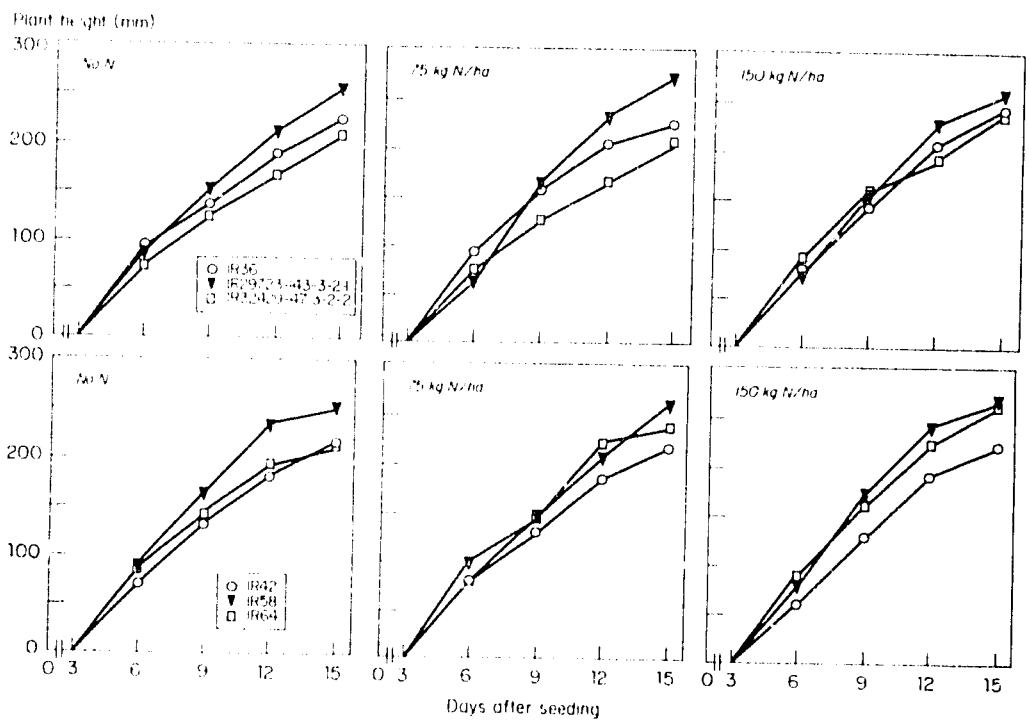
In the field, uneven seed distribution during broadcast seeding, bird and rat damage, and death of pregerminated seeds contributed to inconsistencies in relating plant density to grain yield or yield components.

Table 7. Rice seedling height at 3 d after broadcast seeding in pots. IRRI, 1986 DS.

Variety or line	Seedling height (mm)		
	No N	75 kg N/ha	150 kg N/ha
IR36	45.8 a	35.4 a	19.6 bc
IR42	27.8 d	31.6 ab	16.0 c
IR58	33.8 bcd	25.8 bc	14.0 c
IR64	34.6 bc	24.2 c	16.6 c
IR29723-143-3-2-1	28.6 cd	14.8 d	24.6 ab
IR32429-47-3-2-2	35.2 b	31.4 ab	30.0 a

Without N fertilizer, yields of broadcast seeded rices, except for IR29723-143-3-2-1, were either similar to or better than that of transplanted rice (Table 8). Application of 150 kg N/ha was favorable to the grain yield production of most transplanted rices.

Among the broadcast seeded cultivars, IR64 consistently yielded high at all N rates. IR64 and IR36 had higher lodging resistance when transplanted than when broadcast seeded. In contrast, IR42 and IR29723-143-3-2-1 were susceptible to lodging, perhaps because of their tall stature.



14. Cumulative height of broadcast seeded flooded rice at various N fertilization rates. Pot experiment, IRRI, 1986 DS.

Table 8. Grain yield of transplanted and broadcast seeded flooded rice as affected by 3 N rates. IRRI, 1986 DS.

Crop establishment method	Grain yield[a] (t/ha)					
	IR36	IR42	IR58	IR64	IR29723-143-3-2-1	IR32429-47-3-2-2
				No nitrogen		
Transplanted	4.0 b	4.5 a	3.3 b	4.6 a	4.8 a	4.4 a
Broadcast seeded	4.5 a	4.8 a	4.0 a	5.0 a	3.9 b	4.3 a
				75 kg N/ha		
Transplanted	5.7 a	6.8 a	5.4 a	6.1 b	6.7 a	6.4 a
Broadcast seeded	5.4 a	5.7 b	5.7 a	6.5 a	6.5 a	6.4 a
				150 kg N/ha		
Transplanted	7.4 a	6.8 a	6.6 a	7.0 a	7.3 a	6.6 a
Broadcast seeded	6.3 b	5.8 b	6.4 a	7.1 a	6.[illegible] b	5.8 b

[a]In a column, at the same N rate, means followed by a common letter are not significantly different at the 5% level by DMRT

SIMULATION OF RICE GROWTH AND DEVELOPMENT

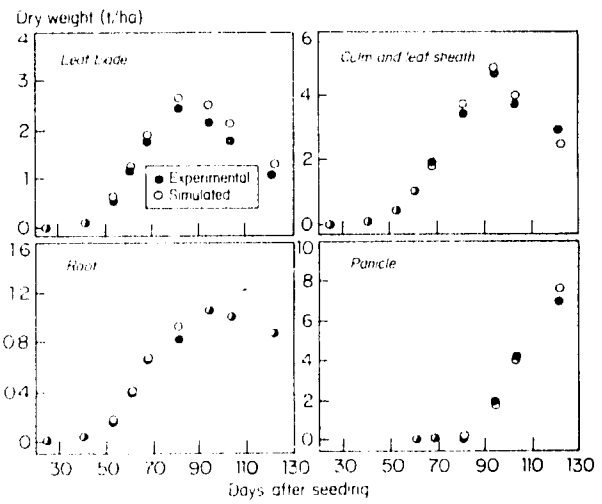
Agronomy Department

Crop growth simulation models integrate knowledge of plant processes such as photosynthesis, respiration, and transpiration and the impact of weather variables on these processes.

A simulation model, LORICE, was developed for rice at the Center for Agrobiological Research, Wageningen, the Netherlands. LORICE simulates the growth and development of irrigated rice with no nutritional or pest problems. Growth is affected by light and temperature. The model was improved by changing some plant parameters and functions based on experimental results. To verify the model, experimentally obtained dry weights of the different plant parts of IR54 were compared with simulated values. IR54 was grown on a wetland site at IRRI in 1984 DS and fertilized with 60-30-30 kg NPK/ha.

Model sensitivity was tested by simulating IR54 yield at different transplanting dates, using 7 yr (1979-86) of IRRI weather data on radiation and temperature for a wetland site.

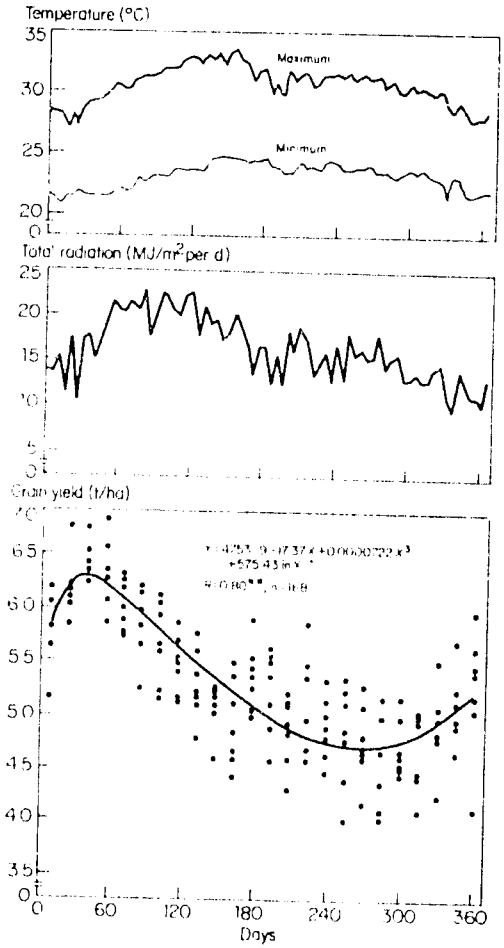
In general, simulated values were greater than the experimental values, but differences were small (Fig. 15). Actual and simulated grain yields were 5.8 and 6.3 t/ha. The model predicted highest yields when rice is transplanted during the first 60 d of the year, and lowest yields when transplanted during the third and fourth quarters of the year



15. Simulated (o) and experimental (●) dry weights of the different plant parts of IR54 transplanted at 25 d after seeding. IRRI, 1986.

(Fig. 16). Simulated yield trends were similar to those of long-term rice garden experiments at IRRI.

Simulation results suggest the possibility of using the model to predict rice growth and production at different times of the year. However, since some plant parameters and functions of the model were adapted for IR54 grown at IRRI and probably supplied with insufficient N, extrapolation to other sites should be done with caution. A version of this model that incorporates soil water balance is being improved to simulate rice growth and development under rainfed conditions.



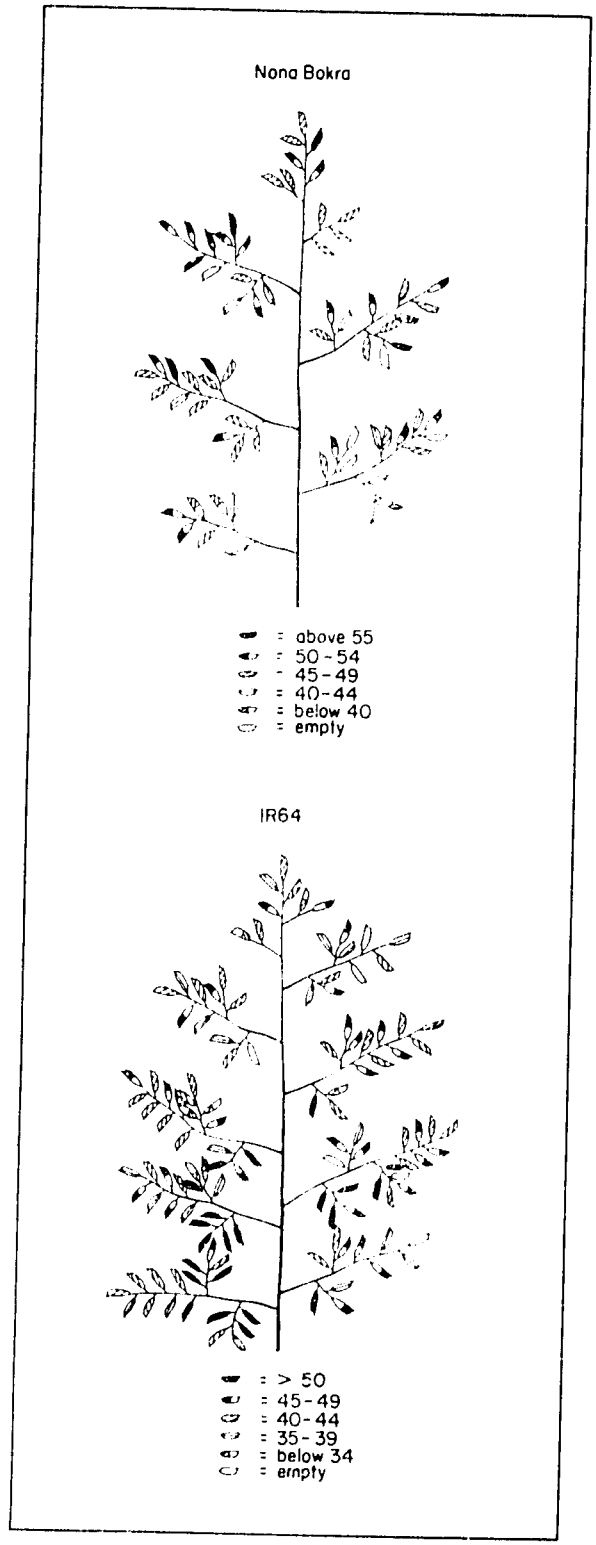
16. Average daily temperature, daily total radiation, and simulated grain yield of IR54 for 7 yr. IRRI, 1979-85.

VARIATION IN EMBRYO WEIGHT OF RICE CULTIVARS

Plant Physiology Department

Seedling growth is related to yield potential and to seedling tolerance for various stresses in F_1 rice hybrids. One of the important factors affecting seedling growth is embryo weight, which is highly variable within a cultivar. Factors affecting embryo weight were examined to learn whether it can be used as a stable varietal characteristic.

Variation in embryo weight. Embryo weight varied significantly, depending on the position of the spikelet on the panicle. In Nona Bokra, spikelets having larger embryos were located on the upper part of the panicle; in IR64, these



17. Distribution of embryo weight (1×10^{-2} mg) of 2 rice varieties in a panicle. IRRI, 1986.

Table 9. Embryo weight of IR58, IR64, and Pokkali from the panicles of one hill. IRRI, 1986.

Panicle no.	IR58		IR64		Pokkali	
	Seeds/panicle[a]	Av weight (mg) of embryo per panicle	Seeds/panicle[a]	Av weight (mg) of embryo per panicle	Seeds/panicle[a]	Av weight (mg) of embryo per panicle
1	67	0.39	136	0.42	67	0.49
2	46	0.41	85	0.42	109	0.49
3	88	0.42	97	0.46	121	0.49
4	70	0.44	85	0.43	64	0.53
5	66	0.40	77	0.42	102	0.47
6	61	0.42	118	0.44	68	0.40
7	53	0.46	74	0.40	49	0.47
8	59	0.46	64	0.44	112	0.47
9	48	0.45	56	0.39	52	0.48
10	46	0.39	68	0.38	92	0.41
11	69	0.44	38	0.41	31	0.43
12	60	0.44	37	0.39	27	0.41
13	65	0.44	35	0.40	15	0.33
14	54	0.47			29	0.39
15	46	0.46			17	0.35
16	43	0.39				
17	42	0.40				
18	39	0.38				
19	24	0.42				
20	21	0.43				
Av		0.43		0.42		0.44

[a]Includes only filled grain.

spikelets were on the lower part of the panicle (Fig. 17). The average embryo weight also showed higher variation among panicles from one hill (Table 9).

In another experiment, the effect of seed setting percentage on embryo weight was examined using male sterile material and artificially thinned panicles. In both experiments, the embryo weight of seeds from extremely low seed setting showed a 6-10% higher value than control material (Table 10, 11).

N fertilization was shown to have no effect on embryo weight. However, materials grown at extremely high temperatures, as in a glasshouse, and those stored for a long time had smaller embryos.

Table 10. Difference in embryo and endosperm weight between isogenic male sterile line and fertile line of IR54753.[a] IRRI, 1986.

Variety	Embryo weight (mg)	Endosperm weight (mg)	Seed setting (%)	Spikelets (no.) observed
IR54753A (male sterile line)	0.33 (110)	18.8 (97)	4	83
IR54753B (fertile line)	0.30	19.3	79	317

[a]Figures in parentheses show relative value to fertile line as 100.

Table 11. Effect of removal of spikelets on the embryo and endosperm weight of IR64.[a] IRRI, 1986.

	Av remaining spikelets/panicle	Embryo weight mg	Embryo weight %	Endosperm weight mg	Endosperm weight %
Upper 2 spikelets					
No thinning	82	0.28		16.0	
Thinned	2	0.30	(107)	16.9	(106)
Upper 5 spikelets					
No thinning	82	0.32		16.4	
Thinned	5	0.34	(106)	17.2	(105)

[a]Upper 2 and 5 spikelets counted from the topmost rachis of the panicle were used for each determination. In thinned plots, other spikelets were removed by scissors. Figures in parentheses show relative value to no-thinning plot as 100.

Thus seeds from a limited number of panicles or from a certain panicle cannot be used as an indicator of the average embryo weight of a given cultivar. At least 110 seeds randomly selected from more than 1 hill are necessary if the sample mean is to be within 5% of the true value.

Intervarietal variation in embryo weight. The embryo weight of 200 seeds of 154 cultivars from 3 groups of rice — indica, japonica, and javanica — were examined. In general, indica rices had smaller embryos than javanicas and japonicas (Table 12). Most of the japonicas with larger embryos are the ones adapted to cool regions, suggesting that embryo weight may be related to seedling cold tolerance. Within each group of rice cultivars, there is little correlation between embryo weight and endosperm weight (indica, $r = 0.51$; japonica, $r = 0.50$; javanica, $r = 0.45$); however, a higher correlation was observed when all 3 groups were correlated (Fig. 18).

GENETIC PURITY AND A METHOD FOR PURIFYING RICE CULTIVARS

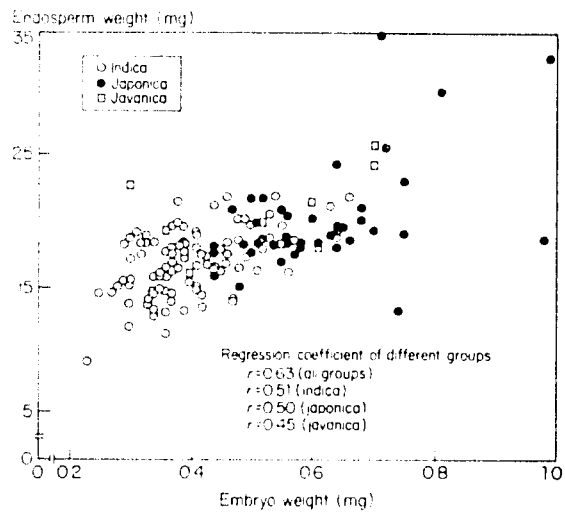
Plant Physiology Department

When a cultivar is propagated, certain agronomic characteristics must be maintained. Often, however, a rice cultivar grown in a certain environment shows an ecotype different from that of the original cultivar. The reason for the difference may be genetic impurity of the original seeds. The existing level of seed impurity may be acceptable or even favorable for practical use in farmers' fields and for breeders; but for physiological and genetic work, this genetic impurity often becomes a hazard in identifying responsible physiological characteristics and in analyzing their inheritance. A suitable technique to determine the genetic purity of seeds of a rice cultivar and a purification method are essential for physiological work.

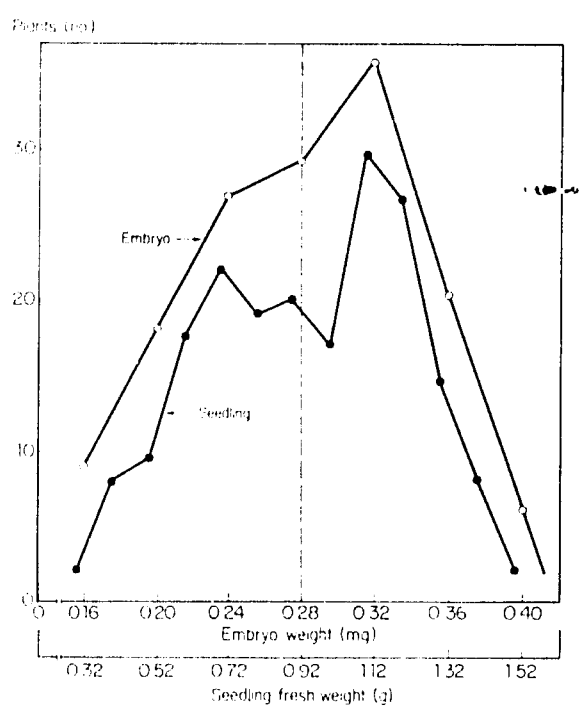
The variability in seedling growth in a cultivar is related to differences in embryo weight (Fig. 19).

Table 12. Average embryo and endosperm weight of rice cultivars from 3 groups. IRRI, 1986.

Cultivar group	Entries (no.)	Embryo weight (mg)	Endosperm weight (mg)
Indica	103	0.40	16.77
Japonica	42	0.61	20.22
Javanica	9	0.53	20.83
Av	154	0.47	17.93

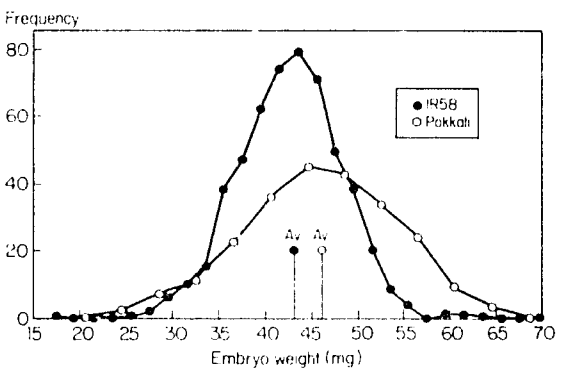


18. Relation between embryo weight and endosperm weight of different groups of rice cultivars. IRRI, 1986.

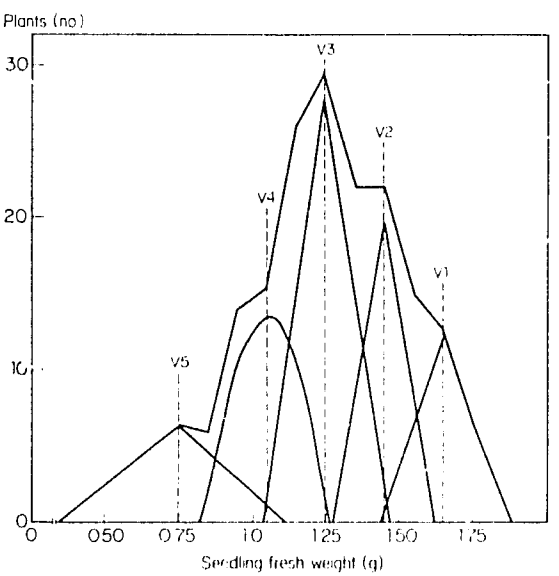


19. Distribution curve of seedling weight and embryo weight of IR60. IRRI, 1986.

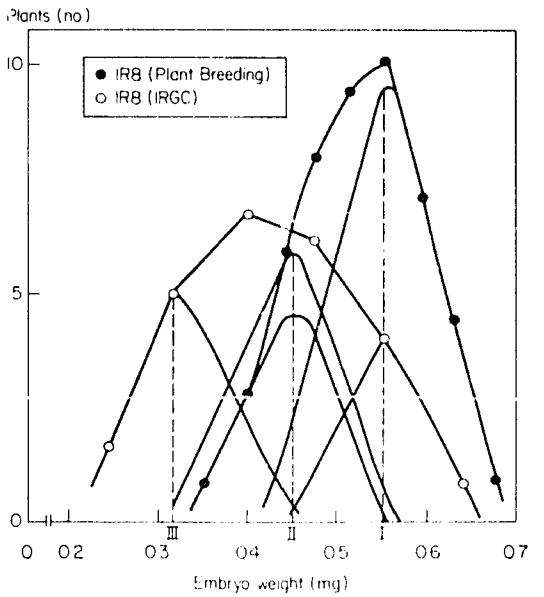
The embryo weight of seeds harvested from one hill grown from one seed showed a normal distribution pattern (Fig. 20). This pattern indicates genetically fixed and pure seed. On the other hand, an irregular or multimodal distribution pattern of embryo weight or seedling weight indicates genetic impurity of seed, i.e., the cultivar is composed of several variants (Fig. 21). The embryo weight distribution pattern of IR8 seeds obtained from the International Rice Germplasm Center and the IRRI Plant Breeding Department varied (Fig. 22). Because of the more frequent cultivation by the Plant Breeding Department, there is a strong



20. Frequency distribution of embryo weight of 2 rice varieties from the panicles of one hill. IRRI, 1986.



21. Distribution curve of seedling weight of IR64. IRRI, 1986. V = variant.



22. Embryo weight distribution curve of IR8 obtained from the International Rice Germplasm Center and IRRI Plant Breeding Department, 1986.

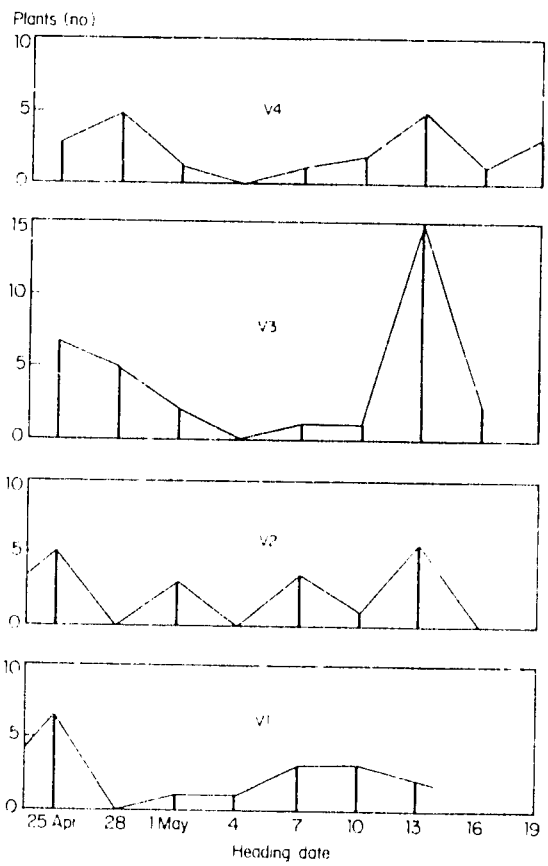
possibility that one variant having a smaller embryo is lost because of some special selection pressure such as RTV.

To determine if this irregular distribution pattern is related to genetic impurity, seedlings obtained from different peaks of the seedling distribution curve were transplanted to the field, and heading time was observed. Materials obtained from different peaks clearly showed different heading periods (Fig. 23). When early and late variants obtained from IR64 after a one-time purification were grown in the field, marked differences in yield and yield components were observed (Table 13). The cultivar that showed a relatively smooth normal seedling distribution pattern showed almost the same heading time, even when the seedlings were taken from various peaks.

The purified seeds obtained from one plant from each peak usually showed a normal distribution curve. In some cases, however, the seedling distribution curve of purified material still showed two or three peaks, indicating that the material was segregating. Seedlings from two peaks of IR64 had different heading times.

Breeders usually observe several qualitative and morphological characteristics such as heading

time, grain type, and leaf color to determine the genetic purity of a variety. Seed purity can be improved remarkably by introducing one quantitative characteristic such as seedling weight. The seedling weight distribution pattern can be used as a convenient indicator of the genetic purity of rice seeds, and purification by using the seedling weight distribution curve can be useful.



23. Distribution curve of heading date of variants (V) of IR64. IRRI, 1986

ANALYSIS OF PHYSIOLOGICAL FACTORS IN YIELD IMPROVEMENT

Plant Physiology Department

One of the most critical factors for the analysis of yield improvement and modeling is a reliable database of energy balance and organ differentiation. Therefore, database collection depending on improved techniques has been initiated using selected recent IR cultivars.

Critical growth analysis of selected IR cultivars. A field experiment was conducted in 1986 DS to determine the growth performance of recent IR cultivars and to analyze factors causing yield decline in IRRI fields. The cultivars were so managed that flowering occurred simultaneously and heading period was comparable among varieties.

Most cultivars lodged at early ripening because of heavy rainfall. Peta, IR42, and IR8 were attacked by RTV at later growth stages.

The leaf area of the early-maturing IR32429-47-3-2-2 and the medium-maturing IR64 developed rapidly but declined drastically before heading (Fig. 24). Transplanted late, these cultivars benefited more at the early vegetative phase from higher solar radiation and temperature. On the other hand, IR29723-143-3-2-1 and Peta, both late-maturing, showed more gradual development of the assimilating area up to heading.

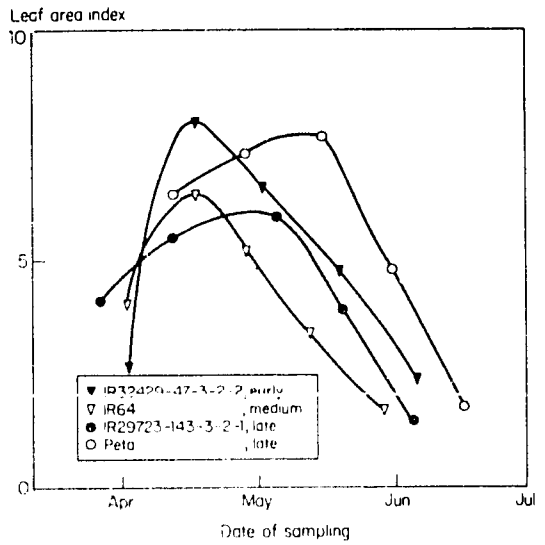
The total N absorbed by the IR cultivars, particularly IR29723-143-3-2-1, increased up to maturity, while that of Peta decreased after heading (Fig. 25).

The total dry weight of IR32429-47-3-2-2, an early-maturing cultivar, increased sharply up to maturity. Those of the other cultivars started to level off toward maturity. Total dry matter produc-

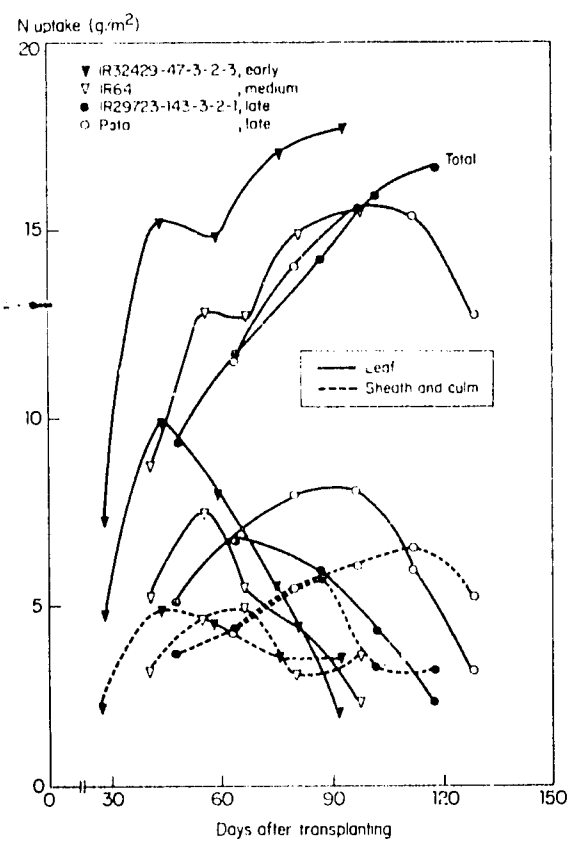
Table 13. Yield components and yields of 2 variants of IR64.[a] IRRI, 1986 WS.

Variant	Panicles (no./m²)	Spikelets (no./panicle)	Spikelets (no. × 10³/m²)	Ripened grains (%)	1,000-grain weight (g)	Yield g/m²	Yield %	Total dry weight (g/m²)	Harvest index
Early	340	68.8	23.4	78.6	25.8	473.1	100	856	0.44
Late	423	61.9	26.2	83.4	26.5	577.9	122	1028	0.41

[a]Under these growing conditions: spacing: 30 × 10 cm (33.3 hills/m²); fertilization: 60-40-40 kg NPK/ha applied basal with 40 kg N/ha topdressed at 20 DBH; transplanting: 14 Aug; heading: 17 Oct for early variant and 22 Oct for late variant. Plant height at harvest was 88.2 cm for the early variant and 95.6 cm for the late variant.



24. Leaf area development of IR cultivars and Peta. IRRI, 1986 DS.



25. N uptake of IR cultivars and Peta. IRRI, 1986 DS.

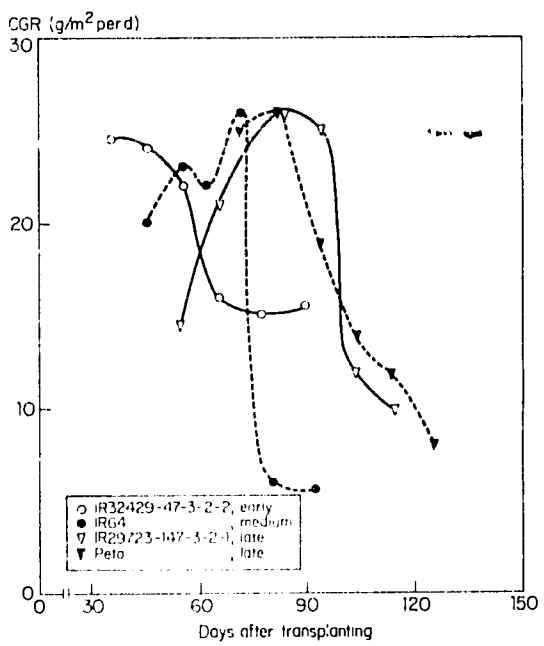
tion was highest in Peta, followed closely by IR29723-143-3-2-1 (Table 14).

While the crop growth rate (CGR) of most cultivars tested declined before heading, that of IR29723-143-3-2-1 increased continuously up to heading and then declined (Fig. 26). The ceiling CGR of 25 g/cm^2 per d was almost the same for IR64, IR29723-143-3-2-1, and Peta.

Table 14. Grain yield, total dry weight, and harvest index of selected IR cultivars and Peta. IRRI, 1986 DS.

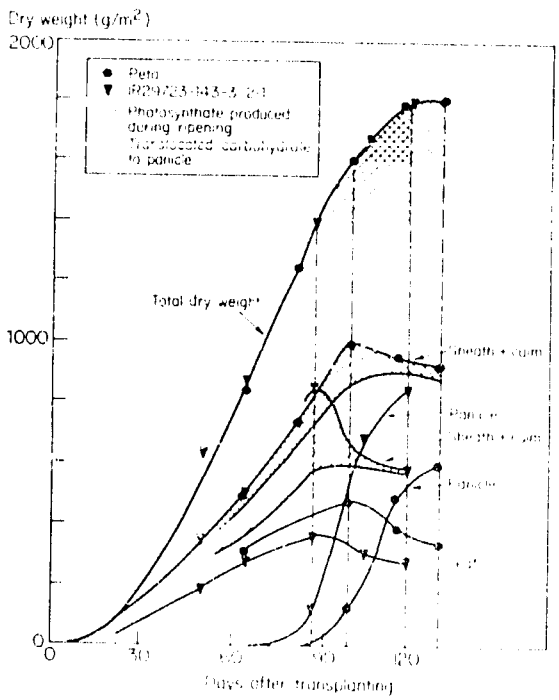
Variety or line	Grain yield[a] (g/m^2)	Total dry weight (g/m^2)	Harvest index[b]
IR58	456	1400	0.33
IR32429-47-3-2-2	618	1470	0.42
IR36	432	1200	0.36
IR35293-135-3-2-3	611	1420	0.43
IR64	622	1470	0.42
Peta	225	1910	0.12
IR21820-154-3-2-2-3	639	1520	0.42
IR8	394	1620	0.24
IR42	514	1580	0.32
IR29723-143-3-2-1	739	1800	0.41

[a]At 0% moisture. [b]Grain yield on dry weight basis divided by total dry weight.



26. Crop growth rate (CGR) of IR cultivars and Peta. IRRI, 1986 DS.

Although the biomass accumulation pattern was similar in the late cultivars Peta and IR29723-143-3-2-1, the panicle weight of IR29723-143-3-2-1 was higher (Fig. 27). The higher panicle weight of IR29723-143-3-2-1 can be attributed to more assimilation after heading and more efficient translocation of the photosynthates in the sheath and culm to the panicle.



27. Dry matter production pattern of traditional variety Peta and modern high-yielding variety IR29723-143-3-2-1. IRRI, 1986 DS.

IR29723-143-3-2-1 gave the best yield of 840 g/m² (Table 15), mainly because of high spikelet number per m² and better grain filling. IR32429-47-3-2-2 and IR64 yielded best among the early and medium cultivars, respectively. The unusually low yields of IR8, IR42, and Peta can be attributed to RTV damage at later growth stages. The harvest index of most normally grown cultivars ranged from 0.41 to 0.43 regardless of growth duration.

Growth performance of IR58 and IR64 at three IRRI sites. Higher variability in growth was observed among the experimental fields of IRRI. To assess the effects of soil fertility on the growth and yield of a cultivar, IR58 and IR64 were grown in 1986 DS at three IRRI locations under similar favorable management. The growth and yield of both cultivars showed wide variation among the three sites, even though the same favorable agronomic management was adopted (Table 16). Yield and dry matter production were highest at site B and lowest at 109. Highest CGR was observed at B, especially in earlier growth stages (Fig. 28). N uptake was higher at B than at M (Fig. 29), although N content in the tissues was at a similar level. This was translated into more spikelets for both cultivars at B, which may be partly attributed to the low fertility of M and 109 compared with that of B (Table 17). The marked variation in productivity among sites complicates

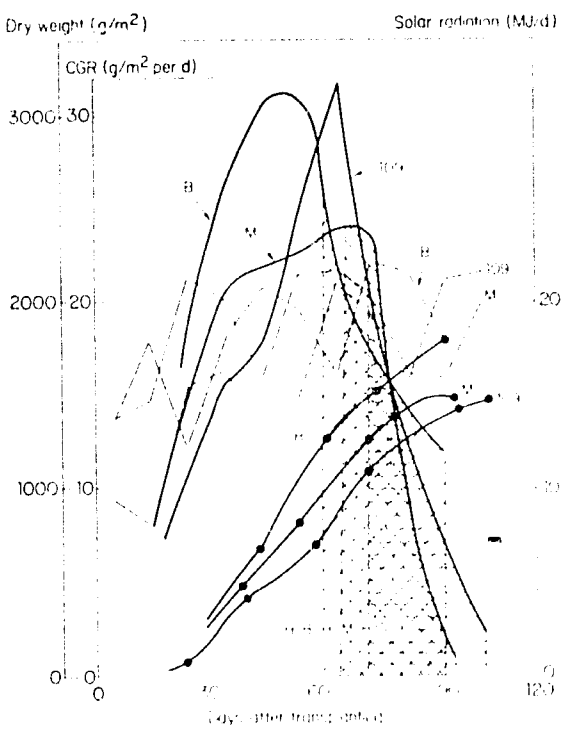
Table 15. Yield and yield components of selected IR cultivars and Peta at 150 kg N/ha. IRRI, 1986 DS.

Variety or line	Growth duration (d)	Grain yield[a] (g/m²)	Panicles (no./m²)	Spikelets (no./panicle)	Spikelets (thousand/m²)	Filled grains (%)	1,000-grain weight[b] (g)
IR58[c]	102	520 cd	630	53	33.6	59.7	22.7
IR32429-47-3-2-2[c]	109	700 b	595	68	40.4	66.6	23.0
IR36	110	490 cd	605	52	31.3	64.3	21.4
IR35293-135-3-2-3[c]	119	700 b	470	76	35.5	75.4	22.8
IR64[c]	112	710 b	490	63	31.0	78.2	25.7
Peta	145	260 e	280	113	31.5	33.0	21.6
IR21820-154-3-2-2-3[c]	129	730 b	470	88	41.2	73.6	21.1
IR8[d]	126	450 d	420	72	30.2	50.2	26.0
IR42[d]	134	590 c	505	92	46.4	60.5	18.5
IR29723-143-3-2-1	134	840 a	440	95	41.9	76.0	23.2

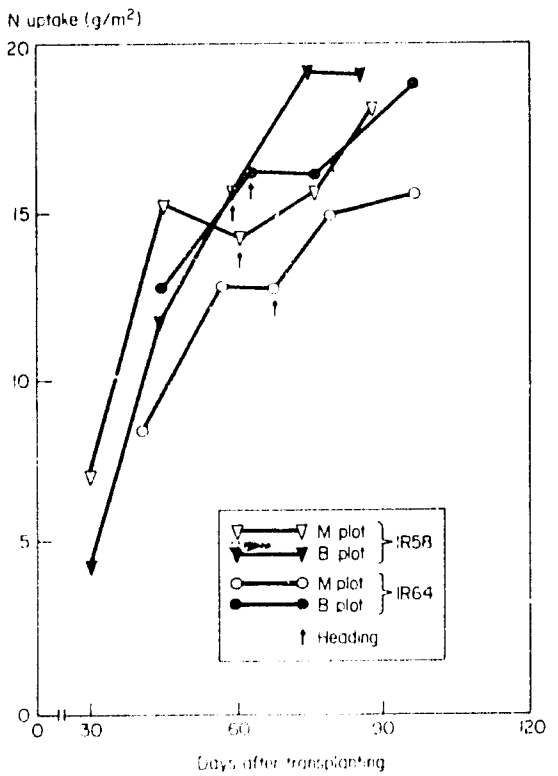
[a]At 14% moisture. [b]Samples dried at 70 °C for 7 d. [c]Lodged on 19 May. [d]Attacked by RTV beginning 22 Apr.

Table 16. Nitrogen uptake, yield, and yield components of IR58 and IR64, IRRI, 1986 DS.

Site	Total N uptake (g/m^2)	Spikelets (thousand/m^2)	Fertility (%)	1,000-grain weight (g)	Yield (g/m^2)	Total dry matter (g/m^2)
			IR58			
B-10	19.0	41.0	86.6	20.5	810	1560
M-11	18.0	33.6	59.7	22.7	520	1400
109	–	28.5	76.8	22.4	490	1200
109	–	29.0	70.4	22.9	532	1290
			IR64			
B-10	18.5	38.4	86.7	25.4	960	1790
B-40	–	33.1	81.1	24.2	740	–
M-11	15.5	31.0	78.2	25.7	709	1470
109	–	30.0	82.3	25.6	684	1470



28. Growth curve and CGR of IR64 and solar radiation at 3 IRRI locations, 1986 DS. Transplanting dates: site B – 6 Feb, M – 21 Feb, 109 – 10 Jan. H – heading. Cross-hatching indicates increase in dry weight after heading.



29. N uptake of IR58 and IR64 at different IRRI locations, 1986 DS. Transplanting dates: IR56 and IR64 in B plot – 6 Feb, IR58 and IR64 in M plot – 16 Feb.

the evaluation of the growth characteristics of rice cultivars. There is a need to develop an agronomic management technique whereby the yield of a cultivar at different locations will be comparable or to assess the potential of different locations for yield and dry matter production to be used as baseline information for growth analysis.

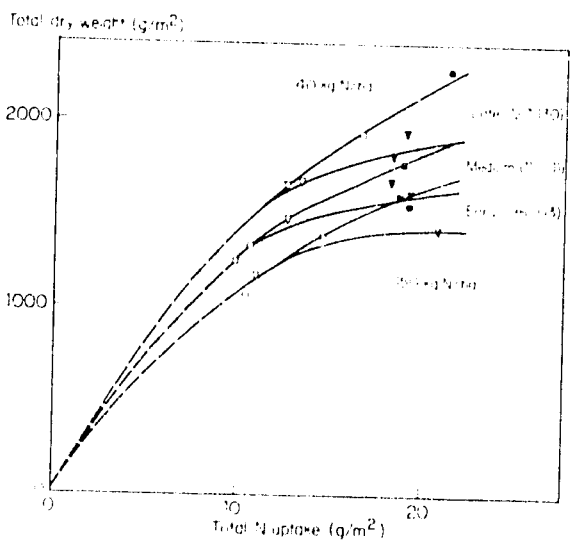
Relation between growth duration and yield of IR cultivars. The relation between growth duration and yield of IR cultivars was analyzed using the results of growth analysis of IR cultivars. Comparison of the growth of cultivars having different

Table 17. Soil analysis from the IRRI Soils Department.[a] IRRI, 1986.

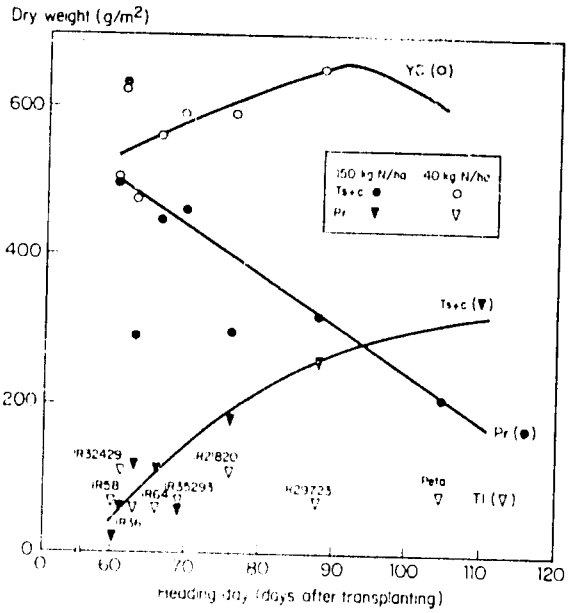
Site	Total N (%)	Organic C (%)	pH	Available P (ppm)
B-10 (old lowland)	0.22-0.24	2.1	5.8-5.9	15
M-11 (old lowland)	0.20	1.7	5.7-6.2	10
109 (new lowland)	0.15	1.4	6.3	13
Optimum level	>0.20	>2	5.5-6.5	>10

[a]Soil depth: B-10 > M-11 > 109.

growth durations showed higher total biomass production for late cultivars. On the other hand, grain yields showed less variability. The total N uptake through growth increased in proportion to growth duration under low N conditions. However, it hardly changed among cultivars of different growth durations under high N conditions (Fig. 30). Therefore, for early cultivars the efficiency of dry matter production per absorbed N was lower. Early cultivars can produce relatively higher spikelet number in spite of lower dry matter accumulation. Furthermore, the accumulation of carbohydrate in the sheaths and culms of early cultivars is limited (Fig. 31, 32), while photosynthetic activity during ripening can be maintained at a high level because of high N content during ripening. Often, the photosynthetic rate to fill the sink capacity of early-maturing cultivars is



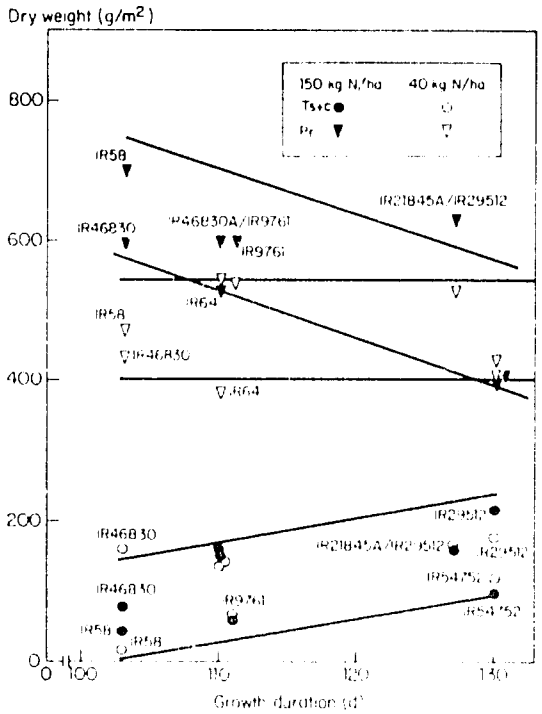
30. Relationship between total dry matter production and total N uptake of IR cultivars with different growth durations. IRRI, 1986 DS.



31. Relationship between growth duration and grain-filling components of IR varieties and Peta. IRRI, 1986 DS. YC = yield components, Ts + c = translocation of carbohydrate from sheath and culm, Pr = photosynthetic activity during ripening stage, Tl = translocation of carbohydrates from leaves.

sufficient, and reaccumulation of carbohydrates is observed in sheaths and culms at maturity.

Yield is determined by the summation of photosynthetic activity during ripening (Pr) and translocation of carbohydrates from sheaths and culms (Ts+c) and from leaves (Tl) (Fig. 31) The Tl of most cultivars is less and almost constant. Ts+c is always higher and Pr lower in late-maturing cultivars. Depending on the contribution of Pr and Ts+c, the yield of cultivars of different growth durations varies. Under high N conditions, early-maturing cultivars had higher Pr and lower Ts+c, while late-maturing cultivars showed lower Pr and higher Ts+c. Consequently, yield was almost



32. Relationship between growth duration and grain-filling components at different N levels. IRRI, 1986 DS.

constant in cultivars with different growth durations. Varietal characteristics such as higher ability to develop sink, higher partitioning of carbohydrate to grain from culm, and higher photosynthesis during ripening have stronger effects than growth duration under favorable fertilization conditions. Under low N, however, the yield of late-maturing cultivars tended to be higher because of higher sink capacity and higher Ts+c (Fig. 32), and the yield decline of early-maturing cultivars was higher than that of late-maturing cultivars when N was reduced (Table 18).

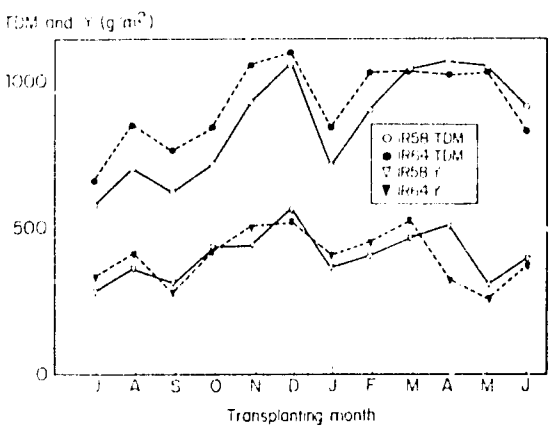
Effect of temperature on growth and yield. A monthly planting test at IRRI evaluated the effect of temperature on the growth of IR58 and IR64. Every 20th of the month, 20-d-old seedlings of both varieties were transplanted at 20- × 20-cm spacing, with and without 120 kg N/ha.

Without N, IR58 yielded 5 t/ha or more when planted in December or April. IR64 showed similar yields when planted in December or March. With 120 kg N/ha, IR58 gave the highest grain yield when planted in December, and IR64 when planted in January (Fig. 33, 34). The biomass produced was also high with December planting. The maximum total dry weights obtained from the 12 plantings were 12.8 t/ha from IR58 and 15.2 t/ha from IR64.

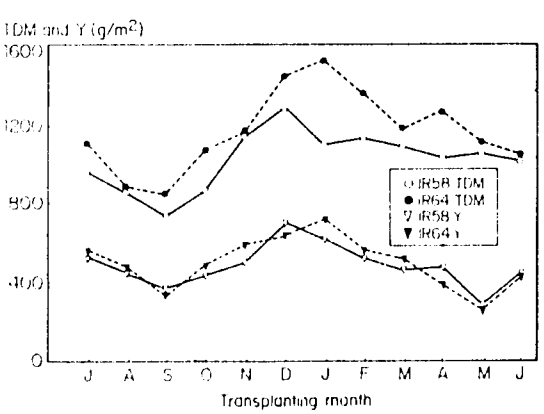
Table 18. Comparison of yield and yield components of early- and late-maturing IR cultivars at 2 N levels. IRRI, 1986.

Cultivar	Growth duration (d)	Yield (g/m²) at	
		40 kg N/ha	150 kg N/ha[a]
IR58	100	620	848 (137)
IR64	110	714	954 (134)
IR21845	130	747	797 (107)
IR29512-181-2-1	130	808	888 (110)

[a]Numbers in parentheses are percentage increase over 40-kg value.

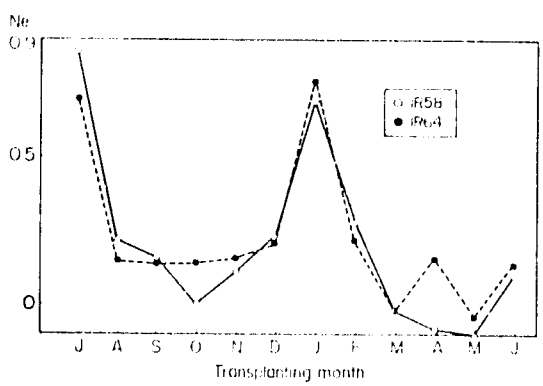


33. Total dry matter (TDM) production and grain yield (Y) of IR58 and IR64 with different transplanting months and no N. IRRI, 1986.



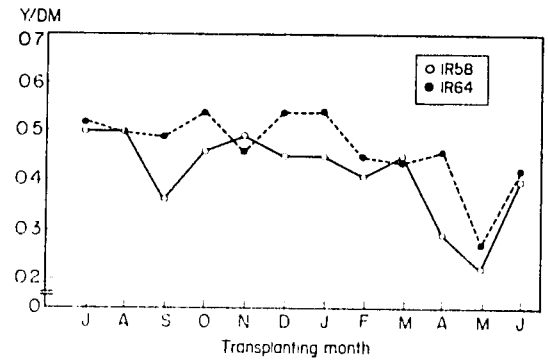
34. TDM and Y of IR58 and IR64 with different transplanting months and 120 kg N/ha. IRRI, 1986.

The yield difference between fertilized and non-fertilized plots was high in the January and July transplantings (Fig. 35). The ratio of yield to total dry matter production decreased after the January transplanting and sharply decreased at the May transplanting (Fig. 36). A high negative correlation was observed between grain yield and average temperature from transplanting to panicle initiation (TI) (Fig. 37), although dry weight at heading was positively related to TI. Spikelet differentiation may thus be negatively related to temperature at panicle initiation even in tropical conditions, because in early-maturing cultivars the effect of ripening on yield is less and yield is highly related to spikelet number. Thus, the higher spikelet number with lower temperatures around panicle initiation could be one of the major causes of higher yield in DS crops.

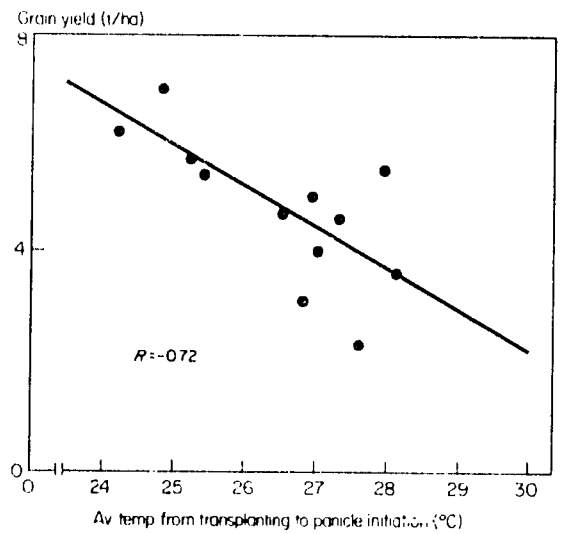


35. Effectiveness of N application on grain yield of IR58 and IR64 in different transplanting months. IRRI, 1985-86.

Effectiveness of fertilization (Ne) $= \frac{\text{yield at 120 kg N/ha} - \text{yield at 0 N}}{\text{yield at 0 N}}$



36. Change in grain yield per total dry matter production (Y/DM) of IR58 and IR64 with transplanting month. IRRI, 1986.



37. Relation between grain yield and average temperature from transplanting to panicle initiation in IR64 with 120 kg N/ha. IRRI, 1986.

Table 19. Varietal differences in N absorption of short-duration varieties and lines at different growth stages. IRRI, 1986 DS.

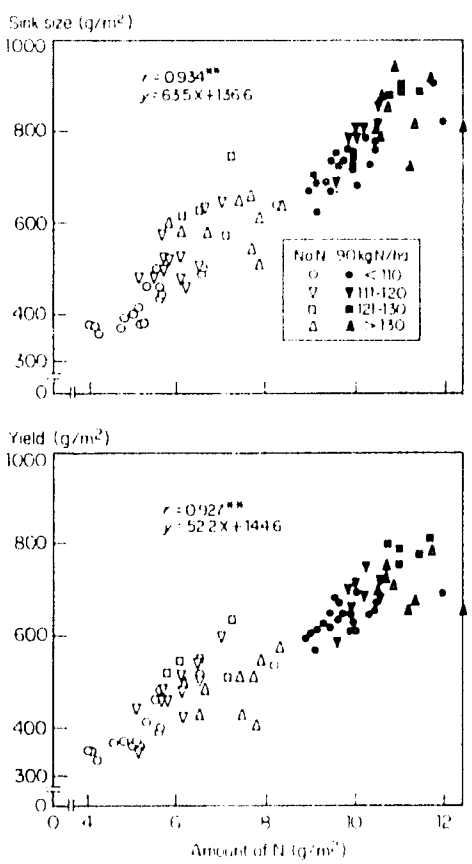
Variety or line	Sink (g/m²)	Yield (g/m²)	N absorbed (g/m²) at			
			Active tillering	Maximum tillering	Flowering	Maturity
IR36	787	708	1.4	2.6	9.9	12.6
IR25588-7-3-1	787	661	1.6	3.2	10.4	13.2
IR25261-135-1-1	823	694	2.0	4.4	11.9	14.4
IR29658-69-2-1-2	801	705	1.5	2.8	10.0	12.4
IR29692-94-2-1-3	742	651	1.4	2.5	9.7	11.3
IR29725-109-1-2-1	738	633	1.3	2.6	9.9	12.6
IR31868-64-2-3-3-3	756	675	1.3	2.5	9.8	12.5
IR32419-81-2-3-3	726	635	1.2	2.1	9.2	11.6
IR32429-47-3-2	738	652	1.3	2.2	9.8	12.0
IR32429-122-3-1-2	725	654	1.5	2.6	10.0	12.4

VARIETAL DIFFERENCES IN NITROGEN RESPONSE WITH SPECIAL REFERENCE TO GROWTH DURATION

Plant Physiology Department

Forty-five varieties and advanced lines grouped as very short (<110 d), short (111-120 d), medium (121-130 d), and long (>130 d) growth duration were planted in 1986 DS at 2 N levels – 0 and 90 kg N/ha (60 kg basal + 30 kg topdressed at panicle initiation) – to study varietal differences in N absorption and the contribution of plant N to yield and yield components, with special reference to growth duration.

Varietal differences in N absorption ability were observed up to maximum tillering, but in subsequent growth stages they were difficult to identify (Table 19).

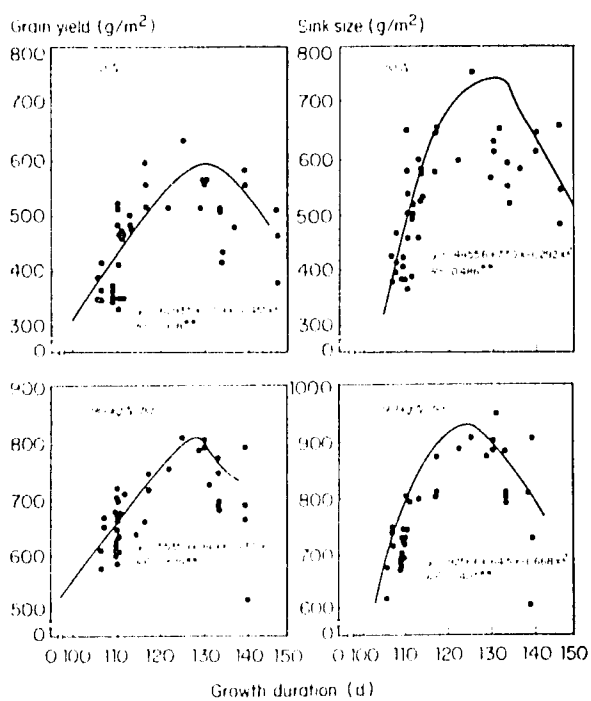


38. Relationship between sink size or yield and the amount of N in the plant at flowering for varieties with different growth durations. IRRI, 1986 DS.

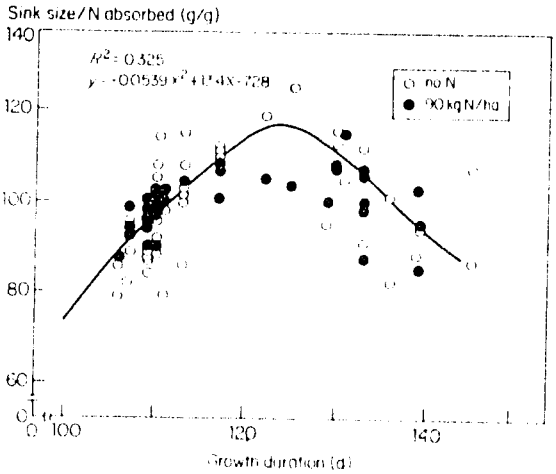
The amount of N in plants at flowering under 0 N and 90 kg N/ha were correlated with growth duration (r = 0.736** and r = 0.734**). The amount of N at flowering was also correlated with the amount of sink and the yield (Fig. 38).

The optimum growth duration for sink size and yield was observed at 125 d (Fig. 39). Likewise, the highest contribution of plant N at flowering to the sink and the yield was observed at 125 d growth duration (Fig. 40).

When growth duration was shorter than the optimum, the yield decreased because of small amounts of differentiated sink caused by low amounts of plant N at the late-stage spikelet initiation. The lower yield of short-duration varieties was also caused by the low contribution of plant N at flowering to sink formation where panicle initiation of very short-duration varieties occurred before the maximum tiller number stage. The contribution of N absorbed after panicle initiation to the differentiation of sink is small, and N absorbed after panicle initiation contributed to panicle formation only by decreasing the number of degenerated spikelets.



39. Relationship between grain yield or sink size and growth duration. IRRI, 1986 DS.



40. Relationship between the contribution of N to sink formation and growth duration. IRRI, 1986

When growth duration was longer than the optimum, the yield decreased because of a shortage of sink as a result of a high number of degenerated spikelets. The percentage of degenerated spikelets was correlated with growth duration ($r = 0.859^{**}$). In this case, plants have a large amount of N at flowering and a large amount of differentiated sink with a relatively large amount of degenerated sink attributed to decrease of N in the laminae from the late stage of spikelet initiation to flowering (Table 20). The low contribution of plant N at flowering to the yield and to the amount of sink of long-duration varieties is caused by spikelet degeneration.

PHYSIOLOGICAL ASPECTS OF INCREASING YIELD OF SHORT-DURATION VARIETIES

Plant Physiology Department

Six entries (105-d maturity) of panicle number type and intermediate type were planted in 1986 DS under 2 N levels (0 and 120 kg N/ha [90 kg basal + 30 kg topdressed]) and 3 spacings (20 × 10 cm, 20 × 20 cm, and 20 × 30 cm) to determine the effects on yield, yield components, and N use efficiency.

Narrow spacing promoted N absorption and tillering at early growth stages and enabled the plants to reach the maximum tiller number stage earlier (Fig. 41). With narrow spacing, both panicle number type and intermediate type varieties had a vegetative lag phase. However, no vegetative lag phase was noted with conventional and wide spacing.

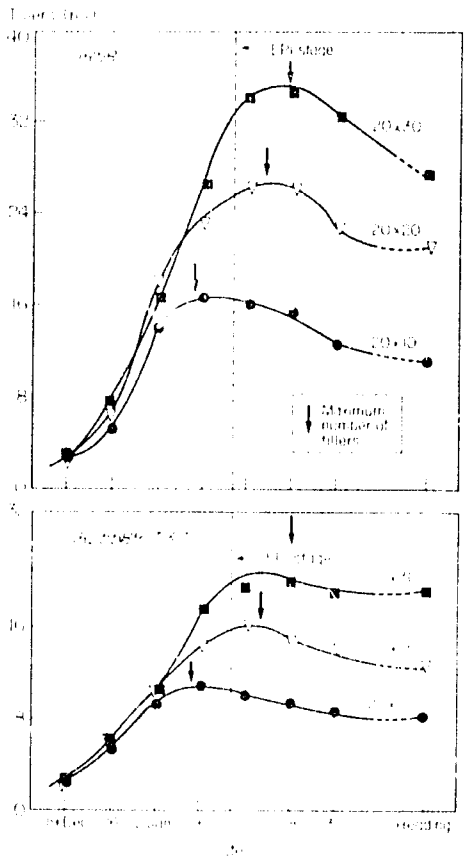
The earliness or lateness of the maximum tiller number stage in relation to panicle initiation makes the difference in yield, yield components, and N use efficiency. Narrow spacing increased N absorption, yield, and sink in both panicle number type and intermediate type varieties at both zero and high N. The amount of N at flowering was correlated with the yield and sink (Fig. 42). However, a higher amount of sink was obtained in the intermediate type varieties (Table 21).

Intermediate type varieties have a higher percentage of sink degeneration than panicle number type varieties. A higher percentage of sink degeneration is noted at narrow spacing, but these values are too small to offset the amount of sink.

Table 20. Yield and yield components of selected varieties and lines. IRRI, 1986 DS.

Variety or line	Growth duration (d)	N content of laminae at flowering (%)	Yield (g/m²)	Sink (g/m²)	Potential sink size (g/m²)	Spikelet degeneration (%)
IR58	106	2.64	572	623	791	22.1
IR19735-5-3-2-1	107	2.88	673	761	944	19.4
IR25588-7-3-1	110	2.58	661	787	1117	29.6
IR36	111	2.51	708	787	1049	25.0
IR29262-65-2-3-3	111	2.44	678	785	1029	23.7
IR64	117	2.14	750	804	1036	22.4
IR24632-34-2	117	2.16	677	814	1165	30.1
IR28228-96-3-2-1-3	122	2.03	759	885	1193	25.8
IR28224-3-2-3-2	125	2.20	812	910	1215	25.1
IR29723-88-2-3-3	133	1.85	692	788	1273	38.1
IR31836-46-1-3-1	133	1.82	689	803	1239	35.2
IR36892-163-1-2-2-1	139	1.72	678	816	1285	36.5
IR29723-143-3-2-1	139	1.82	798	919	1477	37.8

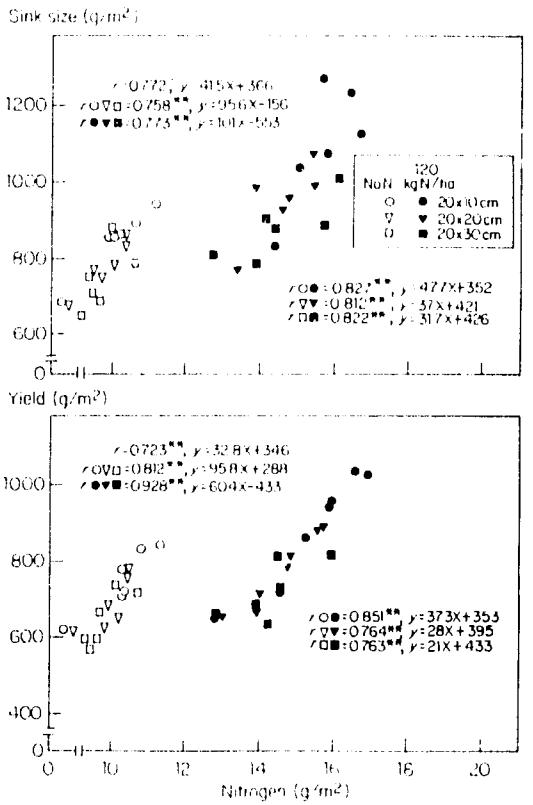
For increasing the amount of sink for short-duration varieties, it is important to increase the amount of differentiated sink by increasing N absorption at early growth stages.



41. Number of tillers at different growth stages of IR58 and IR25588-7-3-1, IRRI, 1986 DS. EPI = early panicle initiation. Arrows indicate maximum tiller number stage

Panicle number type varieties have a higher percentage of ripened grains. Narrow spacing does not decrease the percentage of ripened grains despite the increasing amount of sink.

Regarding the contribution of plant N at flowering to yield and sink, higher N efficiency is obtained



42. Relationship between sink size or yield and the amount of N in the plant at flowering for different plant spacings. IRRI, 1986 DS

Table 21. Effect of spacing and N level on the yield, sink size, contribution of N at flowering to yield and sink formation, sink degeneration, and ripening of short-duration varieties and lines (105-d maturity).[d] IRRI, 1986 DS.

Treatment	Grain yield (g/m²)		Sink size (g/m²)		Yield:N at flowering		Sink:N at flowering		Sink degeneration (%)		Ripening (%)	
	PN	I	PN	I	PN	I	PN	I	PN	I	PN	I
Spacing (cm)												
20 × 10	822	865	905	1048	65.7	65.4	72.4	79.1	6.7	11.6	91.0	83.0
20 × 20	742	731	831	901	61.8	60.3	69.3	73.9	5.5	9.8	89.7	82.0
20 × 30	696	671	791	837	52.5	57.0	65.4	72.2	4.7	8.4	89.0	80.3
N level (kg/ha)												
0	676	703	762	836	70.2	63.9	76.8	80.9	5.8	10.5	91.0	83.7
120	814	810	923	1023	53.6	54.7	61.0	69.1	5.5	9.5	88.0	79.3

[d]PN = panicle number type (IR58, IR64, IR60), I = intermediate type (BG367-4, IR25588-7-3-1, IR29692-65-2-3-3).

in a no-N plot with narrow spacing. The lower N efficiency in a higher-N plot is caused by top-dressing at the panicle initiation stage, and the higher N efficiency in a narrow-spacing plot is explained by the occurrence of panicle initiation after the maximum tiller number stage. The contribution to sink formation of N absorbed after panicle initiation is small compared with that of N absorbed before panicle initiation.

GRAIN FILLING IN RICE AS AFFECTED BY SIZE AND LOCATION OF SOURCE AND SINK

Plant Physiology Department

The grain size of rice is physically restricted by the hull and is considered as the most-stable yield component. However, single grain weight can vary greatly within a plant and among cultivars. Increasing kernel density can increase its weight and enhance potential yield. High density grains also increase milling and head rice recovery. An understanding of the factors that cause spikelets to fill to their maximum capacity and density may help in increasing the proportion of heavy grains.

Experiments using IR58 studied the distribution of heavy grains on the panicle and the factors affecting this distribution, evaluated the relationship of leaf size and position to grain filling and the competition for assimilates among spikelets, and investigated the effect of sink size and position on grain filling.

Source size and position. To determine the role of leaf position and source size on grain filling and the distribution of heavy grains in the panicle, the following treatments were imposed on the main culm at flowering: control, all leaves removed except the flag leaf, flag leaf and 2d leaf remaining, 4th leaf removed, flag leaf removed, flag leaf and 2d leaf removed, and all leaves removed.

Grain yield. With only the flag leaf and 2d leaf, grain yield was similar to that of intact plants (Table 22). Removal of the two leaves from the top or from the bottom resulted in almost the same residual leaf area, but yield was lower with removal of the top two leaves. These results indicate the greater influence of the source nearer the sink (panicle) than those further down. Removing the flag leaf alone or in combination with other leaves reduced grain yield. Total defoliation resulted in the greatest reduction in grain yield.

Table 22. Effect of source size and position on the grain yield of IR58, IRRI, 1986.

Treatment	Leaf area (cm^2/plant)	Grain weight	
		mg/plant	As percent of control
All leaves attached	183	1779	100
Only flag leaf attached	40	1440	81
Flag leaf and 2d leaf attached	90	1720	97
4th leaf removed	142	1997	112
Flag leaf removed	143	1547	87
Flag leaf and 2d leaf removed	93	1189	67
All leaves removed	0	1013	57
LSD (0.05)		217.5	

Removal of the 4th leaf, i.e. retaining the top three leaves, increased grain yield, indicating a negative assimilation rate of the 4th leaf, probably because of senescence or competition for assimilates.

The three top leaves appeared to be the major sources of assimilates for grain filling. The flag leaf and the 2d leaf showed important roles in grain filling. The 3d leaf may translocate up or down and may have less effect on grain filling.

Heavy grains. Grains differ in weight and density. Heavy grains (>22 mg/grain) constituted the largest number in control and treated plants (Table 23) except in 2 treatments. When the flag leaf and 2d leaf were removed or when all leaves were removed, most grains weighed <16 mg.

The total grain weight was significantly correlated with the number of heavy grains ($r = 0.953^{**}$).

Removal of the flag leaf and subsequent leaves increased empty spikelets and poor grains, but removing the 4th leaf increased heavy grains and decreased light grains. Removal of leaves below the 2d leaf showed a pattern of grain weights similar to that of the intact plant.

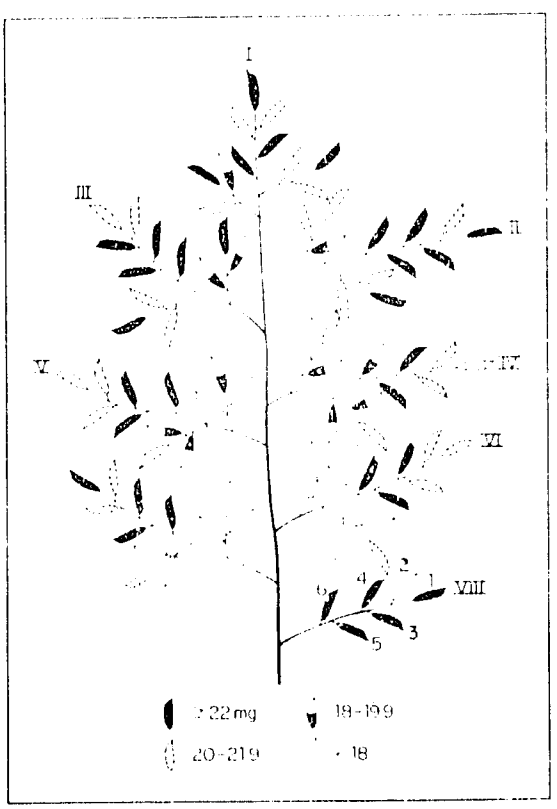
Location of heavy grains. Heavy or well-filled grains were generally found on the primary branches (Fig. 43). The grains on the secondary branches weighed less than those on the primary branches. The grains on secondary branches in the

Table 23. Effect of size and position of source on the number of grains of different grades in IR58. IRRI, 1986.

Treatment	Grains (no.) at weight intervals of				
	>22 mg	21.9-20.0 mg	19.9-18.0 mg	17.9-16.0 mg	<16 mg
All leaves attached	35.6	24.6	13.1	4.1	10.4
Only flag leaf attached	29.3	21.6	6.9	3.9	23.4
Flag leaf and 2d leaf attached	34.0	25.7	12.5	5.5	9.3
4th leaf removed	48.1	27.9	10.2	4.4	4.3
Flag leaf removed	32.3	22.9	6.4	3.5	23.4
Flag leaf and 2d leaf removed	17.5	21.5	4.2	4.4	32.3
All leaves removed	11.3	13.8	5.3	3.1	52.2
LSD (0.05)	13.6	ns	ns	ns	8.3

upper part of the panicle were heavier than those in the lower part. The differences in final grain weight at various positions within the panicle generally follow the order of flowering.

Removal of leaves below the flag leaf reduced the leaf area by 78% and left a 40-cm^2 leaf area.



43. Location of grains of different weights in a panicle of IR58 with all leaves intact (leaf area = 183 cm^2). IRRI, 1986. Roman numerals indicate branch numbers, arabic numerals indicate spikelet numbers.

Nevertheless, the number of heavy grains and their distribution on the panicle were similar to when the flag leaf was removed, which left 143 cm^2 of leaf area (Fig. 44). When the assimilate was limited, either by reduction in leaf area or removal of the most active leaf, the same spikelets that are generally heavy were the ones that were well filled. Grains on secondary branches and on the lower part of the panicle were poorly filled. There was no indication that the flag leaf supplies assimilates to any specific branch of the panicle.

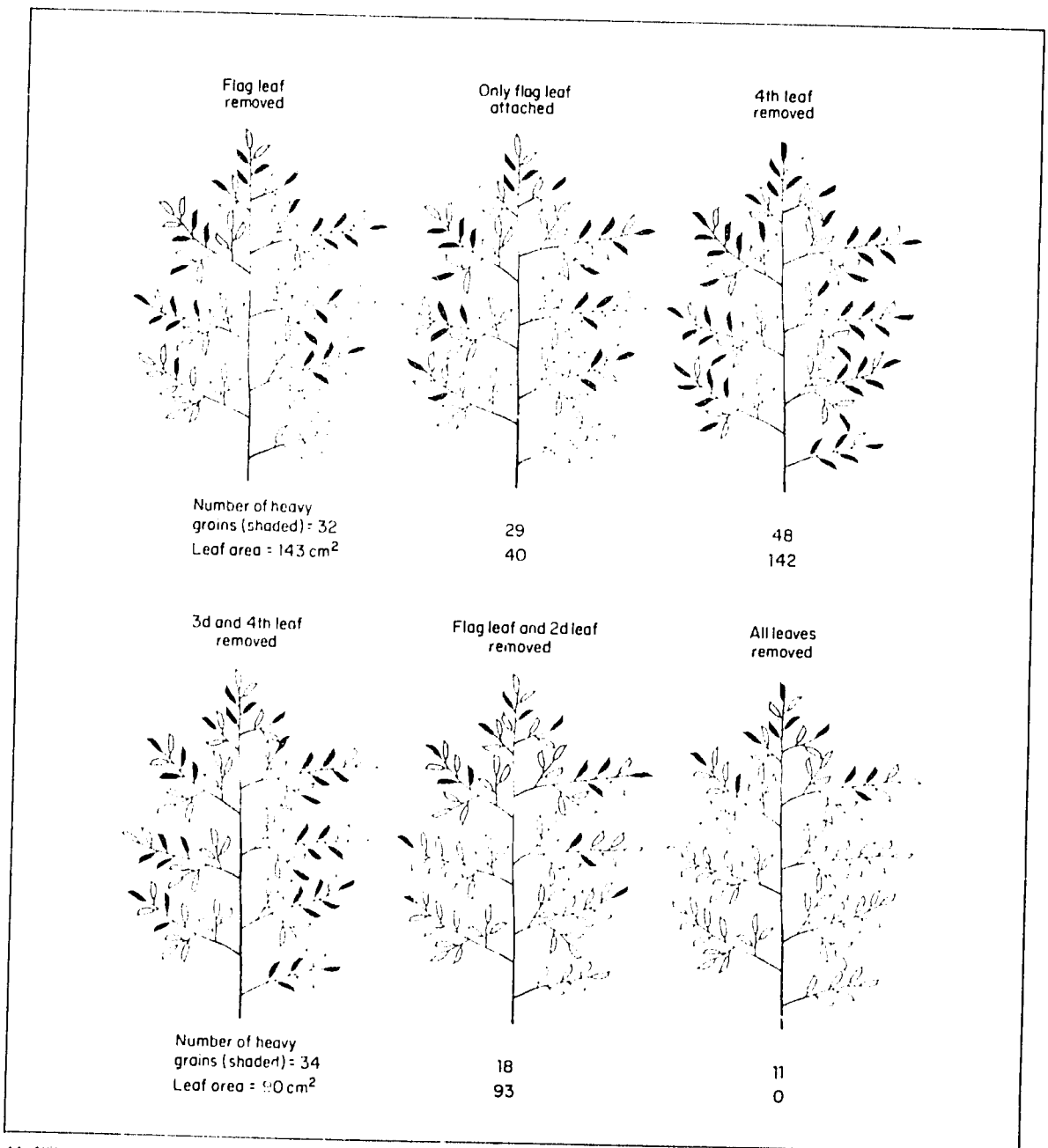
Removing the flag leaf or the 4th leaf gave the same residual leaf area. However, removal of the 4th leaf increased the number of heavy grains on primary branches and terminal spikelets of secondary branches (Fig. 44).

When two leaves from the bottom or the top were removed, the reduction of leaf area was similar, but removal of the top leaves had more adverse effects on the number of heavy grains (Fig. 44). The flag leaf is generally important in producing heavy grains as well as in grain filling. Leaf area is not critical, but the activity and location of leaves are important. Spikelet filling was not related to the distance from the source. When the supply of assimilates was limited by defoliation, spikelets of upper panicle branches, which were also the spikelets that flowered first, became stronger sinks than the lower branches in the panicle. There are positional differences in grain weight within a panicle.

Sink size and position. To study grain filling in relation to sink size and relative position on the panicle, sink size was manipulated by removing spikelets at flowering (Table 24).

Spikelet weight. Removal of terminal spikelets reduced total spikelet weight but increased the average weight of spikelets (Table 24). Removal of spikelets on the secondary branches considerably increased single spikelet weight, while removal of spikelets on the primary branches did not, suggesting that the capacity to accumulate carbohydrate is greater in primary branch spikelets than in secondary branch spikelets. Also, there was an indication of competition for carbohydrate among spikelets on the primary and secondary branches in the control.

Removal of some spikelets from the panicle increased the weight of the remaining spikelets,



44. Effect of size and position of source (leaf) on location of the best filled grains. IRRI, 1986.

Table 24. Effect of reduction in spikelet number per panicle on total spikelet weight and average weight per spikelet of IR58, IRRI, 1986.

Treatment[a]	Spikelets		Total spikelet weight		Av spikelet weight (mg)
	no./panicle	As percent of control	mg	As percent of control	
Control	98.2	0	1741	0 a	17.7 d
Terminal spikelets removed	64.0	36	1247	28 cd	19.5 b
Spikelets on primary branch removed	37.2	63	682	61 f	18.2 cd
Spikelets on secondary branch removed	45.5	54	954	45 e	21.0 a
Branch I removed	81.5	18	1490	14 b	18.3 bcd
Branches I and II removed	58.6	41	1101	37 de	18.9 bc
Branch VIII removed	81.5	18	1516	13 b	18.7 bc
Branches VII and VIII removed	73.9	26	1404	19 bc	18.8 bc

[a]Primary branch I is the topmost and VIII is the lowest on a panicle.

implying that in intact plants grain weight is less than the potential weight. Increases in individual spikelet weights did not compensate for the loss in number of spikelets.

Dimensions and density of grains. Heavy grains (≥22 mg) had the largest grain and kernel size in all dimensions measured (Table 25). Lightweight grains had smaller dimensions, indicating that the size of the spikelet contributes to the final grain weight. The size of the hull is determined before heading; when it is small, the physical limitation prevents the kernel from developing further. The spikelet length at heading is highly correlated with the 1,000-kernel weight. Weight per grain was closely correlated with hull size. Within a panicle, the large kernels are those from large hulls or spikelets. The production of large spikelets may be related to their position on the panicle and in turn to the vascular bundle supplying the spikelets.

Primary branches had more high density grains (sp gr >1.20). Thus, the spikelets on the primary branch may have a greater capacity to accumulate carbohydrate than those on secondary branches in terms of weight and density of grains.

Location of grains of different weights. Generally, the 5th and 6th spikelets on primary branches were heavy and gradually became lighter towards the top, except for the terminal spikelet (Fig. 43). However, the terminal spikelets on the secondary branches were always heavier than those of lower ones. When terminal spikelets were removed, the proportion of heavy grains increased, and they were on the primary branches (Fig. 45).

Removal of one branch from the top or bottom reduced spikelet number by 18%, but production of heavy grains did not significantly differ between treatments (Fig. 45).

The number of heavy grains was not significantly different from the control when two branches from the top or bottom were removed. The differential ability of spikelets to accumulate carbohydrate, depending on their position on a

Table 25. Grain and kernel properties of IR58 differing in spikelet weight,[a] IRRI, 1986.

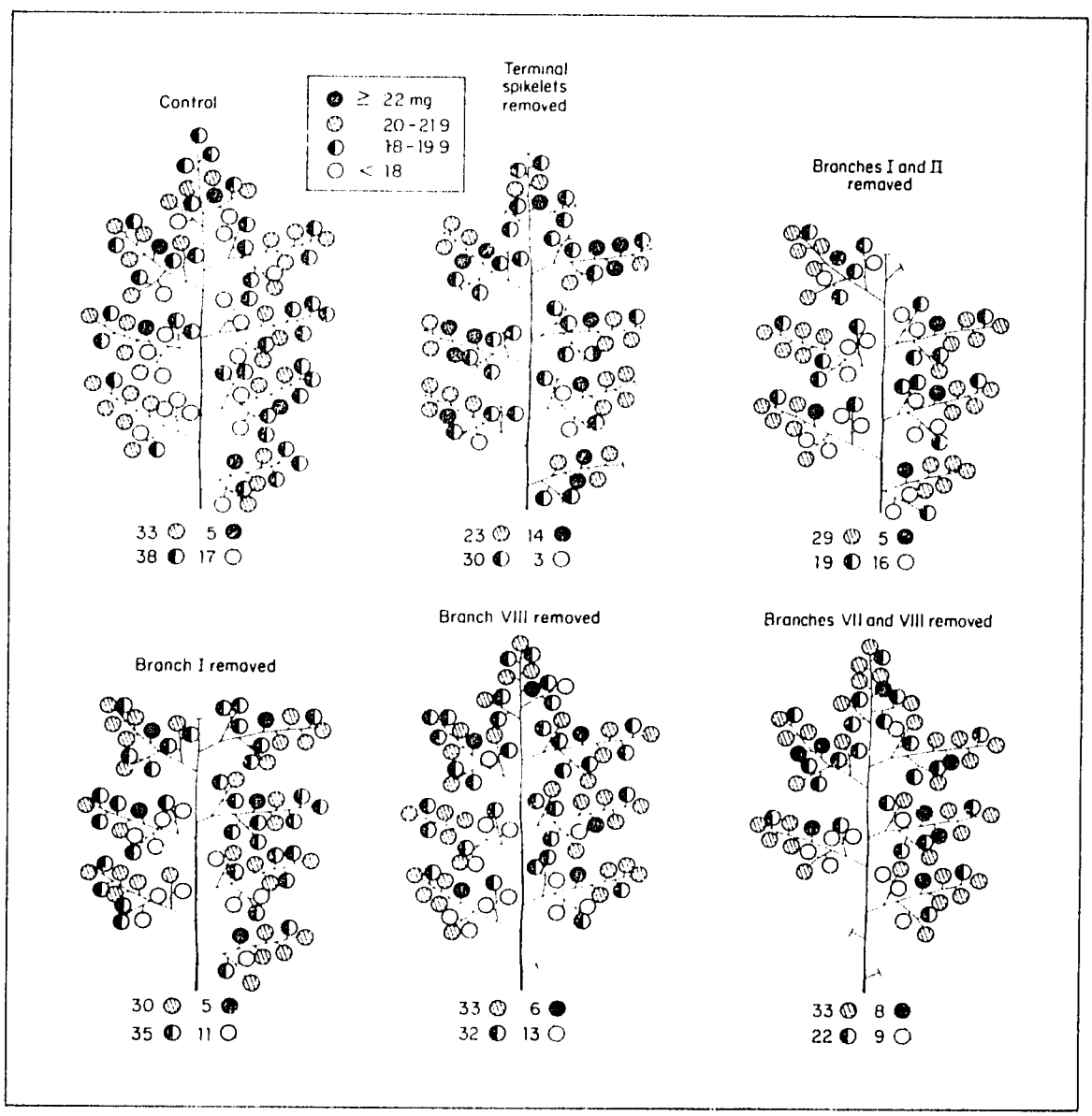
Spikelet weight[b] (mg)	Grain			Kernel		
	Length (mm)	Width (mm)	Thickness (mm)	Length (mm)	Width (mm)	Thickness (mm)
≥ 22	8.62 ± 0.03	2.66 ± 0.01	1.93 ± 0.004	6.19 ± 0.02	2.31 ± 0.01	1.73 ± 0.01
21.9 - 20	8.44 ± 0.04	2.65 ± 0.01	1.88 ± 0.01	5.99 ± 0.02	2.28 ± 0.01	1.63 ± 0.01
19.9 - 18	8.19 ± 0.04	2.58 ± 0.02	1.87 ± 0.01	5.81 ± 0.02	2.21 ± 0.01	1.67 ± 0.01
17.9 - 16	7.96 ± 0.04	2.48 ± 0.02	1.82 ± 0.01	5.68 ± 0.03	2.14 ± 0.01	1.63 ± 0.01
15.9 - 10	7.49 ± 0.1	2.41 ± 0.03	1.72 ± 0.02	5.21 ± 0.01	1.98 ± 0.02	1.54 ± 0.02

[a]Mean ± standard error. [b]8.9% of moisture content.

panicle, was apparent. Among the spikelets on a primary branch or a secondary branch, the terminal spikelet flowers first, followed by the basal spikelet, and proceeds acropetally in a branch. The early opening spikelet immediately creates a sink for carbohydrate to be translocated from the source. Thus, flowering order apparently affects grain filling.

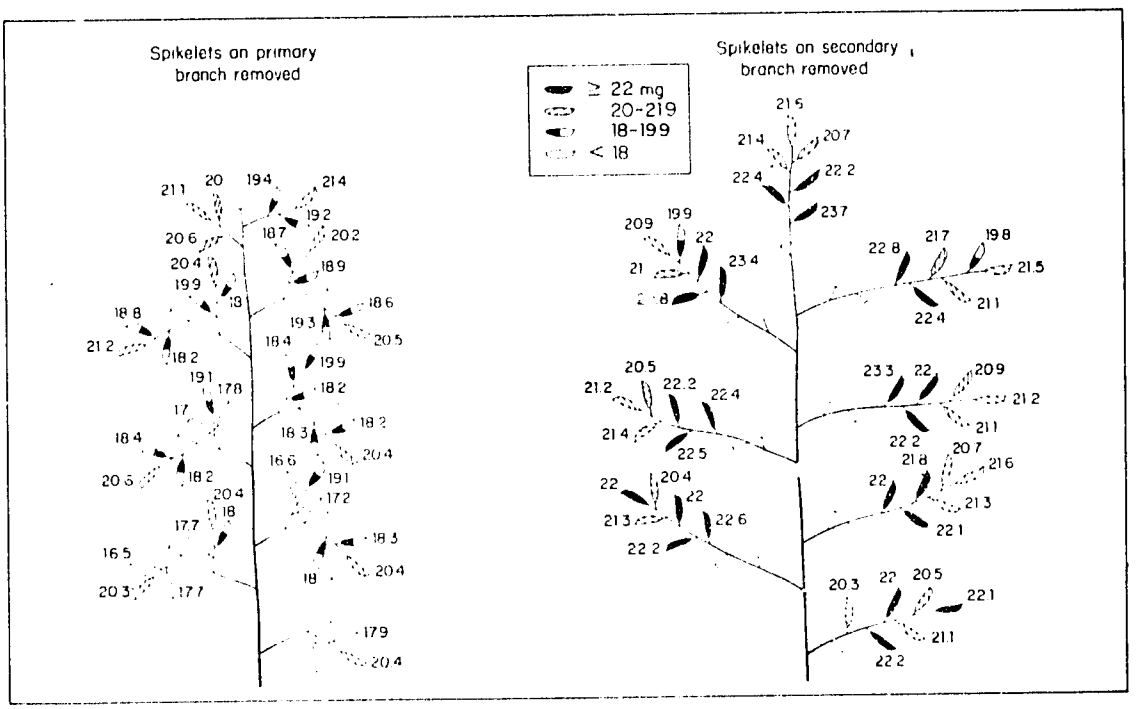
Removal of spikelets from the primary branch did not increase heavy grains (Fig. 46), perhaps because hull size limited the growth of the remaining spikelets. However, removing spikelets from the secondary branch increased the weight of spikelets with large hull sizes. Increasing the source or assimilate supply does not necessarily increase grain weight if grain size is limited by spikelet size. Spikelets on the primary branch were always better filled than those on the secondary branches.

Grain filling rate. Increase in grain weight was analyzed based on the linear-plateau model. In the

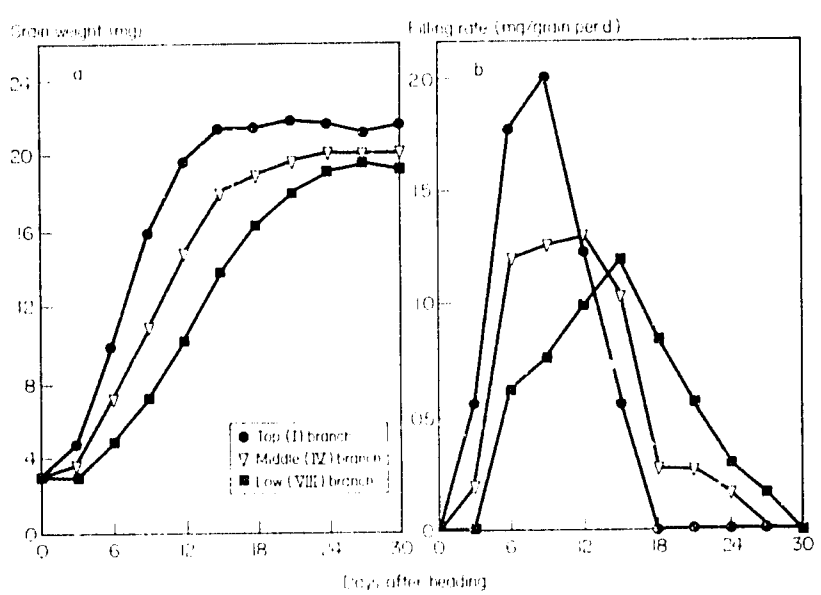


45. Effect of sink size and position on the location of grains of different grades. IRRI, 1986. The number of grains of a given grade is under each illustration.

top branch (I), dry matter weight started to increase 3 d after flowering (DF), rapidly increased up to 15 d, then leveled off (Fig. 47a). In the middle branch (IV), grain weight increased almost linearly up to 15 d and became constant 24 d after heading (DH). The increase in grain weight of branch VIII



46. Effect of sink size and position on the location of grains of different grades in IR58. IRRI, 1986.



47. Dry matter accumulation in the grain (a) and daily rate of accumulation (b) at different positions of the branch on the panicle. IRRI, 1986.

was slower than in upper branches and reached the final weight at 27 DH. The grain filling rate was at its maximum 9 DF at 2.0 mg/d in the top branch, 12 DF at 1.3 mg/d in the middle branch, and 15 DF at 1.2 mg/d in the lower branch (Fig. 47b). Grain filling rate and duration varied with branch location on a panicle. Spikelets on the top branch filled faster than those on the lower branches.

The 5th and 6th grains on the primary branch had the highest grain filling rates and final weights among the grains on the top branch (Table 26). The 2d grain had the lowest grain filling rate and weight and longest grain filling duration. On the secondary branch, the terminal grain had a greater grain filling rate and weight than the lower ones. The 2d grain had the lowest filling rate and weight and longest grain filling duration. The grain filling rate was lowest and the duration longest in secondary branch grains and in lightweight grains.

Grains on the primary branch of panicle branch VIII had the same trend in grain filling rate and duration, but grains on the secondary branch, especially the basal grains, had a long initial lag phase, followed by a rapid increase in dry weight.

The grain filling rate and duration were greatly dependent on the position of the grain and the branch. The rate ranged from 1.71 to 1.03 mg grain per d on primary branches, and from 1.64 to 0.57 mg/grain per d on secondary branches. Grain filling duration ranged from 12 to 18 d on primary branches and from 12 to 29 d on secondary branches.

Grain filling rate depends on the location of the branch (top or bottom) and on whether the branch is primary or secondary. The filling period and the days from heading to maximum grain weight also vary with position of the branch on the panicle. Thus, identifying the date of physiological maturity is difficult even within a panicle.

ENHANCING YIELD POTENTIAL

Plant Physiology Department

Relationship between grain size and high density grains. Forty-three short-duration cultivars, 15-40 g/1,000 grains, were used to assess the relationships between grain size and grade of grain. The grades of grain were determined by the specific gravity method. The poor grade grains had from 1.00 to 1.06 sp gr; average grade, from 1.08 to 1.14; good grade, from 1.16 to 1.20; and high density (HD) grains, >1.20.

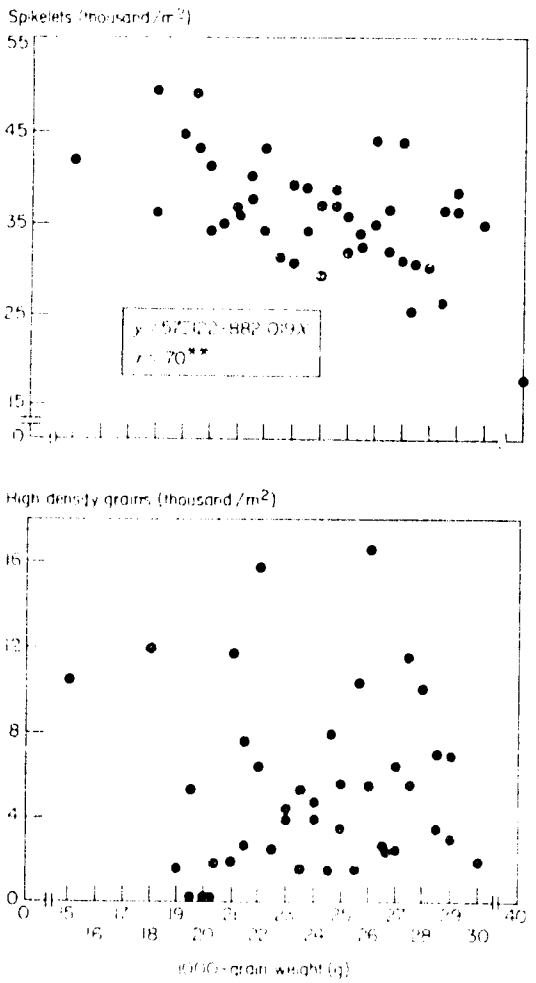
Spikelet number per m^2 decreased as 1,000-grain weight increased (Fig. 48). Among the smaller-grain cultivars (15-23 g/1,000 grains), IR34615, IR747 (L), IR25926, and IR30 had high numbers

Table 26. Estimated grain filling rate, duration of grain filling, and weight of grain at different positions on a panicle, IRRI, 1986.

Position[a]	Top branch (I)			Middle branch (IV)			Lower branch (VIII)		
	Rate (mg/grain per d)	Grain weight (mg)	Duration (d)	Rate (mg/grain per d)	Grain weight (mg)	Duration (d)	Rate (mg/grain per d)	Grain weight (mg)	Duration (d)
P-1	1.59	21.3	1[illegible].9	1.56	21.4	12.3	1.35	21.3	14.5
P-2	1.49	20.3	12.9	1.30	20.4	15.0	1.0[illegible]	19.7	18.4
P-3	1.58	21.7	12.7	1.37	21.3	14.6	1.1[illegible]	20.7	17.7
P-4	1.64	22.8	12.8	1.41	21.8	14.3	1.13	21.2	17.7
P-5	1.71	23.2	12.4	1.44	22.3	14.1	1.14	21.7	17.8
P-6	1.71	23.0	12.1	1.46	22.3	13.8	1.15	21.6	17.6
S1-1	1.64	22.2	12.2	1.44	20.6	13.3	0.82	20.3	23.1
S1-2	1.16	19.6	15.9	0.71	18.3	24.8	0.60	16.7	28.6
S1-3	1.26	20.5	15.6	0.79	18.2	22.5	0.60	16.4	28.0
S2-1	1.65	22.3	12.0	1.13	19.4	15.8	0.71	19.6	27.6
S2-2	1.24	20.2	15.3	0.62	17.2	27.8	0.57	16.2	28.6
S2-3	1.31	21.1	15.1	0.64	17.7	27.5	0.61	16.7	28.8

[a]P-1 = topmost spikelet on the primary branch, P-6 = 6th spikelet on the primary branch; S1-1 = topmost spikelet on the 1st secondary branch, S2-3 = 3d spikelet on the 2d secondary branch.

of HD grains. In the 24- to 30-g range, the variability was higher; IR28211, IR32307, IR29692-117, and IR29725-135 showed high values. The large-grain cultivar Zhy Lian-Aiyu-Naa did not produce any HD grains. A high percentage of HD grains was noted in a wide range of grain sizes. The number of HD grains showed no relationship with grain size (Fig. 48).



48. Relationship of spikelet number and high density grains with 1000-grain weight. IRRI, 1986.

There was generally a large difference between HD and good grains within and among cultivars (Table 27), indicating that grain yield may be improved by increasing the percentage of good grade grains.

Increasing the percentage of HD grains in short-duration cultivars would help to enhance yields; the grain size, in the range used, does not seem to be a limitation. However, cultivars with large grains (around 40 g or heavier) may not be useful for higher yield potentials.

Light intensity and grades of grain. IR36 was grown in the growth cabinets of the phytotron continuously at 195, 390, and 780 μmol/m^2 per s. High light intensity increased the number of spikelets, resulting in higher grain yields. HD grains and good grains increased with higher light intensity (Fig. 49).

HD and good grades of grain made up the bulk of the grain yield. The similar proportions of the different grades of grain indicate that sink size was probably determined earlier, based on the capacity of the source to supply carbohydrate.

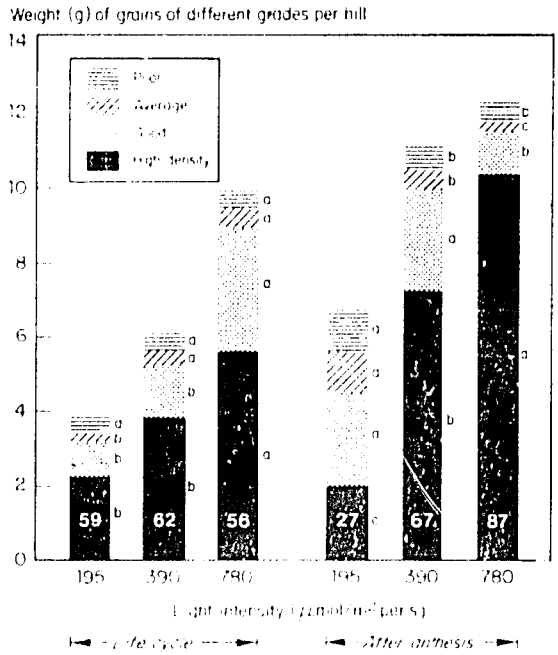
When the plants were exposed to different light intensities after anthesis, the contribution of HD grains to total grain yield markedly increased at high light intensity; the grain yield was made up mostly of HD grains.

The percent contribution of HD grains to the total grain yield of IR36 was a major determinant of grain yield. Thus, cultivars having a higher proportion of HD grains would be better even under low light conditions.

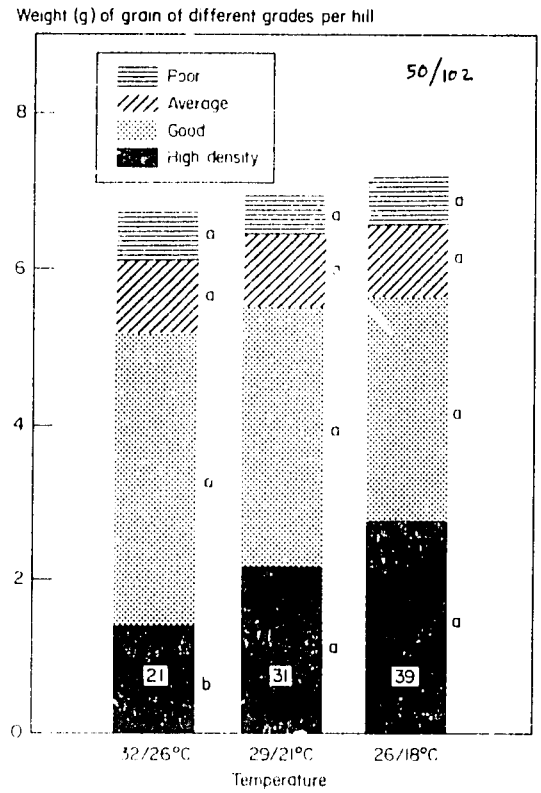
Improving the environmental conditions after anthesis can result in better grain filling and better grade grains.

Table 27. Percent contribution to the total spikelets of the different grades of grain in 43 cultivars. IRRI, 1986.

Spikelets (thousand/m²)	High density grains (%)	Good grade (%)	Average grade (%)	Poor grade (%)	Empty spikelets (%)
		Mean			
36.0 ± 6	14.6 ± 12	44.1 ± 12	9.0 ± 5	12.3 ± 8	19.9 ± 7
		Range			
11.8 – 49.0	0 – 52	0 – 68	3 – 26	5 – 53	6 – 41



49. Weight of grain of each grade in IR36 when exposed to different light intensities throughout its life cycle and after anthesis. Figures inside the bar are the percent contribution of high density grains to total grain yield. Bars of the same shade at the same stage of treatment followed by the same letter are not significantly different at the 5% level by DMRT.



50. Influence of temperature regime after anthesis on the weight of grain of different grades in IR36. IRRI, 1985 DS. The figures in the dark shade are percent of the total weight. Bars followed by the same letter are not significantly different at the 5% level by DMRT.

Temperature and high density grain production. IR36 was grown in the greenhouse and transferred to the naturally lit growth cabinets with the following day/night temperature regimes at flowering: 32/24 °C (high), 29/21 °C (medium), and 26/18 °C (low).

Low temperature increased the duration of the ripening phase. Medium and low temperature regimes resulted in higher weight and proportion of HD grains (Fig. 50). The increase in HD grain weight with lower temperature regime indicates the importance of a longer grain filling period.

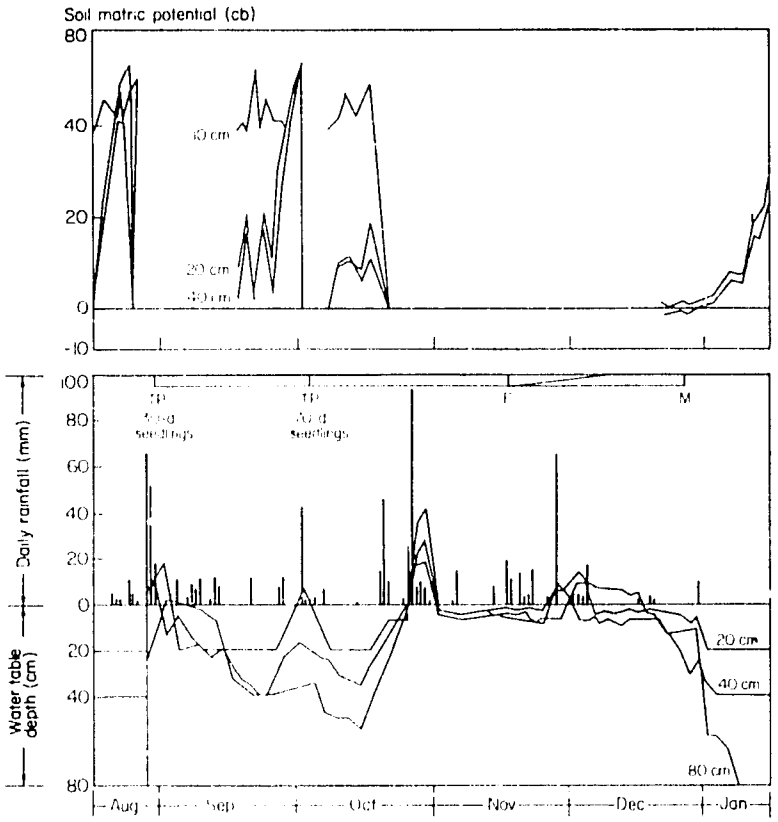
SEEDLING SENSITIVITY TO LATE TRANSPLANTING AS INFLUENCED BY HYDROLOGY AND NITROGEN LEVEL

Multiple Cropping Department

Insensitivity to late transplanting is a plant character required in varietal improvement for rainfed lowland areas with unpredictable rainfall patterns. Sixteen elite cultivars varying in photoperiod sensitivity were tested in four experiments in a difficult rainfed environment in Solana, Cagayan, Philippines, to evaluate their sensitivity to late transplanting. Seedling ages ranged from 30 to 70 d. The hydrology among experiments varied from irrigated to rainfed, and seedbed conditions varied from stressed to unstressed.

The decrease in rainfall frequency starting 15 d after transplanting substantially lowered the water table (Fig. 51). Soil matric potential increased during this period to a maximum of 69 cb at the end of September. The rainfed experiments were subjected to a long period without standing water in the field at the vegetative and reproductive stages.

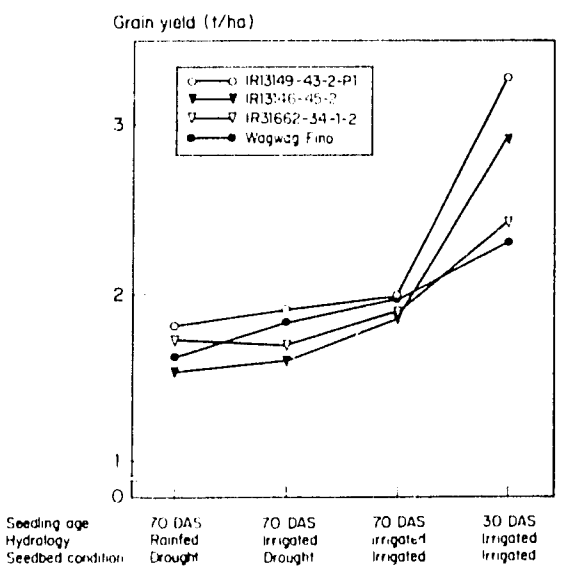
Tiller number and grain yield were lower with aged seedlings. The yield increase due to irrigation (7-24%) was not as pronounced as that due to planting young (30 d) seedlings (48%). The



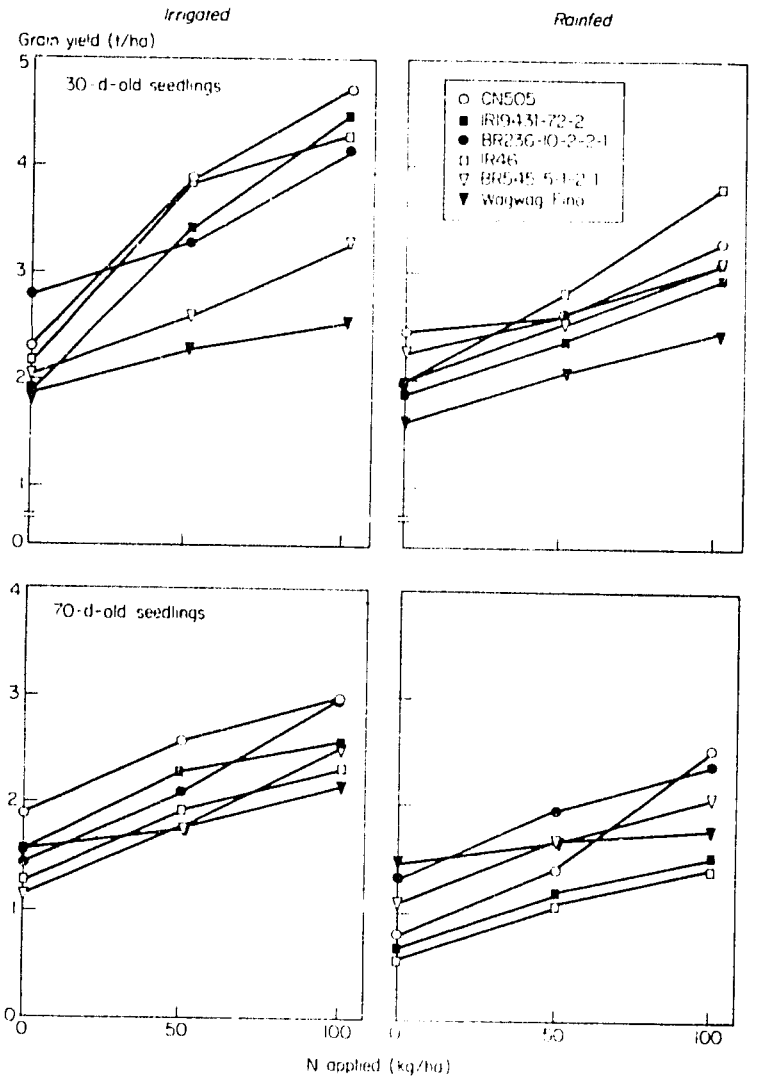
51. Soil moisture tension, daily rainfall, water table depth, and seedling age in an adaptation trial, in stratum 1, Solana, Cagayan, Philippines, 1985 WS. TP = transplanting, F = flowering, M = maturity.

occurrence of sublethal drought in the seedbed did not contribute to cultivar sensitivity to late transplanting (Fig. 52). Compared with improved cultivars, the popular locally adapted, photoperiod-sensitive Wagwag Fino performed well in those environments in which aged seedlings were used but did not respond well to better conditions. A few cultivars performed well across all environments, particularly IR13149-43-2-P1, a photoperiod-insensitive entry. IR13146-45-2 yielded better than Wagwag Fino in the favorable environment but performed slightly worse than the adapted rainfed cultivar in the aged seedlings condition.

The N response of six promising cultivars was evaluated in four environments composed of two seedling ages combined with two hydrological conditions (Fig. 53). Response to N was high for most cultivars in irrigated fields with 30-d-old seedlings. The response was much less pronounced



52. Mean yields of 4 best cultivars tested under various seedbed and field conditions. IRRI, 1986. DAS = days after sowing.



53. Yields of 6 cultivars as affected by N and age of seedlings under rainfed and irrigated conditions. Solana, Cagayan, Philippines, 1985 WS.

when young seedlings were used in rainfed fields, or when 70-d-old seedlings were used in irrigated fields (Fig. 53). N response was lowest (maximum yields about 2.0 t/ha) when old seedlings were combined with rainfed growing conditions.

The check cultivar Wagwag Fino showed little N response in any environment. The cultivar with the most consistently superior performance was CN505 (Fig. 53), but in rainfed fields with old seedlings, none of the entries were significantly superior to Wagwag Fino. If the environments in the experiments are assumed to represent the spectrum of interannual hydrological conditions and management levels employed by farmers in a given rainfed environment, the decision about which cultivar to select would depend on the comparative performance of the test cultivars in each situation, weighted by the frequency with which each situation occurs.

Genetic evaluation and utilization (GEU) program

Grain quality and nutritional value

Cereal Chemistry, Plant Breeding, Agronomy, Plant Pathology, Plant Physiology, and Statistics Departments, International Rice Germplasm Center, International Rice Testing Program, and Rice Farming Systems Program

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BREEDING PROGRAM AND EVALUATION

Cereal Chemistry, Plant Breeding, Plant Physiology, and Statistics Departments, International Rice Germplasm Center, International Rice Testing Program, and Rice Farming Systems Program

Elite lines (*Plant Breeding and Cereal Chemistry*). The six outstanding elite lines from the irrigated rice breeding program consisted of three intermediate-amylose content (AC) lines with intermediate gelatinization temperature (GT), similar to IR64, and three high-AC lines, two with low GT like IR42 and one with intermediate GT like IR36 and IR62 (Table 1). IR31868-64-2-3-3-3 had the softest cooked rice among the three intermediate-AC lines and had the softest gel consistency (GC). IR32307-107-3-2-2 had the softest cooked rice among the three high-AC lines and also had soft GC. The ranking of Amylograph consistency values of the samples corresponded well to their ranking based on cooked rice Instron hardness.

Sixteen intermediate-AC elite lines from the 1985 wet season (WS) and 36 from the 1986 dry season (DS) were assessed. AC and cooked rice Instron hardness correlated positively in both crops, as did cooked rice hardness and Amylograph consistency. Cooked rice hardness correlated negatively with 90 mg flour GC in both crops. IR35366-40-3-3-2-2 had the softest cooked rice, similar to that of cooked waxy IR39368-31-1-2 and softer than that of the low-AC line IR5420-1-1-2-3 (Table 1). As a group, intermediate-AC lines with low GT had harder cooked rice (10.4-12.5 kg Instron values) than those with intermediate GT (6.6-11.4 kg). In addition, samples with more than 10% milled rice protein had hardness values higher than 10 kg.

In 1986 DS, 12 lines with soft and medium GC were verified among high-AC elite lines with low GT through the use of both 90 mg and 100 mg rice flour in the GC test. The soft-GC lines tended to have lower cooked rice hardness and lower Amylograph consistency than medium- and hard-GC types (Table 1). Those with medium GC tended to have intermediate hardness and Amylograph consistency. Amylograph peak viscosity of the 10% paste was also lower in soft-GC samples than in hard-GC samples, as was observed among high-AC rices with intermediate GT. Thus, alkali spreading value can no longer be used to monitor

Table 1. Mean milled rice properties for 2 crops of elite lines and check IR varieties and 1 crop of high-amylose lines, IRRI, 1985 WS and 1986 DS.

Variety or line	Protein (%)	Amylose content (%)	Alkali spreading value	Gel consistency (mm)	Cooked rice Instron hardness (kg/7 cm^2)	Amylograph consistency	
						10%	12%
IR64 (check)	8.4	20.4	4.2	64	7.6	–	120
IR36 (check)	8.2	25.2	4.9	38	8.8	255	–
IR42 (check)	7.2	26.0	7.0	30	10.6	575	–
IR28224-3-2-3-2	6.7	27.1	7.0	36	9.9	470	–
IR28228-12-3-1-1-2	6.8	23.8	4.4	38	9.8	–	440
IR31868-64-2-3-3-3	7.9	21.0	3.6	50	7.3	–	200
IR32307-107-3-2-2	7.8	26.3	4.3	94	8.6	265	–
IR32429-47-3-2-2	9.0	24.4	4.4	30	10.2	–	425
IR32453-20-3-2-2	6.2	26.3	7.0	30	9.5	510	–
IR39368-31-1-2	8.0	1.2	6.1	96	6.7	15	–
IR5420-1-1-2-3	8.2	16.2	7.0	74	7.8	–	190
IR35366-40-3-3-2-2	7.0	21.0	4.2	46	6.4	–	220
IR33043-46-1-3	7.2	26.1	7.0	73	8.7	245	–
IR39323-182-2-3-3-2	6.9	25.4	7.0	73	9.2	230	–
IR13754-5-2	7.0	25.3	7.0	48	9.4	345	–
IR39357-133-3-2-2-2	8.5	26.0	7.0	45	9.5	295	–
IR28224-3-2-3-2	6.6	25.3	7.0	39	10.7	500	–
IR32843-92-2-2-3	6.5	26.9	7.0	32	10.2	395	–
IR32453-20-3-2-2	6.2	25.2	7.0	30	9.6	425	–

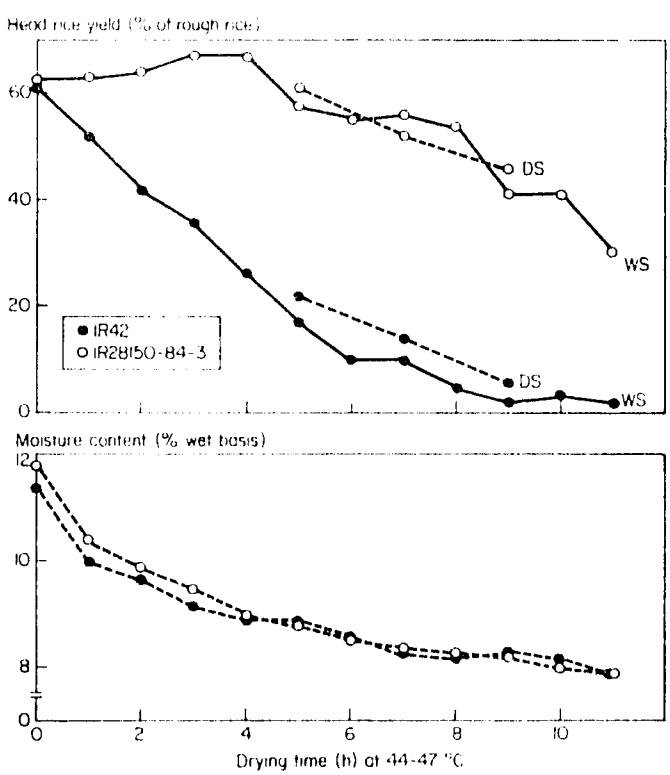
GC among high-AC rices in the breeding program because now not all of the low-GT samples have hard GC.

Screening for stable head rice yield (*Cereal Chemistry and Plant Breeding*). To replace the infrared moisture balance technique, a simpler screening method was devised using 1985 WS IR42 as a susceptible check and IR28150-84-3 as a resistant check. Rough rice (8 g) was dried in a forced draft or air oven at 45 ± 2 °C for 5-9 h and then stressed by overnight exposure to ambient conditions of temperature and humidity. The resulting brown rice was milled in a Kett Pearlest mill for 30 s. Good differentiation was obtained between 4 and 10 h heating (Fig. 1). Similar results were obtained for the 1986 DS crop of the same rices. Moisture content of the oven-dried grains was 8-9% (wet basis) and was similar for the 2 rices (Fig. 1).

Field grain samples of 29 IR varieties and IR28150-84-3 were harvested in 1985 WS at normal maturity and at 1 wk later. Harvests in 1986 DS were at normal maturity and at 1 and 2 wk later. Rough rice was oven-dried at 38-40 °C in the laboratory and aged in sealed jars for 2 mo before milling.

Delayed harvest in 1986 DS reduced head rice yield more than in 1985 WS (Table 2). In 1985 WS, head rice yields at regular harvest and at 1-wk delayed harvest were correlated ($r = 0.90^{**}$). In 1986 DS, head rice yield at regular harvest correlated with head yield after 1-wk ($r = 0.76^{**}$) and 2-wk ($r = 0.68^{**}$) delays of harvest. Harvest head rice yields for the 2 crops were correlated ($r = 0.44^{*}$). Applying the oven-drying stress technique to duplicate 8 g rough rice of the 2 crops for 7 or 9 h at 45 °C was more discriminating than using 5 h. The considerable variation in weight loss among the samples had to be minimized to obtain consistent head rice yields.

Protein screening (*Cereal Chemistry, Plant Breeding, Statistics, and Rice Farming Systems Program*). *Yield trials* (*Cereal Chemistry, Plant Breeding, and Statistics*). Growth duration again



1. Changes in head rice yield of IR42 and IR28150-84-3 rough rice, 1985 WS and 1986 DS crops, and in moisture content, 1985 WS crop, during drying in an air oven at 44-47 °C. IRRI, 1986.

Table 2. Changes in head rice yields of 29 aged IR varieties and IR28150-84-3 with delayed harvest and drying at 45 °C for 5-9 h to induce fissuring.[a] IRRI, 1985 WS and 1986 DS.

Property	1985 WS		1986 DS	
	Range	Mean	Range	Mean
Head rice yield (%)	46 – 71	57.0	40 – 71	54.9
Change in head rice yield (%) from				
1 wk delay in harvest	−11 ~ +3	−1.4	−23 ~ +4	− 7.5
2 wk delay in harvest	--	--	−24 ~ +3	−10.3
Drying 5 h at 45 °C	−18 ~ 0	−8.0 (24)	−14 ~ +4	− 5.6
Drying 7 h at 45 °C	--	--	−27 ~ +5	−12.7 (17)
Drying 9 h at 45 °C	--	--	−28 ~ −3	−15.9 (17)

[a]Number in parentheses is number of samples treated when less than 30.

Table 3. Ranges of and correlations among growth duration, brown rice protein (BRP), and rough rice yield in replicated yield trials. IRRI, 1985 WS and 1986 DS.

Property	1985 WS (n = 370)			1986 DS (n = 370)		
	Range	Correlation with		Range	Correlation with	
		Growth duration	Rough rice yield		Growth duration	Rough rice yield
BRP (%)	6.5-11.1	−0.57**	0.03	6.0-10.4	−0.39**	−0.34**
Growth duration (d)	96 -140		−0.26**	104 -141		0.24**
Rough rice yield (t/ha)	2.2- 6.2			4.1- 7.7		

negatively correlated with brown rice protein (BRP) and grain yield in 1985 WS (Table 3). Only 4 entries had higher yield and BRP than IR36: IR1996-163-2-1-2 (8.5% BRP, 5.4 t/ha), IR32307-45-2-3-2 (8.5% BRP, 5.5 t/ha), IR35443-73-3-2-3 (8.7%, 5.4 t/ha), and IR39379-135-2-1-2-3 (9.2% BRP, 5.5 t/ha). In 1986 DS, growth duration correlated negatively with BRP but positively with grain yield. None of the entries including IR1996-163-2-1-2 was better than IR36 in yield and BRP. Among the six entries with higher yield and BRP than IR42 was IR28224-3-2-3-2, one of the six outstanding elite lines in Table 1. In the previous four seasons, yield-growth duration correlation coefficients were also negative in WS and positive in DS (Annual reports for 1984 and 1985).

Early-maturing traditional varieties (Cereal Chemistry). Ongoing studies on the replicated yield trials show that BRP and growth duration are negatively correlated. To verify whether such a relationship exists in traditional rices, eight traditional short-duration varieties selected by plant physiologists, plus IR36 and IR58, were planted in the field and greenhouse in 1985 WS to flower in early November. Only 6 of the 8 varieties had growth durations close to the check varieties (Table 4), and Fortuna and Guze had low grain yields (less than 10 g/hill). Their harvest indexes and N harvest indexes were lower than those of IR36 and IR58, but protein contents were comparable to those of the check varieties except for Pinursigue, with 7.7% panicle protein and duration of 114 d, and Sinariaya, with 7.9% panicle protein and duration of 118 d. The medium-duration rices had lower panicle protein content but higher yield per hill. Straw N of Pinursigue and Sinariaya was also lower than in the check varieties. The results suggest that traditional varieties also show a negative correlation between panicle protein content and growth duration.

IR varieties in farmers' fields (Cereal Chemistry and Rice Farming Systems Program). It was difficult to obtain IR rices differing in growth duration grown in the same farmers' fields in the Asian Rice Farming Systems Network (ARFSN) project in Santa Barbara, Pangasinan, Philippines.

Table 4. Comparison of traditional short-duration varieties with IR36 and IR58. IRRI, 1985 WS.

Property	Traditional varieties		IR36	IR58
	Short[a]	Medium[b]		
Duration (d)	109 -118	130	114	109
Grain yield (g/hill)	5 - 22	35	18	22
Harvest index	0.39- 0.50	0.42	0.58	0.55
N harvest index	0.47- 0.60	0.53	0.69	0.65
Rough rice protein (% N x 5.95)	7.7 - 9.4	7.2	8.5	9.1
Straw protein (% N x 6.25)	4.6- 7.9	4.8	5.6	6.2

[a]Fortuna, Guze, Macan Pulot, Norin 20, Pinursigue, and Sinariaya. [b]Mean of FB121 and BPI-76.

Only IR42 and IR48 had medium growth duration. Data on rough rice protein (RRP) and straw protein showed overlapping values among varieties (Table 5). RRP values tended to be lower than those obtained on the IRRI farm. Mean straw protein values, even for early maturing rices, were less than 6%.

Inheritance of amylose content (*Plant Breeding and Cereal Chemistry*). Seven low-GT indica varieties representing all AC classes — waxy, very low (5-9%), low, intermediate, and high — were crossed in all possible combinations including reciprocals. The seeds of parents and F_1, F_2, B_1F_1, and B_2F_1 generations of all the crosses were produced in a single season to minimize environmental effects. Single grain analysis for AC was done for all populations.

In waxy nonwaxy crosses, the appearance of the F_1 endosperm depended on the AC of the nonwaxy parent and its gene doses in the endosperm. A single dose of a high- or intermediate-AC gene was potent enough to produce AC almost equal to that of the nonwaxy parent. Many crosses showed clear dosage effects. AC increased with gene dosage, although not always linearly.

Segregation ratios of 1:1:1:1, 1:1:2, 1:3, and 1:1 were observed in F_2 single-grain AC analysis because of different dosage effects and the effect of minor genes and modifiers. Differences in AC were found to be governed by one major gene. There is also ample evidence for segregation of modifiers in all crosses. Segregation in B_2F_1 seeds depended primarily on the difference between AC in seeds containing one and three doses of a higher-AC gene. The greater difference gave clear categories.

Improved amylose test (*Cereal Chemistry*). Although the simplified amylose assay using acetate buffer at pH 4.5–4.8 is used extensively, the iodine-blue color is not blue but greenish, and shows amylopectin interference even with the use

Table 5. Protein content of rough rice and straw in farmers' fields in Asian Rice Farming Systems Network, Santa Barbara, Pangasinan, Philippines. IRRI, 1986.

Variety	Protein content (%)					
	Rough rice[a]			Straw[b]		
	Samples (no.)	Range	Mean	Samples (no.)	Range	Mean
IR36	10	5.6-8.2	7.0	6	4.0-5.6	4.8
IR42	16	6.2-8.2	7.0	6	3.7-5.8	4.7
IR48	5	6.1-7.1	6.7	–	–	–
IR60	24	6.2-8.4	7.6	15	3.3-7.4	5.3
IR62	8	6.4-8.2	7.0	5	4.5-7.1	5.5
IR64	8	6.4-8.2	7.3	6	4.1-5.4	4.8
Diket	4	6.7-7.9	7.4	1	–	5.2

[a]N X 5.95. [b]N X 6.25.

of amylose-amylopectin standards instead of amylose alone. Thus, waxy rices usually show up to 2-3% AC. Also, acetic acid may be inhaled during pipetting. In a search for alternate buffers to provide blue amylose-iodine color and minimize amylopectin interference, various buffers were tried. Borate at pH 8.5-9.0 gave the most satisfactory results. In the AutoAnalyzer module, the sample in 0.09 N NaOH was first neutralized with borax-HCl buffer before adding iodine to reduce iodine decomposition.

Comparison of the acetate and borate buffer methods showed more realistic amylose values for waxy rice and less interference of amylopectin in the amylose-iodine complex at alkaline borate pH (mean 2.3% vs 6.2%) (Table 6). Borate buffer was slightly more sensitive than acetate buffer to lipid interference, as shown by a greater decrease in amylose value between defatted and undefatted milled rices. A corresponding manual method was developed to provide fairly stable blue starch-iodine color.

Gene action analysis for grain protein (*International Rice Testing Program*). A 10 × 10 diallel cross (excluding reciprocals) involving genotypes spanning the available range of BRP content was undertaken. Plot means of BRP and protein per seed (P/S) in F_2 seeds were subjected to diallel analysis by Hayman's approach.

Estimates of the variance parameters indicated significant additive gene action and average partial dominance for both the traits in the parental genotypes. For both the traits, recessive alleles were in excess of the dominant ones, but less so for P/S. Alleles with positive and negative effects were distributed unequally at the additive loci as well as between the parental genotypes. The narrow sense heritability value was higher for P/S (51%) than for BRP (40%).

Analysis of the zymogram patterns of shikimate dehydrogenase isozymes involved in amino acid biosynthesis revealed that the 10 parents and their 45 crosses could be divided into 3 groups based on the dosage of a higher mobility band (HMB) allele. Each group differed significantly from the others in mean BRP and P/S, both traits showing increments with increased doses of the HMB allele; mean BRP was 10.8, 13.2, and 14.1% and mean P/S was 2.78, 3.73, and 4.28 mg for the 0, 1, and 2 doses of HMB allele, respectively. Only those parental genotypes having HMB alleles fell in the dominant, high quadrant of the standardized deviation plot for the parents.

Lysine screening of anther culture grains (*Cereal Chemistry and Plant Physiology*). Brown rice of 42 anther culture-derived selections with salinity tolerance was screened for BRP and lysine content by dye binding capacity using Acilane Orange G dye. BRP ranged from 7.9 to 11.3% and correlated significantly with dye binding capacity (r = 0.88**). No entry with high dye binding capacity was observed.

Longevity of rough rices at high relative humidity (*Cereal Chemistry and International Rice Germplasm Center*). Varietal differences in seed longevity were confirmed in 3 waxy, 5 low-AC, 4 intermediate-AC, and 19 high-AC rough rices from 1984 WS stored at 28-30 °C at ambient (60-80%) relative humidity (RH) with and without breaking of dormancy in 3 d at 55 °C. Waxy rices

Table 6. Comparison of lipid and amylopectin interference in apparent amylose content of 5 milled rices[a] in 0.019 *M* pH 4.5-4.9 acetate and 0.008 *M* pH 8.5-9.0 borate buffers. IRRI, 1986.

Buffer	Treatment	Apparent amylose content (% dry basis)			
		Potato amylose – amylopectin		Potato amylose standard	
		Range	Mean	Range	Mean
Acetate	Defatted	1.6 - 26.8	14.8	8.8 - 31.6	20.8
0.019 *M*	Undefatted	1.2 - 23.1	12.4	8.3 - 28.4	18.6
Borate	Defatted	1.4 - 26.4	14.4	4.4 - 28.2	16.8
0.008 *M*	Undefatted	1.2 - 22.0	11.8	4.0 - 24.0	14.1

[a]IR29, IR2071-137-5, IR24, IR64, and IR8.

were confirmed to lose viability faster than nonwaxy rices at high RH, but no clear-cut trend was noted among the nonwaxy rices. Mean days after harvest for germination to drop to 50% (mean viability period [MVP]) was 319 d for waxy, 545 d for low AC, 460 d for intermediate AC, and 486 d for high AC. The high value for low AC was due in part to the highest MVP of 668 d for IR2071-137-5-5-1, although excluding this rice still resulted in a high mean value of 514 d. Not all dormant rices had long viability periods; dormant varieties like CO 29 and Seraup 27 had low MVP values of 358 and 321 d, respectively. Breaking of dormancy by heating for 3 d at 55 °C reduced the MVP in 24 of the 31 rices.

GRAIN QUALITY AND NUTRITIONAL FACTORS

Cereal Chemistry, Agronomy, Plant Breeding, and Plant Pathology Departments, and Rice Farming Systems Program

Country samples (*Cereal Chemistry*). Popular varieties and lines grown in 19 rice-producing countries, including International Institute of Tropical Agriculture (IITA)-grown varieties from Ghana and Sierra Leone, were analyzed as part of the periodic assessment (about every 5 yr) of quality characteristics of country samples.

The samples from Bangladesh had high AC except for DA31 (16%). They had either low or intermediate GT, variable GC, and average milled rice protein content (MRP) (Table 7). Their cooked rices were soft, probably because of their average protein content.

The first set of Bhutan rices were those collected by the International Rice Germplasm Center as upland rices. They had intermediate to high AC, low GT, and medium to hard GC. MRP was low at 5.4-7.5% except for Kamsing (9.0%). The second set of samples had nine intermediate-AC rices, all with low GT and hard GC. Samples had soft cooked rice, including the high-AC Wangdi Kaap.

The Brazilian samples were predominantly high AC with low GT and hard to medium GC. Cooked rice hardness values were 10 kg or higher except for the low- and intermediate-AC samples.

The Bulgarian rices had low AC except for one line with intermediate AC. All had low GT and soft or medium GC.

The rices from Taiwan, China, all had low AC, low GT, and soft GC except for the medium-GC Tainung Sen 20. All cooked rices were soft, but the Sen varieties had higher length-to-width ratio (2.7-2.9) than the japonica varieties (1.5-1.8).

The Cuban samples showed nonwaxy AC, GT, and GC types. The hard cooked rices (>10 kg Instron values) had high AC, low GT, and hard GC. Four other samples of Jucarito 104 representing two K levels showed similar grain properties.

Fifteen Ghanan varieties grown at IITA had predominantly high AC, intermediate GT, and soft or hard GC; some had intermediate AC with low GT and medium to soft GC. All had soft cooked rices.

The Hungarian rices had low or intermediate AC, low GT, and variable GC except for low-amylose Kalaris with intermediate GT. Samples with hard GC had cooked rice hardness values >10 kg.

The Indonesian rices had 19-28% AC with intermediate or high-intermediate GT and medium to hard GC. MRP was high. Sentani was the only low-AC sample. The hardest cooked sample had the highest MRP.

The Iranian rices had either high AC with low to intermediate GT and hard GC, or intermediate AC with intermediate or low GT and medium to hard GC. MRP was highest in Hassanee. The elongation ratio was 1.5-2.0. The harder cooked rices had hard GC values.

The Madagascar (Malagasy Republic) rices had variable AC, low GT, and soft or medium GC except the high-AC Rojofotsy with intermediate GT. The cooked rices were soft.

The Malaysian rices were mainly high AC, low or intermediate GT, and medium to soft GC. Waxy Pulot Siding had the softest cooked rice, followed by intermediate-AC Makmur.

The Nigerian national program rices and IITA-bred lines had combinations of intermediate, high, and low AC with low or intermediate GT and hard or medium-soft GC. Cooked rice Instron hardness values >10 kg were for samples with low GT and hard GC, regardless of AC. These rices are consumed mainly as parboiled rice. Rough rices are

Table 7. Range of milled rice properties of national samples. IRRI, 1986.

Source	Sample	Amylose content[a]	Gelatinization temperature[b]	Gel consistency[c]	Protein (%)	Cooked rice hardness (kg/7 cm²)	Length-to-width ratio
Bangladesh	12 varieties	H>L	L>I	H>S>M	6.2- 8.4	7.7- 9.1	2.0-3.5
Bhutan	14 varieties	I, H	L	M>H	5.4- 9.0	–	1.5-2.2
	11 varieties	I>H, L	L	H>S	5.9- 7.7	6.7- 8.1	1.7-3.1
Brazil	3 varieties	H, I	L>I	M>H	6.2- 7.2	10.1-10.2	3.1-3.2
	6 lines	H>I, L	L	H>M>S	6.9- 8.2	7.6-11.3	3.0-3.6
Bulgaria	3 varieties	L	L	S	6.1- 7.4	6.0- 7.3	1.7-2.6
	4 lines	L>I	L	S, M	6.0- 9.5	7.0- 8.3	1.5-2.0
China (Taiwan)	10 varieties	L	L	S>M	4.6- 8.6	5.9- 7.6	1.5-2.9
Cuba	10 varieties	L, H>I	L>I>HI	S>M, H	7.1- 9.0	6.8-11.0	2.9-3.7
Ghana (from IITA)	15 varieties	H>I	I>L>HI	S, M>H	5.8- 8.3		1.7-2.9
Hungary	7 varieties	L, I	L>I	M>H, S	6.2- 7.8	7.4- 9.5	1.5-3.1
	7 lines	I, L	L	M>H	5.7-10.7	7.6-10.5	2.2-2.8
Indonesia	10 varieties	I, H>L	I>HI, L	M, H	7.8-10.6	7.1- 9.7	2.4-3.1
Iran	9 varieties	I, H	I>L	M, H	7.1- 9.6	7.3- 9.7	2.4-3.7
	1 line	H	L	H	7.1	8.8	3.6
Madagascar	9 varieties	H>I>L	L>I	S, M	5.4-10.4	6.3- 9.1	1.7-3.5
Malaysia	8 varieties	H>I, Wx	L>I, HI	M, S>H	5.7- 7.6	5.1-10.3	2.8-3.6
Nigeria	10 varieties	I, H>L	L>I	H>M>S	5.8-10.6	8.2-11.8	2.6-3.8
Philippines	7 varieties	I>Wx, H	HI, I, L	S>M, H	6.5- 7.5	5.9- 7.6	2.4-3.0
	6 lines	I>H	I, HI>L	H>M, S	5.7- 7.5	5.9- 9.7	2.7-3.4
Portugal	9 varieties	L>I	L>I	S>M, H	5.6- 7.8	6.8- 7.6	1.8-3.9
Sierra Leone (from IITA)	15 varieties	I>H>L	I>L	M>H>S	6.4- 9.0	–	1.6-3.1
Sri Lanka	10 varieties	H>I	I	H>S>M	6.7- 8.5	7.7-10.0	1.5-3.0
Turkey	14 varieties	L>I	L>HI	S>M, H	6.0-10.0	6.6-10.5	1.6-2.7
Vietnam	11 varieties	H>I, L	L>I>HI	H>S>M	6.0- 8.7	6.3- 9.5	2.2-3.8

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

parboiled in the laboratory prior to milling and assessment of grain quality.

The Philippine varieties and lines from the Maligaya Rice Research and Training Center had mainly intermediate AC with intermediate or high-intermediate GT and variable GC. Two waxy varieties with low GT were included. Protein contents were average.

The Portuguese rices had mainly low AC, low GT, and soft to medium GC, except for Estrella A with intermediate GT and Safari with intermediate AC and hard GC. All cooked rices were soft. Length-to-width ratio was 1.8-2.4, except for Estrella A, which was 3.9.

Fifteen Sierra Leone varieties grown at IITA had variable AC and GC and intermediate or low GT.

The Sri Lankan rices had high or intermediate AC, intermediate GT, and hard to soft GC. The three intermediate-AC samba rices had harder cooked rice (9.7-10.0 kg Instron values) than the high-AC rices (7.7-9.8 kg). Of three parboiled rices analyzed for aflatoxin, one showed a high level.

The Turkish rices had predominantly low AC, low GT, and soft to hard GC, except for IZ68 with intermediate AC and Bal/SK (5YO3) with high-intermediate GT. Baldo had higher MRP (10%) than the others (6.0-9.5%) and had the hardest cooked rice.

The rices from Vietnam had mainly high AC with low or intermediate GT and hard to soft GC, except for V.X.1.5 with low AC and high intermediate GT, and TAM with intermediate AC. The softest cooked rices were V.X.1.5 (6.3 kg) and V.X.1.7 (6.4 kg) with high AC, intermediate GT, and soft GC.

Rice starch properties (*Cereal Chemistry and Plant Breeding*). *Very low-amylose rices* (*Cereal Chemistry and Plant Breeding*). Food scientists at the University of Strathclyde in Glasgow, Scot-

land, tested 2 low-GT, very low-AC rices — IR37307-8-ch-3-34 (7% AC) and IR37815-29-2-2-2 (10% AC) — for lipid content and enthalpy of gelatinization. IR37307-8-ch-3-34 had 0.8% starch lipids and enthalpy of 14.2 J/g. IR37815-29-2-2-2 had 1.0% starch lipids and enthalpy of 12.6 J/g. Starch lipid levels were much higher than for waxy starches (0.02-0.06%), but enthalpy values were similar to those of low-GT waxy starches (13-15 J/g). Our analyses of milled rice lipids for these 2 samples were 1.6% and 1.3% nonstarch lipids and 0.7 and 0.6% starch lipids, respectively.

Amylose and amylopectin of high-amylose rice (*Cereal Chemistry*). In a cooperative study, starch chemists at Kagoshima University, Japan, purified and characterized the amylose and amylopectin of starch granules from high-AC rices. The starches were selected based on GC: hard (IR42), medium (IR36), and soft (IR32). We found that hard-GC rices had harder cooked rice than those with soft-medium GC. The studies demonstrated that their amyloses had similar properties and were comparable to the amylose from low-AC Japanese rice starches. An amylopectin-like contaminant (6%) of amylose was not removed by 1-butanol recrystallization; it was removed only by ultracentrifugation of crude amylose in 50 °C water for 1 h at 100,000 *g*.

Amylopectins from high-AC starch had higher iodine affinity (1.6-2.6 vs 0.4-0.9%) and limit viscosity (150-170 vs 134-137 ml/g) but lower molecular weight based on degree of polymerization (4,700-5,800 vs 8,200-12,800 glucose units) than amylopectins from low-AC starch. However, IR42 amylopectin had higher iodine affinity than amylopectins of IR32 and IR36 (Table 8). The calculated true AC of the low- and high-AC starches was similar; the high apparent AC of high-AC rice was due to the greater iodine affinity of its amylopectin. The higher iodine affinity of IR42 amylopectin could have been due to its higher outer long-chain linear fraction. This was shown by isoamylase debranching of amylopectin followed by either gel filtration or precipitation from 1-butanol-saturated water. This higher proportion of long-chain linear fraction in amylopectin may also explain the harder texture of cooked IR42 compared with that of IR32 and IR36.

Glycemic index of high-amylose rice (*Cereal Chemistry*). A high-AC rice in earlier studies showed a lower glycemic index (plasma glucose and insulin response) than waxy, low-AC and intermediate-AC rices (Annual report for 1984). Because of the wide variation in cooked rice properties among high-AC rices, nutritionists at the University of Toronto, Canada, estimated in normal subjects the glycemic index of three high-AC rices differing in gel and Amylograph consistency and GT, and of processed rice products (parboiled rice and rice noodles). Results suggest a higher glycemic index for low-GT IR42 than for intermediate-GT IR36 and IR62 (Table 9). The major factor seems to be the shorter cooking time of the low-GT rice and its harder GC. Processed rice products also tended to have a lower glycemic index than unprocessed milled rice.

Texture of cooked rices with similar amylose content (*Cereal Chemistry*). Laboratory taste panels at a rice processing company in the US and at another in Europe assessed the cooked rice

Table 8. Comparison of amylose content of low-AC and high-AC rice starch based on iodine affinity of amylose and of amylose and amylopectin. Kagoshima University-IRRI, 1986.

Variety	Iodine affinity (%)			True amylose content (%)	
	Amylose	Amylopectin	Starch	True[a]	Apparent[b]
Hokkaido (unknown variety)	20.3	0.87	4.36	18.0	21.8
Koshihikari	20.1	0.39	3.69	16.7	18.5
Sasanishiki	20.0	0.49	4.00	17.4	20.0
IR32	20.3	1.62	5.08	18.5	25.4
IR36	21.1	1.62	4.94	17.0	24.7
IR42	20.0	2.57	5.27	15.5	26.4

[a]Based on actual contribution of iodine affinities of amylose and amylopectin to iodine affinity of defatted starch. [b]Based on iodine affinity of amylose as 20%, regardless of iodine affinity of amylopectin. Potato amylose standard had iodine affinity of only ~16%.

Table 9. Comparative in vitro and in vivo digestibilities in healthy human subjects of 3 high-AC rices differing in GC and GT, and of parboiled rice and rice noodles. Univ. of Toronto-IRRI, 1986.

Cooked samples	In vitro digestibility (mg sugars released/ml·h)	Plasma glucose response (mmol/liter·3 h)	Glycemic index (% of white bread)	Starch type	
				GC	GT
IR62	0.38 ± 0.01 c	55.2 ± 6.5 b	61 ± 10 b	Soft	Intermediate
IR36	0.39 ± 0.02 c	64.7 ± 3.9 ab	72 ± 10 ab	Medium	Intermediate
IR42	0.46 ± 0.01 b	81.0 ± 7.6 a	91 ± 12 a	Hard	Low
Parboiled IR42	0.39 ± 0.03 bc	61.3 ± 9.0 ab	66 ± 8 ab	Hard	Low
Rice noodles (commercial)	0.65 ± 0.02 a	52.9 ± 8.6 b	58 ± 12 b	Medium	–

texture of three pairs of milled rices: C4-63G-IR64, Akibare-Milyang 23, and Malagkit Sungsong-IR65. In the intermediate-AC pair, IR64 had properties similar to those of C4-63G but slightly lower GT and harder cooked rice. For the low-AC pair of Korean rices, Akibare had softer cooked rice than Milyang 23. Malagkit Sungsong gave a softer and more tacky product than IR65 in the waxy pair. No significant, consistent difference was detected by sensory profile and by bench top evaluation for all three pairs cooked in excess water to optimum cooking time. One panel noted color differences for all pairs.

The double bite or texture profile technique for cooked rice using the Instron machine was also tried on the three pairs. Reproducibility of the double bite technique was very poor with a single grain layer and 50 or 75% compression. The micro Kramer shear press was also tried but the results were not similar to those of Ottawa texture measuring system (OTMS) extrusion cell: low-AC rices gave higher hardness values than intermediate-AC rices, probably because of adhesion to the Kramer cell blades. Hardness value by back extrusion using the OTMS cell was no better than the OTMS extrusion cell hardness value.

To reduce the effect of size and shape of cooked rice on hardness determination, rice flour dispersions in water were cooked and the gel strength measured. The cooking method needs improvement to minimize clumping and to obtain uniform cooking.

Rice products (*Cereal Chemistry and Plant Pathology*). *Parboiling process* (*Cereal Chemistry*). Differences in starch GT among rice varieties have caused difficulty in adopting a uniform parboiling procedure. Studies were made to develop a laboratory procedure that will produce fully parboiled rice for all varieties. Intermediate- and low-GT rough rices achieved equilibrium moisture content or optimum hydration within 6 h in 60 °C water, equivalent to 40-46% moisture (dry basis). Steaming at a pressure of 0 kg/cm^2 for 30 min was sufficient for parboiling; however, IR42 required only 25 min.

Aflatoxin production during soaking in parboiling (*Cereal Chemistry and Plant Pathology*). An increase in aflatoxin level was reported for rough rice soaked in colonized water for 6 d in Sri Lanka. Because of the universal concern about aflatoxin contamination in parboiled rice, 4 varieties differing in amylose content were soaked in water inoculated with *Aspergillus parasiticus* NRRL 2999 spores (1×10^3/ml) and colonized grains at 30-32 °C for 4 d. The resulting parboiled brown rice showed no aflatoxin, and the hull had total aflatoxin of 5 μg/kg by the minicolumn technique. Thus, aflatoxin contamination should not occur during the 4-d soaking in parboiling if undamaged or sound rough rice is used, even if the soaking water contains spores of a toxigenic strain of *A. parasiticus*. However, recycling the soaking water already rich in aflatoxin may result in greater contamination.

Fermented rice cakes (*Cereal Chemistry*). Overnight aging of rice batter increased batter viscosity; IR64 showed the highest viscosity among 11 samples. Cake height and AC were significantly correlated for the 10 nonwaxy rices ($r = 0.84^{**}$), but not with alkali spreading value ($r = 0.05$). Waxy rice cake collapsed during steaming. The untrained laboratory panel showed an overall preference for intermediate-AC cakes but considered high-AC cakes acceptable. Low-AC cakes

were less acceptable, as they were too sticky and mushy. Texture profile analysis of freshly steamed cake revealed overlapping hardness values among the AC types but higher adhesiveness for waxy and low-AC cakes, except high-GT Century Patna 231. Cohesiveness values also overlapped among AC types, but deformation recovery was lowest for low-AC rices. One-day storage of the cakes increased hardness values of high- and intermediate-AC samples, particularly intermediate-GT, high-AC samples. Washing of wet milled IR64 flour with water tended to reduce cake height and increase cake hardness.

Gun-puffed milled rice (*Cereal Chemistry*). The puffing gun used required 500 g milled rice with 13-15% moisture content to bring about a chamber pressure of 11.3 kg/cm^2 by heating with a gas burner for 3-7 min (to 200-210 °C). Volume expansion in the puffing gun was 2-3 times the expansion ratio during oil-puffing of parboiled and of cooked milled rice (12.9 vs 5.4 and 4.5), and the puffed grains of 22 rices tested retained the shape of raw rice. AC correlated negatively with expansion ratio (r = -0.49**) and positively with hardness (r = 0.66**). Protein content also correlated negatively with expansion ratio (r = -0.76**). The untrained laboratory panel preferred intermediate- and low-AC puffed rices to waxy and high-AC rices in terms of crispness and texture. Puffed waxy rice lacked crispness, although it was soft-textured and the lightest, almost melting in the mouth. Korean japonica rices (13-17% AC) approached waxy rice in low Instron hardness of puffed rice.

The gel viscosity of rice grains in 0.2 N KOH decreased by 81-97% on gun-puffing, but the rice retained its AC. The gel viscosity of the puffed grains correlated negatively with AC (r = -0.52*), suggesting that amylopectin was more extensively degraded than amylose during gun-puffing, probably because of protection of amylose by starch lipids.

Oil-puffing of 127 °C-parboiled milled rice and precooked milled rice did not adversely affect the nutritional value of rice proteins based on the levels of lysine, cysteine, methionine, and tryptophan in protein before and after puffing. Only gun-puffed rice decreased significantly in cysteine content (1.6 vs 3.1%) without lysine degradation (4.3%). The low lysine content of puffed and toasted rice breakfast cereals may result from the toasting step after puffing, rather than from the puffing step.

Rice wine (tapuy) (*Cereal Chemistry*). In a cooperative study with food microbiologists at the Institute of Food Science and Technology (IFST) of the University of the Philippines at Los Baños (UPLB), the suitability of two waxy and eight nonwaxy rices differing in AC and GT for rice wine (*tapuy*) production was assessed, using an improved method with high saccharifying *Rhizopus oryzae* spores followed by *Saccharomycopsis capsularis* cells and high alcohol-tolerant *Saccharomyces cerevisiae* cells. Waxy and low-AC rices showed the highest *tapuy* yield, ethanol content, and ethanol conversion, followed by intermediate-AC rice and then high-AC rice (Table 10). *Tapuy* aged for 1 mo showed significant differences in mean scores of aroma, color, flavor, astringency, acidity, and general quality, but only color scores correlated with AC. The weight and starch content of residual mash were positively correlated with AC. Separation of fermenting mash was faster in IR64 digests than in waxy and low-AC digests.

Rice protein properties (*Cereal Chemistry, Agronomy, and Rice Farming Systems Program*). *Sulfur-deficient brown rice protein* (*Cereal Chemistry and Agronomy*). BRP deficient in cysteine and methionine was obtained from rices grown on S-deficient soils in the IRRI greenhouse (Annual report for 1985). Solubility fractionation showed 17% albumin-globulin, 5% prolamin, and 78% glutelin for normal IR64 BRP as compared with 9% albumin-globulin, 13% prolamin, and 78% glutelin for cysteine-methionine-deficient (2% vs 5% of protein) IR64 BRP. Disc gel electrophoresis confirmed the higher prolamin content of S-deficient BRP. The higher prolamin content may explain in part the lower cysteine-methionine content in S-deficient BRP, because of the low content of cysteine-methionine in prolamin and the presence of a 4% prolamin-like fraction in glutelin.

Protein and energy utilization of rice-legume diets (*Cereal Chemistry and Rice Farming Systems Program*). The complementarity of rice protein and legume protein grown in the ARFSN was verified in rat feeding trials using cooked IR58 milled rice-cooked legume (2:1 N ratio) at the National Institute of Animal Science (NIAS), Copenhagen, Denmark. Antinutrition factors,

Table 10. Mean properties of milled rice, *tapuy*, and residue after fermentation and their correlation coefficients with milled rice AC. IFST, UPLB-IRRI, 1986.

Property	Mean values for AC types[a]				$r_{amylose}$ (n=10)
	Waxy (2)	Low AC (3)	Intermediate AC (2)	High AC (3)	
Milled rice amylose (% dry basis)	3.1	15.8	22.2	26.7	1.00
Tapuy yield (ml/800 g rice)	2360	2255	2090	1870	−0.91**
Ethanol content (% dry vol)	12.6	12.6	12.2	11.2	−0.67*
Ethanol conversion (% of dry wt)	33.2	31.9	28.6	23.4	−0.86**
Panel color score[b]	4.2	4.0	3.5	3.6	−0.77**
Wt of residual mash (g/800 g rice)	166	228	326	571	0.84**
Starch (%) in residual mash	0	0.6	2.2	4.1	0.88**

[a]Waxy IR29 and IR65; low-AC IR24, IR43, and Inga; intermediate-AC IR48 and IR64; and high-AC IR36, IR42, and IR62. Numbers in parentheses indicate number of samples. [b]Mean of 8 panelists rating each 1-mo-old sample 10 times using a 5-point scale: 1 = intense yellow, 2 = yellow, 3 = dull yellow, 4 = slightly yellowish, and 5 = straw/almost colorless.

galactose-containing sugars, and tannins (phenols) were also analyzed in the diets. The dietary proteins were still deficient in lysine based on 5.5 g/16 g N as 100% rather than in S-amino acids (cysteine + methionine) (Table 11). Cysteine plus methionine values were 3.6–4.0 g/16 g N for 6 rice-legume diets and 3.0–4.4 g/16 g N for the 4 cereals as compared with the World Health Organization amino acid pattern of 3.5 g/16 g N as 100%.

Energy digestibility was high for all diets except sorghum, which had the highest tannin content (Table 11). The same was true for protein digestibility. Sorghum protein had the highest biological value, but its resulting net protein utilization was lowest. The rice-legume diets had greater net protein utilization than rice alone and the other cereal diets. Rice had better net protein utilization than the other three cereals, including whole wheat.

BY-PRODUCTS AND RESIDUES

Cereal Chemistry and Plant Breeding Departments

Properties of harvest rice straw (*Cereal Chemistry and Plant Breeding*). Animal nutritionists at the Institute of Animal Science (IAS) of UPLB tested the effectiveness of in vitro digestibility assays for feed value of straw on 1985 WS and 1986 DS harvest straw of 29 IR varieties and IR28150-84-3 in a demonstration plot. A wide range of values was obtained for both crops, but neither in vitro

Table 11. Mean total sugars, phenols, and energy, and energy and N utilization by growing rats of boiled cereals and IR58 milled rice-legume (2:1 N ratio) diets (mean of 2 varieties, except IR58 rice only). NIAS-IRRI, 1986.

Boiled diet	Total sugars (% glucose)	Phenols (% as catechin)	Lysine (g/16 g N)	Energy (kJ/g)	Digestible energy (% of total)	True digestibility (% of N)	Biological value (% of absorbed N)	Net protein utilization (% of N)
Milled rice	0.2	0	3.5	18.2	92	86	74	63
Field maize	3.9	0	2.3	18.8	88	91	64	58
Sorghum	2.0	1.7	2.6	18.6	77	51	90	46
Wheat	2.7	0	3.2	17.9	87	93	63	59
Rice-bush sitao	3.6	0.6	4.5	18.1	88	82	79	65
Rice-cowpea	1.9	0.1	4.7	18.1	90	88	75	66
Rice-mungbean	1.7	0.1	4.8	18.1	91	90	76	66
Rice-peanut	1.7	0.1	3.7	20.2	91	87	74	67
Rice-pigeonpea	2.4	0.1	4.1	18.1	87	83	79	66
Rice-soybean	1.5	0	4.0	18.9	91	89	79	70
Pooled SD	±0.1	±0.1	±0.3	±0.1	±1	±1	±1	±1

dry matter digestibility (IVDMD) nor in vitro organic matter digestibility (IVOMD) for the two crops was significantly correlated (Table 12). Digestibility values were generally higher in WS than in DS. Growth duration, harvest index (HI), and proportion of harvest straw were correlated for the two crops. The higher HI and proportion of harvest straw for DS were mainly the result of the shorter plants in the DS crop relative to the WS crop. The WS straw contained more leaf blade and less leaf sheath than the DS straw in cooperative studies with Tropical Development and Research Institute (TDRI) scientists.

In cooperative studies with TDRI scientists, variation in rice plant and straw characteristics at harvest of IR62 in 1986 DS was examined on 24 hills from a 10- × 2.5-m plot. Wide variation was noted among hills: 12-24 tillers, 60-74 cm plant height to uppermost node, 26-47 g plant weight, 0.46-0.57 HI, 36-48% harvest straw, and 31-44% leaf blade, 26-55% leaf sheath, and 12-30% stem in harvest straw. Plant-to-plant variation in IR62 revealed similar ranges in plant characteristics as among mean values for IR varieties.

Selected harvest straw in 1985 WS differing in in vitro digestibility was analyzed in detail. Straws with better IVDMD and IVOMD had less neutral detergent fiber, acid detergent fiber, cellulose, and ash and more free (hot 70% ethanol soluble) sugars than straws with low IVDMD and IVOMD values (Table 13). The changes, however, were not proportionate, as can be seen for IR36. Cutin content estimated from acid detergent fiber ranged from 2.0 to 2.8% and was not simply related to digestibility of straw. The straws had overlapping polysaccharide levels soluble in oxalate (0.3-0.8%), 0.3% KOH (0.9-2.1%), 0.6% KOH (4.3-5.5%), 1.1% KOH (2.1-2.7%), 4% KOH (3.3-5.7%), and

Table 12. Range and mean of in vitro dry matter and organic matter digestibilities of harvest straw and other properties of 29 IR varieties and IR28150-84-3, 1985 WS and 1986 DS, and correlation coefficients between crops. IAS, UPLB-IRRI, 1986.

Property	1985 WS		1986 DS		
	Range	Mean	Range	Mean	r (n=30)
IVDMD of harvest straw (%)	35.1 - 47.2	41.6	33.0 - 43.6	38.3	0.01
IVOMD of harvest straw (%)	33.8 - 49.2	43.2	26.9 - 41.8	33.6	0.22
Growth duration (d)	100 -142	118.2	103 -138	120.9	0.97**
Harvest index	0.28- 0.60	0.46	0.29- 0.64	0.52	0.54**
Harvest straw (% of total)	38 - 64	53	46 - 74	61	0.73**

Table 13. Detailed analysis of harvest straw of 3 IR varieties differing in in vitro digestibility of dry matter and organic matter. IRRI-IAS, UPLB, 1985 WS.

Property	IR26	IR36	IR65	Pooled SD
		Whole straw		
Growth duration (d)	117	112	114	
Harvest index	0.52	0.57	0.45	±0.03
N harvest index	0.65	0.70	0.60	±0.04
Harvest straw IVDMD (%)	38.6	43.6	46.6	±2.1
Harvest straw IVOMD (%)	33.8	44.7	49.2	±1.7
		Harvest straw[a]		
Protein (% N × 6.25)	5.7	6.5	5.8	
Neutral detergent fiber (%)	71.8	71.1	68.7	±0.8
Acid detergent fiber (%)	52.0	50.3	49.0	±0.8
Hemicellulose (%)	19.8	20.8	19.7	±0.5
Crude silica (%)	11.4	10.0	13.5	±1
Lignin (%)	5.6	5.6	4.5	±0.3
Cellulose (%)	32.4	32.2	28.8	±1.0
Cutin (%)	2.6	2.5	2.2	±0.4
Crude ash (%)	21.0	20.9	18.7	±0.5
Free sugars (%)	3.1	3.0	5.3	±0.4

[a]Dry basis.

10% KOH (3.5-5.3%). Silica was shown to be extracted in the 0.3% KOH fraction and was not removed by dialysis.

A comparison of in vitro digestibility of harvest straw of modern and traditional rice varieties differing in straw strength or lodging resistance showed overlapping values for both IVDMD and IVOMD (Table 14). Earlier studies have also shown that modern and traditional rices have similar proportions and fiber composition of leaf blades, leaf sheaths, and stems.

Effect of silica content (*Cereal Chemistry*). The silica content of straw was manipulated by growing IR36 and IR42 plants hydroponically at 0-200 ppm SiO_2 in 1985 WS and IR36 and IR58 plants at 0-400 ppm SiO_2 in 1986 DS. Higher SiO_2 levels were used because SiO_2 levels in the straw of 200 ppm SiO_2 culture were still low. The addition of SiO_2 decreased leaf openness and percentage of leaf blades but increased stem internode bending hardness, HI, grain yield, height of flag leaf, and milled rice AC.

Silica levels increased with increasing SiO_2 level in the culture solution (Table 15). IVDMD and IVOMD of both straw and hull in the 1985 WS crop showed lower values for SiO_2-containing samples. For the 1986 DS crop, only the IVDMD values were significantly lower for the SiO_2 containing straw and hull. Digestibility values tended to be lower for the DS crop except for the IVDMD of straw.

Scanning electron micrography of the fresh leaf blades of hydroponically grown plants (after treatment with cetyltrimethyl ammonium bromide to remove the cuticular layer) showed an almost total lack of dumbbell-shaped silica cells in the 0 ppm SiO_2 sample as compared with the regular array of silica cells in the 400 ppm SiO_2 samples (Fig. 2).

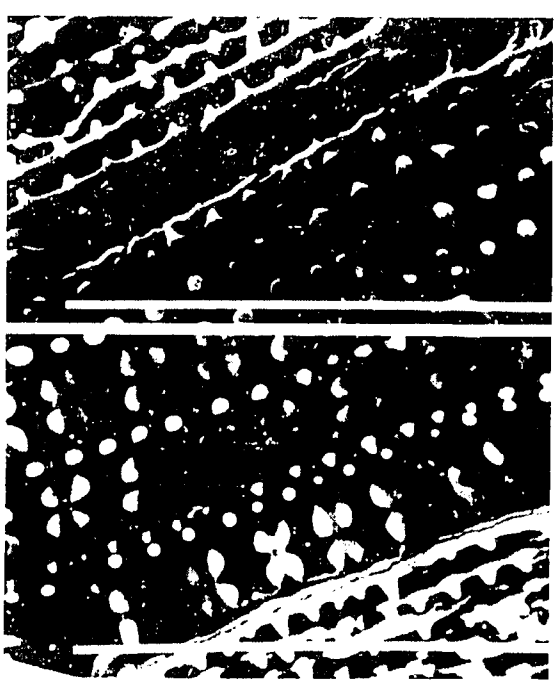
Table 14. In vitro dry matter and organic matter digestibilities of harvest straw of IR and traditional rice varieties. IAS, UPLB-IRRI, 1986 DS.

Lodging type	Modern		Traditional	
	IVDMD (%)	IVOMD (%)	IVDMD (%)	IVOMD (%)
Strong (nonlodging)	41(2)	33(2)	37-44	33-37
Weakly lodging	46	38	–	–
Weak (strongly lodging)	33	30	39(2)	33(2)

Table 15. Mean silica content and in vitro dry matter and organic matter digestibilities of total straw and hull of IR36 and IR42 or IR58 rices. IRRI-IAS, UPLB, 1986.

SiO_2 level (ppm)	Straw			Hull		
	SiO_2 (%)	IVDMD (%)	IVOMD (%)	SiO_2 (%)	IVDMD (%)	IVOMD (%)
			1985 WS (IR36 and IR42)			
0	0.7	58.7	54.7	(3.5)[a]	23.1	19.4
100	5.7	50.8	48.9	–	–	–
200	8.6	50.0	50.4	(10.7)[a]	16.7	14.1
			1986 DS (IR36 and IR58)			
0	0.4	57.2	43.6	0.4	16.4	5.0
100	4.6	57.5	46.4	7.2	15.4	4.4
200	9.4	53.2	43.9	11.6	13.8	4.2
300	11.6	48.2	39.8	15.5	13.2	3.2
400	13.8	50.8	44.0	17.6	13.1	3.5
Pooled SD	±0.9	±4.0	±4.4	±0.7	±2.3	±2.4

[a]Crude ash.



2. Scanning electron micrographs at harvest of surface of leaf blades of IR58, grown in 0 (top) and 400 (bottom) ppm SiO_2, showing effect on silica cells. Cuticular layer removed with hot 4% cetyltrimethyl ammonium bromide in 5.6% H_2SO_4. Bar is 100 μm. IRRI, 1986.

Genetic evaluation and utilization (GEU) program

Disease resistance

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IRTP DISEASE RESISTANCE TRIALS

Plant Pathology and Plant Breeding Departments and International Rice Testing Program

From 1985 International Rice Testing Program (IRTP) trials (data received and analyzed in 1986), entries performing well across locations are summarized below. Others that performed well at specific sites appear in the IRTP section of this report.

Disease	*Entries*
Bacterial blight	DV85, IR13423-17-1-2-1, IR22082-41-2, IR26717-1-1-2-1-1, IR27325-63-2-2, IR29295-70-1-1-1-1-3-1, IR29341-85-3-1-3, IR40, IR54, IR8192-166-2-2-3, IR9830-26-3-3, RP633-76-1
Blast	Huan-sen-goo, IRAT109, IRAT13, IRAT134, IRAT147, SR3044-78-3, Ta-poo-cho-z, Tetep
Tungro	ARC11554, Boteswar, Kachamota, Naria Bachi, Pankhari 203
Ufra nematode	Ba Tuc, Bazail 65, Rayada 16-011, Rayada 16-013, Rayada 16-05, Rayada 16-06, Rayada 16-07, Rayada 16-08, Rayada 16-09

BACTERIAL BLIGHT

Plant Pathology and Plant Breeding Departments and International Rice Testing Program

Screening (*Plant Pathology, Plant Breeding, and IRTP*). An increasing number of entries — including material from IRTP, hybridization blocks, observational yield trials, replicated yield trials, germplasm accessions, pedigree nurseries, and other countries — are evaluated every year for resistance to bacterial blight (BB) (Table 1). Because resistance genes *Xa-4* and *xa-5* are being deployed in the varietal improvement program, race 1 (PXO 61) and race 2 (PXO 86) were used individually to screen progenies derived from these gene sources.

Evaluation (*Plant Pathology*). *Seedling resistance.* Rice resistance to BB has been demonstrated at the seedling stage, when both strong and weak interactions between rice varieties and pathogen isolates have been found. Selected varieties were tested at different leaf positions for reaction to various races. Some showed resistance beginning at the 2-leaf stage (Table 2). Resistance was also differential. Some variety-isolate interactions were strong. Other varieties showed increased resistance at the 4th leaf position and became stable thereafter. Lesions that progressed differently with prolonged incubation were also noted in some varieties.

Partial resistance. Partial or intermediate resistance has been identified in cereal crops that are more durable to some diseases than others. This type of resistance is assumed — and has been demonstrated — in traditional or unimproved cereal cultivars. Because the breakdown of the major gene resistance to BB has been documented in rice, partial resistance was sought. A preliminary study tested a large number of cultivars at different growth stages with many pathogen isolates. Lesions extended faster on young plants than on older ones. The differences between cultivars were similar to those found with a single measurement of lesion length later than 14 d after inoculation (DAI). At 14 DAI, the ED_{50} and the decrease in lesion length with dosage were measured on 10 cultivars with a virulent isolate. Susceptible varieties had a lower ED_{50} than resistant ones. Lesion length increased sharply with increased inoculum concentration in some varieties and gradually in others. Sixteen varieties were found to have a moderate level of resistance to nine isolates. Six of them were further evaluated against an additional 10 isolates. Few significant interactions between the varieties and the isolates were noted, except with the major genic effect tested with two isolates (Table 3). This could indicate that the resistance is either race nonspecific or that the specific interaction is too small to be identified by this method.

Performance of IR varieties. In the 1986 wet season (WS), we made a similar trial in a farmer's

Table 1. Breeding materials and varieties screened for resistance to BB races 1 and 2. IRRI, 1986.

Nursery[a]	Entries (no.) with given disease score[b]						
	1	3	5	7	9	1/7[c]	Total
IRTP material		245	49	60	15	15	384
		(13)	(222)	(131)	(12)	(2)	(380)
Chinese Pedigree Nursery (1986 DS)	1264			287		179	1730
Korean breeding lines (1986 DS)	6			15			21
	(1)	(3)		(18)			(22)
Korean pedigree lines (1986 DS)	326	88		1053		4	1471
		(16)		(1455)			(1471)
USDA material			5	74	64		143
			(5)	(83)	(52)	(1)	(141)
Hybridization block (1986 DS)	9	10	14	223	7	5	268
	(144)	(11)	(3)	(87)	(14)	(12)	(271)
Hybridization block (1986 WS)		90	107	41	28		266
		(34)	(182)	(29)	(8)		(253)
Rainfed Lowland Observational Yield Trial (1986 DS)	165	3		27		8	203
	(2)	(12)	(34)	(152)		(2)	(202)
Rainfed Lowland Observational Yield Trial (1986 WS)	141	546	40	37	13	6	783
		(31)	(597)	(49)	(1)	(4)	(682)
Irrigated Lowland Observational Yield Trial (1986 DS)	330	27	13	117		30	517
	(1)	(11)	(5)	(499)		(1)	(517)
Irrigated Lowland Observational Yield Trial (1986 WS)	44	392	132	23	25	1	617
		(2)	(264)	(78)	(4)		(348)
Irrigated Lowland Replicated Yield Trial (1986 DS)	321	7	13	40		21	402
	(3)	(33)	(59)	(307)			(402)
Irrigated Lowland Replicated Yield Trial (1986 WS)	2	164	168	26	17	1	378
		(45)	(302)	(21)	(4)		(372)
Germplasm bank (1986 DS)	156	66	93	3800		55	4170
Upland Replicated Yield Trial (1986 WS)		36	55	9			100
		(90)	(10)				(100)
Upland Observational Yield Trial (1986 WS)		45	54	1			100
		(94)	(6)				(100)
Pedigree nurseries	55,208			10,231		5594	71,033
	(14,281)			(21,503)		(646)	(36,430)
Total	59,972	1719	743	16,064	169	5919	82,586
	(14,432)	(395)	(1689)	(24,412)	(952)	(668)	
Grand Total							82,586
							(41,691)

[a]DS = dry season, WS = wet season. [b]Reaction of race 2 in parentheses. [c]Segregating.

Table 2. Interaction between varieties and isolates of *Xanthomonas campestris* pv. *oryzae* at different leaf positions at the seedling stage. IRRI, 1986.

Variety group	Representative variety	Isolate	Mean lesion area (%) at leaf position			
			2	3	4	5
1	Chherlingo Shiwuwa	PXO 86	1	1	2	2
2	Baegumchalbyeo	PXO 86	98	54	52	37
3	YR1617-13-2-2	PXO 71	90	72	10	10

field to compare, under high disease pressure, the performance of IR58 and IR64 carrying the *Xa-4* gene for BB resistance with IR line IR1695, having adult plant resistance (*Xa-6*). IR56, IR58, IR64, and IR1695 were planted in Mabitac, Laguna, Philippines, where BB was endemic. The seedlings were inoculated with a low dose of an isolate from the same area 1 d before transplanting, while control seedlings were left uninoculated.

During 1986 WS, disease pressure was apparently high in both inoculated and uninoculated plots. Inoculated IR58 and IR64 plots did not significantly differ from uninoculated plots

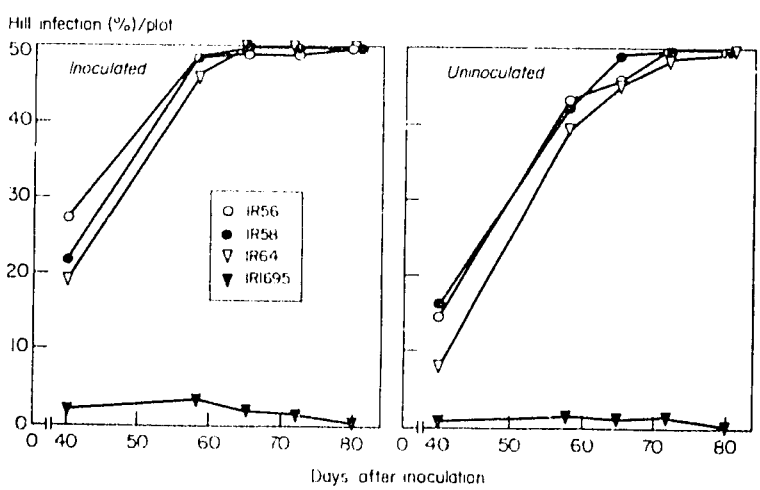
Table 3. Lesion length of 6 rice cultivars in response to infection by 19 Philippine isolates (different race groups) of *Xanthomonas campestris* pv. *oryzae* measured at 14 DAI. IRRI, 1986.

Isolate			Length of lesion[a] (cm) on					
No.	Race	Origin	TN1	IR9101-124	GRS1-282	IR28	IR40	Cisadane
BB 1287	1	IRRI farm	35.6	3.2	1.8	1.9	1.9	1.3
BB 1194	2	IRRI farm	30.6	25.8	19.5	21.7	9.7	14.4
IRN 812	2	Nueva Ecija	37.8	24.7	23.8	26.8	21.4	17.1
IRN 863	2	Albay	37.5	20.4	21.0	19.2	16.4	15.1
IRN 907	2	South Cotabato	37.1	23.3	23.3	25.2	20.5	21.0
IRN 764	2	Tarlac	36.6	22.6	23.1	23.8	19.1	19.0
PXO 149	2	Laguna	34.6	22.4	23.1	25.5	21.2	20.2
IRN 825	2	Camarines Sur	33.2	23.4	19.5	22.0	16.8	13.0
BB 1317	2	IRRI farm	30.9	19.2	18.6	20.4	15.0	14.0
PXO 86	2	IRRI farm	30.4	21.1	23.0	22.9	17.9	18.1
BB 1325	2	IRRI farm	30.4	18.3	19.4	22.6	16.2	17.1
IRN 705	2	Davao	13.4	18.1	20.9	20.3	15.4	16.8
IRN 711	2	Leyte	1.1	9.8	10.2	11.4	9.3	5.3
IRN 526	3	Bohol	37.8	25.8	25.5	25.9	20.7	18.1
IRN 922	3	Iloilo	35.2	24.4	23.9	22.7	18.5	16.7
IRN 332	3	Bicol	33.7	17.6	18.7	16.9	15.9	14.3
PXO 71	4	Palawan	30.5	13.4	6.2	8.1	6.7	5.2
PXO 122	6	IRRI farm	27.7	13.8	14.0	13.7	12.7	11.1
PXO 99	6	IRRI farm	25.8	15.6	14.6	17.0	12.5	11.4

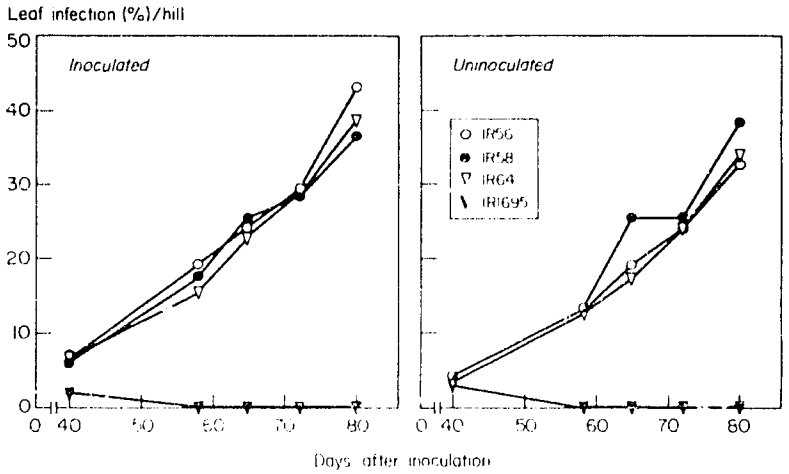
[a]LSD at 5% = 6.98, based on Bonferroni.

based on hill and leaf infections (Fig. 1, 2). The difference in severity between IR58 and IR64 (Fig. 3), both carrying gene *Xa-4*, may be related to the background resistance of the varieties, since they were the results of selection from multiple or compound crosses.

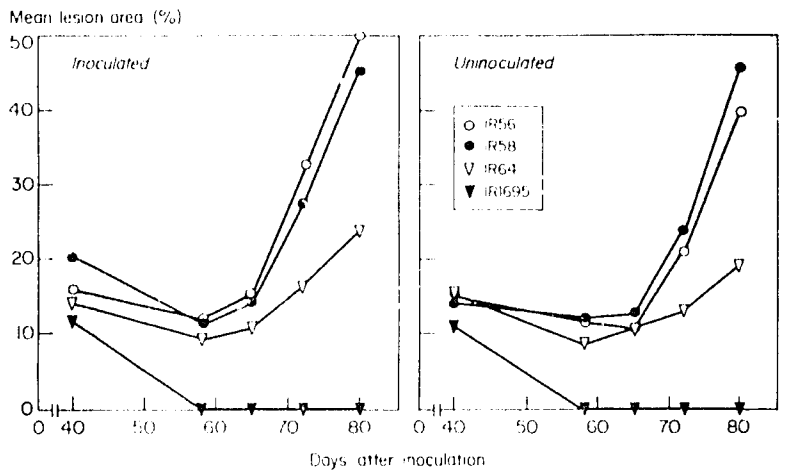
Collaboration. A joint project with the Rural Development Administration (RDA), Korea, was initiated to evaluate a set of rice cultivars against Korean isolates. Nine varieties, resistant to some or all Philippine races, were also resistant to three Korean races at all rice growth stages (Table 4). Milyang 83 from Korea performed similarly. Among 11 varieties, 6 from Korea showed adult plant resistance to the same races in Korea (Table 5). Other varieties had different reaction patterns to Korean races and may be used to differentiate the isolates.



1. Bacterial blight (BB) progression in 3 IR varieties and IR1695, based on hill infection in inoculated and uninoculated plots in a farmer's field in Mabitac, Laguna, Philippines, 1986 WS.



2. BB progression in 3 IR varieties and IR1695, based on leaf infection in inoculated and uninoculated plots in a farmer's field in Mabitac, Laguna, Philippines, 1986 WS.



3. BB progression in 3 IR varieties and IR1695, based on mean lesion area in inoculated and uninoculated plots in a farmer's field in Mabitac, Laguna, Philippines, 1986 WS.

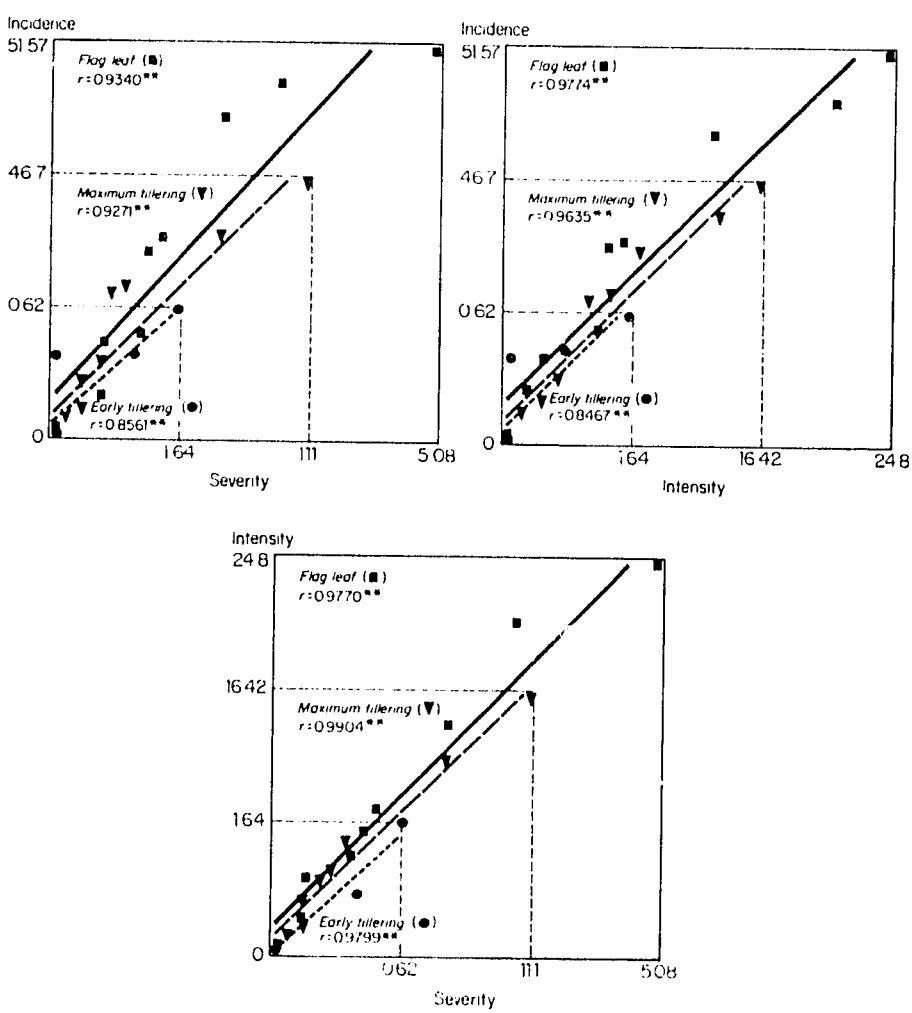
Table 4. IRRI germplasm accessions showing overall resistance to 3 BB races, IRRI-RDA, 1986.

Variety	Mean lesion area[a] (%)								
	Korean race 1			Korean race 2			Korean race 3		
	SS	MTS	FLS	SS	MTS	FLS	SS	MTS	FLS
Raital	5.8	1.4	1.0	10.0	1.0	1.0	5.0	1.0	1.0
Aus 295	3.0	1.0	1.0	5.8	1.0	1.0	3.9	1.0	1.0
AC19-1-1	5.0	1.2	1.0	1.0	1.0	1.0	3.8	1.0	1.0
Kalimekri 77-5	5.0	1.0	1.0	3.4	1.0	1.0	2.7	1.0	1.0
Andel	3.0	1.0	1.0	1.0	1.0	1.0	4.4	1.0	1.0
Oval 29A	1.3	1.0	1.0	1.0	1.0	1.0	3.8	1.0	1.0
Polbiri	2.3	1.0	1.0	5.0	1.0	1.0	5.3	1.0	1.0
Aus 176	3.0	1.0	1.0	5.0	1.0	1.0	5.0	1.0	1.0
DV85	3.0	1.0	1.0	2.3	1.0	1.0	5.3	2.0	1.0
Milyang 83	5.0	1.0	1.0	2.3	1.0	1.0	5.3	2.0	1.0

[a]SS = seedling stage test, 20 d after sowing (DAS); MTS = maximum tillering stage test, 45 DAS; FLS = flag leaf stage test.

Table 5. Varieties from IRRI and Korea showing adult plant resistance to BB races in Korea. IRRI-RDA, 1986.

Variety	Mean lesion area (%)					
	Korean race 1		Korean race 2		Korean race 3	
	SS	FLS	SS	FLS	SS	FLS
Shodua	47.0	1.9	29.0	1.4	25.0	1.0
Chamara	85.0	1.0	65.0	1.0	96.0	1.0
Pa Morlai	70.0	2.0	92.5	2.0	100.0	1.0
Chherlinge Shiwuwa	92.0	1.0	55.0	1.0	100.0	1.3
Sann Putt	96.7	7.1	95.0	10.0	90.0	2.9
Suweon	55.0	2.3	75.8	2.0	95.7	2.1
Suweon 346	92.5	1.0	75.0	1.0	85.0	16.1
Cheolweon 40	98.0	2.6	75.0	13.8	83.6	5.2
Jinbu 4	88.3	8.8	69.0	10.9	75.8	12.2
IRI 375	95.0	1.0	93.0	3.3	97.2	4.1
Yeongdeog 5	99.0	3.4	81.7	2.2	87.5	5.7



4. Correlations among 3 scoring parameters to assess BB on 9 varieties at 3 growth stages. IRRI, 1986.

Another study in Korea assessed the resistance of current commercial cultivars under epidemic conditions. Three scoring parameters -- percentage of infected hills/plot, percentage of infected leaves/hill per plot, and percentage of leaf area affected/hill per plot -- were compared. The correlation coefficients among the parameters were highly significant; any one could be used to assess the resistance of varieties in the field (Fig. 4). The mean effect of variety and scoring time, and the effects of interactions between isolates and varieties and between scoring time and varieties were highly significant using any of the three scoring parameters.

As part of the IRRI-Chinese Academy of Agricultural Sciences (CAAS) collaboration, 20 Chinese commercial cultivars were evaluated for resistance to 4 isolates in China. Four sets of two variety-two isolate combinations at maximum tillering and one at booting showed strong interaction with isolates in China (Table 6). Differences in lesions were rather small. Perhaps some varieties showing strong interaction at maximum tillering with some isolates increased their resistance as they matured. The majority of the varieties used in the test had adult plant resistance.

Several varieties tested previously at the seedling stage at IRRI were tested against BB isolates in China. These varieties showed specific resistance to races at IRRI, but most displayed broad-spectrum resistance to Chinese isolates (Table 7).

For details of the Japan-IRRI Collaborative Project on Bacterial Blight, see the section on Cooperative Country Projects.

Pathogen variation. *Philippines.* The survey of the BB pathogen population in major rice-growing

Table 6. Strong variety × isolate interaction of selected Chinese varieties at maximum tillering and booting in different provinces in China, CAAS, 1986.

Variety	Lesion area[a] (%)				
	Zhe 173	HN84-31	KS6-6	HB82-21	HB84-21
Yangeng 2	30	13	10	–	–
Yunyu 1	12	42	–	–	–
Chaitang	12	–	55	5	–
Aoyu 24	9	40	–	–	–
Wei 84-894	–[b]	–	5	28	–
H84-213	8[c]	–	–	–	50[c]
Zhong Xi 8409	35[c]	–	–	–	5[c]

[a]Mean of 3 replications. [b]No interaction with any of the 5 isolates. [c]Interaction at booting.

Table 7. Reaction of selected germplasm varieties to BB isolates in China and the Philippines.[a] IRRI and CAAS, 1986.

Variety	Mean lesion area (%)									
	IRRI						CAAS			
	Race 1	Race 2	Race 3	Race 4	Race 5	Race 6	KS6-6	Zhe 173	HN84-31	HB84-21
Camor	15	20	10	60	40	40	1	3	3	1
Bali Ray	95	1	65	75	1	45	28	5	44	3
Bowalia Sadi-A	75	15	10	75	1	95	7	7	20	5
Chota Kati-A	3	1	15	40	20	25	1	1	1	1
Khoia	10	10	3	30	20	60	2	1	1	3
Chamara	75	45	40	75	55	25	25	5	18	8
Polbiri	15	1	35	60	1	60	1	1	2	1
S/C 223	1	5	75	40	55	65	1	1	3	1
PL 3144	45	10	10	60	30	35	1	5	8	2
Sarudhan	1	10	5	45	50	55	1	1	1	1

[a]Tests were at the seedling stage at IRRI and at tillering at CAAS.

areas in the Philippines was continued. As in the past several years, race 2, virulent on rices with the *Xa-4* gene, was still dominant (Table 8). The majority of the rices planted were improved high-yielding varieties, many of which carry *Xa-4*.

China. The virulence of *Xanthomonas campestris* pv. *oryzae* (Xco) isolates in China from 1985-86 was also tested on Japanese, Chinese, Korean, and IRRI differential varieties as part of IRRI-CAAS collaboration. None of the isolates (in five groups) were comparable in virulence to the known races in Japan and the Philippines. Also, none were virulent on varieties carrying the *Xa-4* gene. IR26, for example, was resistant to all isolates tested.

Serological relationship. Ninety isolates were grouped using polyclonal antiserum to Xco (R-2 iso PXO 86) extracellular glycoproteins and glassbead-disrupted cells in saline as antigens. In Ouchterlony double-diffusion tests, 98% of the isolates fell into 2 serovars (S-1 and S-2), while the other 2% belonged to another 2 serovars (S-3 and S-4). Most field isolates were S-1. No race-specific immunogen was detected by intragel absorption tests of the antigens with the antiserum.

Immuno-electrophoretic tests yielded two precipitating immunogens: heat-labile and heat-stable (100 °C, 30 min). Ouchterlony double-diffusion tests showed that the heat-stable immunogen was specific in pv. *oryzae*, while the heat-labile immunogen was common to *oryzae* and other pathovars of *X. campestris* such as *arrhenatheri, begoniae, campestris, cerealis, citri, glycines, graminis, hyacinthi, malvacearum, oryzicola, phaseoli, phlei,* and *vesicatoria*.

Table 8. Virulence of the BB pathogen population in the Philippines, 1986.

Race group	Virulent on	Frequency[a] (%)
1	Cas 209, IR8	20.9
2	IR8, IR20	60.5
3	Cas 209, IR8, IR20	12.8
4	Cas 209, IR8, IR1545	0
5	IR8	5.8
6	Cas 209, DV85, IR8, IR20, IR1545	0

[a]Based on 86 isolates tested on IRRI differential varieties (Cas 209, IR8, IR20, IR24, IR1545-339, DV85) at 40 DAS.

Eighteen enzymes — alanine dehydrogenase (dH), isocitrate dH, phosphogluconate dH, leucine dH, sorbitol dH, glutamic dH, glucose 6-PO_4 dH, shikimate dH, malic dH, esterase, phosphoglucose isomerase, malic enzyme, phosphoglucomutase, leucine aminopeptidase (AP), arginine AP, alanine AP, catalase, and peroxidase — of glassbead-disrupted or sonicated cells of the Philippine's Xco races were examined in horizontal starch gel electrophoresis. The potential of electrophoretically detectable isozymes as markers was analyzed. Race 6 could be easily identified from other races (99 test isolates) by the zymograms of malic enzyme and malic dH; the rest of the enzymes of the 6 races had either similar isozyme patterns or no activity, or yielded inconsistent test results.

BLAST

Plant Pathology and Plant Breeding Departments

Screening (*Plant Pathology and Plant Breeding*). During 1986, 117,748 materials from the Genetic Evaluation and Utilization (GEU) program, national programs, the International Rice Germplasm Center (IRGC), and the IRTP were tested in the IRRI blast (Bl) nursery (Table 9).

In 1986 a previously unidentified race capable of attacking the variety Carreon was isolated from upland screening plots at Cavinti, Laguna, Philippines. This new race was introduced in the IRRI Bl nursery and is being maintained and used for screening.

Evaluation of GEU elite lines and IR varieties (*Plant Pathology*). Using an upland nursery mini-plot technique, the IR varieties and dry season (DS) elite lines were evaluated for their Bl resistance relative to the partially resistant check IR36 and susceptible check IR50. IR64, which is currently being cultivated widely in the Philippines, had a slower rate of disease progress than IR36 (Table 10). Future surveys of *Pyricularia oryzae* in the Philippines should reveal if the resistance of IR64 remains effective, as has the resistance of IR36, or if the pathogen can become more aggressive on IR64 with time.

Some of the GEU elite lines showed little disease in the nursery trial (Table 11), probably indicating that for those lines fully compatible races of

P. oryzae were absent in the nursery. Recent experience suggests lines with resistance similar to that of IR36, such as IR32307-107-3-2-2 (Table 11), probably will have acceptable Bl resistance in lowland fields. However, for completely resistant lines such as IR35366-90-3-2-1-2

Table 9. Source and number of materials tested at the IRRI Bl nursery, 1986.

Source		Entries (no.)
F_2 populations		8,473
Pedigree nurseries		96,815
Irrigated lowland	62,738	
Rainfed lowland	17,151	
Deepwater	16,926	
Yield trials, elite lines, and hybridization block		4,618
National programs		2,639
IRGC accessions		4,097
IRTP nurseries		969
Tissue culture-derived plants		137
	Total	117,748

Table 10. Percent diseased leaf area (DLA) of IR varieties evaluated for resistance to Bl in upland nursery miniplots.[a] IRRI, 1986.

Variety	DLA[b] (%)
IR54	2.3
IR58	8.2
IR64	13.1
IR29	16.1 PR
IR45	16.7 PR
IR60	17.8 PR
IR28	19.0 PR
IR62	21.8 PR
IR43	22.5 PR
IR46	25.6 PR
IR36 (partially resistant check)	26.2
IR42	28.4 PR
IR44	29.7 PR
IR40	30.3 PR
IR38	31.7 PR
IR8	32.8 PR
IR34	33.8 PR S
IR20	34.7 PR S
IR26	34.9 PR S
IR48	36.1 PR S
IR24	36.4 PR S
IR32	38.7 PR S
IR56	38.9 PR S
IR65	39.4 PR S
IR50 (susceptible check)	49.5
IR30	50.9 S
IR22	51.3 S
IR52	98.3

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

Table 11. Percent diseased leaf area (DLA) of GEU elite lines evaluated for resistance to Bl in upland nursery miniplots.[a] IRRI, 1986.

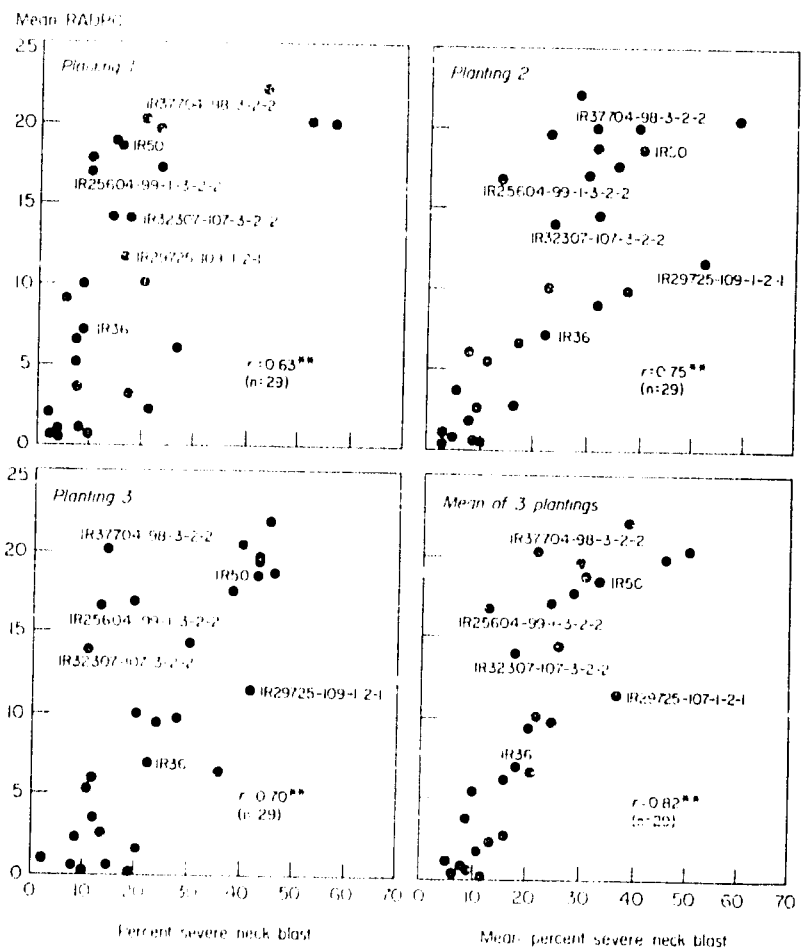
Line	DLA[b] (%)
IR39368-31-1-2	0.0
IR37721-9-2-1-3	0.0
IR37712-90-3-3-3-2	0.1
IR32843-92-2-2-3	0.1
IR39422-18-1-2-2	0.1
IR31868-64-2-3-3-3	0.3
IR32429-68-3-3-3	0.4
IR37865-29-3-1-3	0.4
IR29658-43-3-2-1	0.9
IR31802-48-2-2-2	0.9
IR32429-47-3-2-2	1.1
IR39423-124-3-3-1	1.4
IR13761-11-3	1.5
IR39357-133-3-2-2-2	1.6
IR28224-3-2-3-2	3.4
IR10147-113-5-1-1-5	4.6
IR10011-16-3-2	4.7
IR32429-122-3-1-2	5.4
IR28222-0-2-2-2-2	5.6
IR12979-24-1-8	5.8
IR5931-113-1	6.7
IR35546-52-3-3-2	9.1
IR28228-119-2-3-1-1	9.1
IR13754-5-2	10.1
IR32720-138-2-1-1-2	12.5
IR33043-46-1-3	13.0
IR6023-10-1-1	14.4
IR35366-90-3-2-1-2	16.2 PR
IR28228-28-1-3-3-2	17.5 PR
IR32453-20-3-2-2	18.5 PR
IR28228-12-3-1-1-2	20.3 PR
IR29723-143-3-2-1	22.6 PR
IR29692-65-2-3-3	24.3 PR
IR32307-107-3-2-2	25.4 PR
IR36 (Partially resistant check)	26.2
IR35353-94-2-1-3	26.8 PR
IR5420-1-1-2-3	28.7 PR
IR35293-125-3-2-3	29.9 PR
IR35366-40-3-3-2-2	32.6 PR
IR27078-11-2	37.0 PR S
IR37704-98-3-2-2	43.8 S
IR29725-22-3-3-3	43.8 S
IR29692-99-3-2-1	44.1 S
IR35361-59-3-3-2	44.4 S
IR39385-124-3-2-2-3	47.6 S
IR50 (susceptible check)	49.5
IR29725-109-1-2-1	52.5 S
IR35546-17-3-1-3	52.7 S
IR28150-84-3-3-2	65.2 S
IR29723-88-2-3-3	71.3

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

(Table 11), future field performance cannot be predicted. When compatible races of *P. oryzae* arise, lines that were previously completely resistant may be severely diseased.

Effects of growth stage on blast resistance (*Plant Pathology*). In 3 lowland field plantings, the level of neck Bl resistance was measured in 29 rice lines. The rices were inoculated at heading, and neck Bl was scored as the percentage of severe neck node infection at harvest. The results for neck Bl were compared with the leaf Bl resistance of the lines as measured in several nursery experiments; a positive correlation between the two sets of data was found (Fig. 5). The correlation was best when the means of the three plantings were used, which probably indicates that in any single planting errors are introduced because of the differences in maturity of the entries. Although the correlation was significant, some lines appear to be exceptions to the general relationship. For example, IR25604-99-1-3-2-2, IR32307-107-3-2-2, and IR37704-98-3-2-2 appeared to be more susceptible to leaf Bl than the partially resistant check IR36, yet their neck Bl resistance was similar. Conversely, IR29725-107-1-2-1 appeared to have intermediate susceptibility to leaf Bl, yet relatively high susceptibility to neck Bl. The lines showing divergence from the general trend are being retested.

In an experiment to test the effects of plant age and variety on Bl, six upland cultivars were stagger-planted, and plants at different growth stages were exposed simultaneously to *P. oryzae*



5. Correlation between leaf blast (Bl) resistance in 3 upland nurseries, expressed as the mean relative area under the disease progress curve (RADPC), and the incidence of severe neck Bl infection in 3 lowland fields trials for 29 IR lines. IRRI, 1986.

inoculum. Regardless of whether the variety was relatively resistant or relatively susceptible, the levels of leaf Bl resistance increased with plant age (Table 12). Also, collar and panicle Bl varied with plant growth stage and variety.

For C22, panicle Bl was less severe when plants were inoculated at booting and flowering, probably because at these stages the panicles had not fully emerged in this variety and thus escaped neck node infection, resulting in lower severity scores. Analysis of variance showed significant variety by plant age interaction for all characters measured, indicating that the degree of change in resistance from one growth stage to another differed among varieties. For example, Kele had a higher infection efficiency (lesions/100 cm^2 leaf) than C22 at early tillering, but this relationship was reversed at maximum tillering. The relative level of resistance also varied between leaf Bl and panicle Bl. For example, Brown Gora SN84 was relatively resistant to leaf and collar Bl, yet relatively susceptible to panicle Bl (Table 12). These results suggest that, to obtain a relevant assessment of the Bl resistance of a variety, both leaf and panicle Bl should be scored.

Virulence (*Plant Pathology*). In 1983-85, *P. oryzae* isolates from different sites in the Philippines were tested for virulence on varieties widely grown in the Philippines. The studies indicated that the varieties grown in an area influenced the virulence pattern of the isolate population.

In 1986, *P. oryzae* isolates from an upland nursery in Cavinti and from farmers' fields in Nueva Ecija and Cavite, Philippines, were sampled. At the Cavinti site, 1 isolate was obtained from each of 10 improved and traditional varieties, 10 from an improved upland variety, and 30 from 3 traditional upland varieties. From Nueva Ecija and Cavite, 50 isolates, mostly from improved lowland varieties, were obtained. The isolates were tested on a total of 35 varieties including a set of Philippine varieties, 6 elite IR lines, and the Japanese differential variety set.

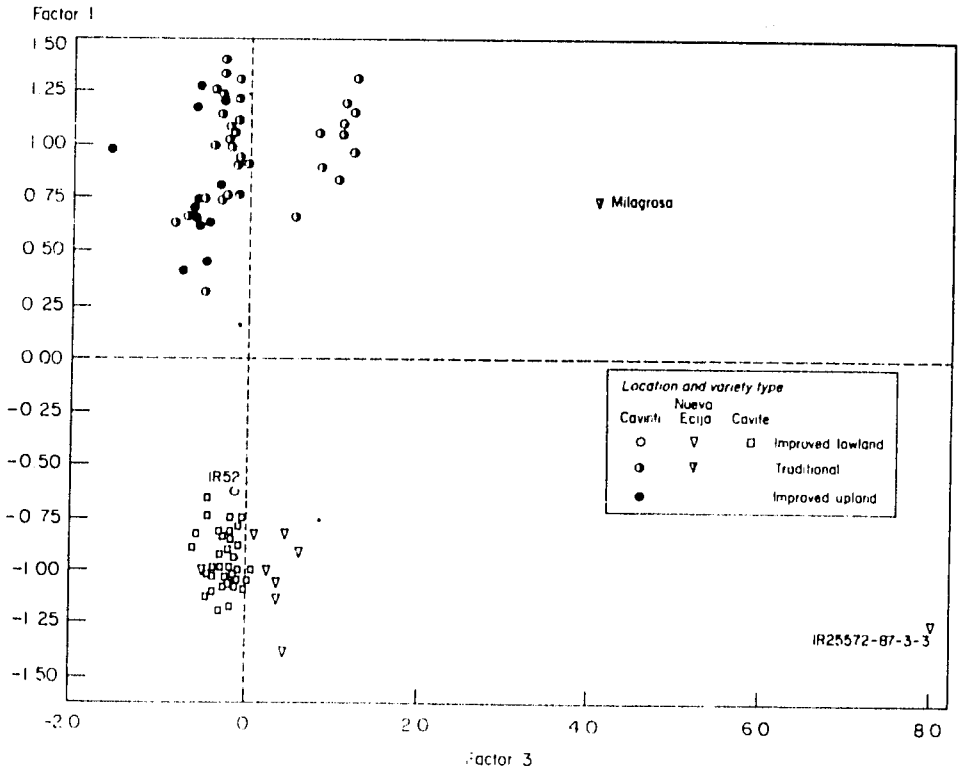
With the use of principal component analysis, the isolates were grouped based on their reaction patterns on the 35 varieties. The virulence patterns of isolates from lowland farmers' fields were distinct from those of the upland (Cavinti nursery) population (Fig. 6). One isolate from Cavinti — derived from the lowland variety IR52 — had a virulence pattern similar to that of lowland isolates. Two isolates from Nueva Ecija showed unique patterns (Fig. 6). One came from Milagrosa, a traditional upland variety, and had a virulence pattern more similar to that of Cavinti isolates than of other isolates from lowland areas. The other isolate, derived from IR25572-87-3-3, was collected from a variety trial experiment. Again, the results showed the importance of the host cultivar in determining the virulence pattern of the isolate.

No isolate from the Cavinti nursery showed a broad spectrum of virulence similar to that of some nursery isolates from previous studies. Perhaps it is individual host genotype that mostly influences virulence pattern, rather than the diversity of host germplasm within a stand.

Table 12. Relative infection efficiency (lesions/100 cm^2 leaf), collar Bl severity, panicle Bl incidence, and panicle Bl severity in 6 upland rice cultivars grown in the greenhouse and exposed to inoculum of *Pyricularia oryzae* at various growth stages.[a] IRRI, 1986.

Cultivar	Lesions/100 cm^2 leaf				Collar Bl severity[b]				Panicle Bl incidence (%)				Panicle Bl severity[c]			
	ET	MT	B	M	ET	MT	B	M	B	F	M	ED	B	F	M	ED
C22	177.0	32.0	6.0	0.5	4.5	3.2	1.9	3.1	100	100	97	100	3.7	4.[illegible]	6.2	6.6
Kele	298.0	8.0	0.3	0.8	1.9	0.3	0.1	1.2	75	97	99	98	2.1	2.7	1.9	1.5
Kinandang Patong	166.0	2.0	0.7	0.0	3.5	1.8	0.4	0.6	27	76	6	21	0.4	1.7	0.2	0.3
Brown Gora SN84	1[illegible].0	0.1	0.0	0.0	0.1	0.4	0.1	0.3	97	100	75	100	1.8	5.5	4.7	3.4
IAC47	48.0	0.5	0.0	0.0	0.8	1.5	0.1	2.0	100	100	100	100	5.4	4.1	3.3	2.6
Denorado	4.0	0.2	0.0	0.0	0.2	0.6	0.1	0.1	68	82	14	17	1.1	1.4	0.4	0.3
LSD (0.05)		26.0				0.9				24.8				0.9		

[a]ET = early tillering, MT = maximum tillering, B = booting, F = flowering, M = milk, ED = early dough. [b]Scored 0 to 5, where 0 = no infection and 5 = severe infection. [c]Scored 0 to 9, where 0 = no infection and 9 = severe infection.



6. Grouping of 100 isolates of *P. oryzae* collected from various varieties in 3 areas in the Philippines based on principal component analysis of their reaction patterns on 35 test varieties (10 points are hidden).

LEAF SCALD RESISTANCE

Plant Pathology Department

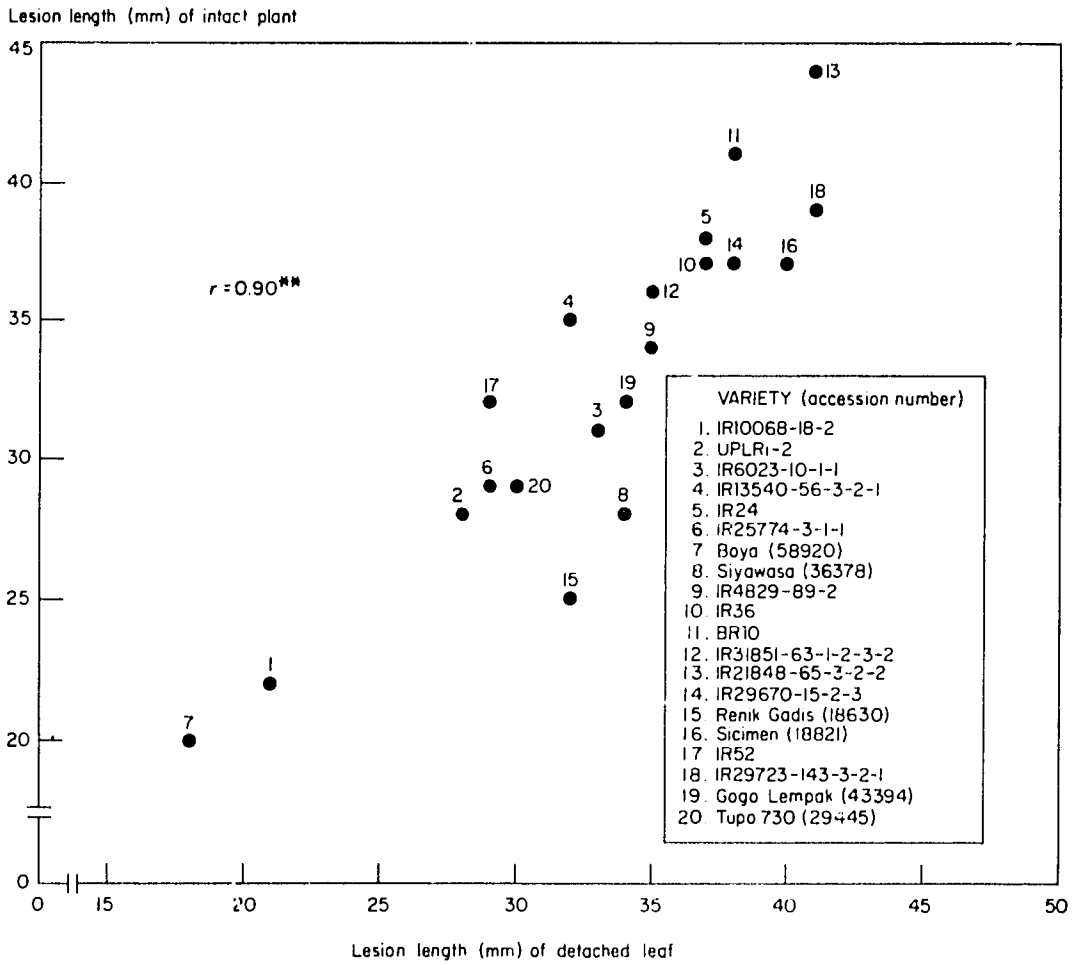
Researchers in Brazil have developed a method of assessing resistance to leaf scald (LSc) disease that requires whole plants and incubation in a dew chamber. To find a simpler method of evaluating germplasm bank accessions, the detached leaf method was developed and compared with the intact plant method. In the detached leaf method, the fully expanded penultimate leaf from a 30- to 45-d-old plant was used. From each leaf a 7.0-cm segment was excised and placed on benzimidazole agar (80 ppm) in a petri dish. A 4-mm mycelial disk was taken from the margin of a *Gerlachia oryzae* colony and placed on the center of the leaf piece. The inoculated leaves in the petri dishes were sealed with parafilm to maintain high moisture, and were incubated in darkness.

Twenty rice varieties varying in LSc resistance were tested using both methods. A total of 25 leaves per variety were inoculated using each method, and lesion length was recorded 72 h after inoculation. The means from two replications were used to compare the methods. The lesion length values obtained using the 2 methods were highly correlated (R=0.90**) (Fig. 7), indicating that the detached leaf technique can be used as a method for assessing resistance to LSc in young plants. Boya (Acc. 58920) and IR10068-18-2 were the most resistant in both methods.

SHEATH BLIGHT

Plant Pathology, Plant Physiology, and Plant Breeding Departments

Screening (*Plant Pathology*). Test materials were screened in the new mass screening upland nursery introduced in 1985. To simplify the process further, relative lesion height was used. The scale was based on the general relationship between sheath blight



7. Relationship between the detached leaf and intact plant methods of assessing leaf scald resistance in rice. IRRI, 1986.

(ShB) severity and estimated yield loss. Relative lesion height was computed using the formula:

$$\text{Relative lesion height} = \frac{\text{lesion height}}{\text{plant height}} \times 100$$

Using the new scale, 672 entries were evaluated (Table 13). Although no highly resistant entries were noted, susceptible materials were readily identified.

In the past, inoculum produced from rice grain-rice hull medium was rapidly contaminated. The use of media such as potato-soil, which is low in nutrients, has significantly lessened the problem of contamination.

Characterization of resistance (*Plant Pathology and Plant Physiology*). Starch, sugar, N, P, K, Ca, Mg, silica, and wax of rice leaves and sheaths were analyzed and associated with varietal resistance (Table 14). Sheath silica content was positively correlated with ShB severity. The content of total carbohydrates in resistant varieties was significantly higher than that in susceptible varieties. A strong negative correlation was shown between ratio of total carbohydrates to N and varietal resistance. P content in leaves was positively correlated to the disease level, and the Ca content showed a similar tendency.

Sheath blight in hybrid rice (*Plant Pathology and Plant Breeding*). ShB development on hybrid combinations and cytoplasmic male sterile (CMS) lines was examined. The results were not consistent enough to show any effect of CMS or

Table 13. Summary of breeding materials and varieties screened for resistance to ShB. IRRI, 1986.

Source	Entries (no.)	Entries (no.) with given reaction[a]					
		HR	R	MR	MS	S	HS
Hybridization block	178	0	6	35	87	37	13
Germplasm bank	85	0	14	22	35	13	1
Upland Observational Yield Trial	81	0	1	11	36	29	4
IRTP materials	250	0	18	54	80	66	32
Hybrid rice and parents	41	0	0	11	22	8	0
IRRI-Korea Collaborative Project	37	0	6	8	12	9	2
Total	672	0	45	141	272	162	52

[a]HR = highly resistant, R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, HS = highly susceptible.

Table 14. Chemical analysis of leaves and sheaths of rice plants and their association with ShB development.[a] IRRI, 1986.

Variety	Parts analyzed[b]	Total carbohydrates (%)	Starch (%)	Sugar (%)	P (%)	Ca[c] (%)	Si (%)	C:N[d]	Area affected (%)
Ta-poo-cho-z	L	7.3	2.5	4.8	1.4	0.5	11.7	3.6	8.3
	S	12.0	3.9	8.1	2.7	0.1	10.2	8.9	1.8
Gyehwa	L	3.9	1.3	2.6	2.2	0.6	16.0	1.5	23.6
	S	5.9	1.6	4.3	3.1	0.1	14.3	4.1	15.3
IR58	L	2.8	1.6	1.2	1.8	0.7	17.0	1.1	58.8
	S	2.9	2.2	0.7	2.3	0.2	17.4	2.1	51.8
IR1317-392-1-2	L	3.2	0.6	2.6	2.0	0.7	15.9	1.1	72.9
	S	3.8	1.7	2.1	3.2	0.1	16.4	2.4	67.3
Correlation coefficient with damage severity[e]	L	−0.836**	−0.626	−0.775*	0.858**	0.62	0.537	−0.863*	
	S	−0.632	−0.290	−0.615	0.509	0.60	−0.715		

[a]Av value of upper 3 leaves and sheaths analyzed at 10 d after flowering. [b]L = leaf, S = sheath. [c]Flag leaf only. [d]Ratio of total carbohydrates to N. [e]Based on analysis of 7 varieties.

hybrid combination on susceptibility to ShB. The F_1 hybrid of 97A/Milyang 54, however, had significantly lower disease incidence than any of the parents.

SCREENING FOR RESISTANCE TO VIRAL DISEASES

Plant Pathology Department

Materials from the IRGC and the GEU program were screened for resistance to tungro (RTV), grassy stunt (GSV), and ragged stunt (RSV) by the greenhouse mass screening method. A total of 15,327 entries were tested for RTV during 1985 and 1986; 31 were resistant (infection rate was lower than 30%). A total of 3,730 entries were tested for GSV during 1986; 11% showed resistance. A total of 7,247 entries were tested for RSV; 9 varieties were resistant: ARC11206, ARC11280, ARC11921, ARC12629, ARC12632, ARC13363, Damnoeub Phear Trach, Damnoeub Pratas Roneap, and SLO 13.

TUNGRO

Plant Pathology and Training and Technology Transfer Departments

Tungro and green leafhopper "biotypes" in South Sulawesi (*Plant Pathology*). As part of the IRRI-Agency for Agricultural Research and Development Collaborative Research on Rice Tungro Virus Disease, conducted at the Maros Research Institute for Food Crops (MORIF), South Sulawesi, Indonesia, a study determined the reaction of selected IR varieties to RTV under natural conditions in the field and with artificial inocula-

tion using green leafhopper (GLH) *Nephotettix virescens* colonies selected on IR54 and TN1.

Natural infection of IR varieties in the field. Plants of selected IR varieties established in the monthly planting trial in the MORIF experimental field and the Lanrang Tungro Nursery were serologically indexed for the presence of rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV) by the latex serological test.

At MORIF, the IR varieties reacted differently, depending on the disease incidence. The GLH population prevailed during the month of planting. RTV incidence was higher in the field planted on 15 Aug (Table 15). IR60 and IR62 had no or low infections. IR26 was mostly infected with RTBV alone.

In the Lanrang Tungro Nursery, fairly high GLH and disease pressure — thus a high incidence of RTV — were observed. All IR varieties planted had relatively high infection with the viruses (Table 16). All IR varieties except IR20 and IR26 were mostly infected with RTBV + RTSV. TKM6 progenies such as IR20 and IR26 had infections with RTBV only. Kelara had low infection with RTBV alone.

Artificial inoculation of IR varieties with IR54 colony. IR varieties that have resistance to GLH, derived mainly from Gam Pai 30-12-15, were selected. TN1 served as the susceptible check. GLH colonies that had been maintained on IR54 and TN1 and fed on RTV-infected plants (variety Cisadane) at MORIF were used for inoculation. Seven-day-old seedlings of each variety were exposed for 1 d to adult GLH in test tubes at 1 insect/seedling.

The IR54 colony transmitted RTV more efficiently than the TN1 colony to all IR varieties. The IR varieties were preferentially infected with RTBV alone when inoculated with the TN1 colony (Fig. 8), but showed high infection rate with RTBV+RTSV when inoculated with the IR54 colony.

Varieties with the resistance gene from Gam Pai 30-12-15 can thus be infected with RTBV+RTSV at a high rate if GLH that have adapted to varieties with the gene are predominant. Preferential infection of Gam Pai 30-12-15 progenies with RTBV alone might be due to their resistance to GLH.

Table 15. Incidence of RTBV and RTSV on selected IR varieties at 45 d after transplanting. Maros Research Institute for Food Crops (MORIF), Indonesia, 1986.

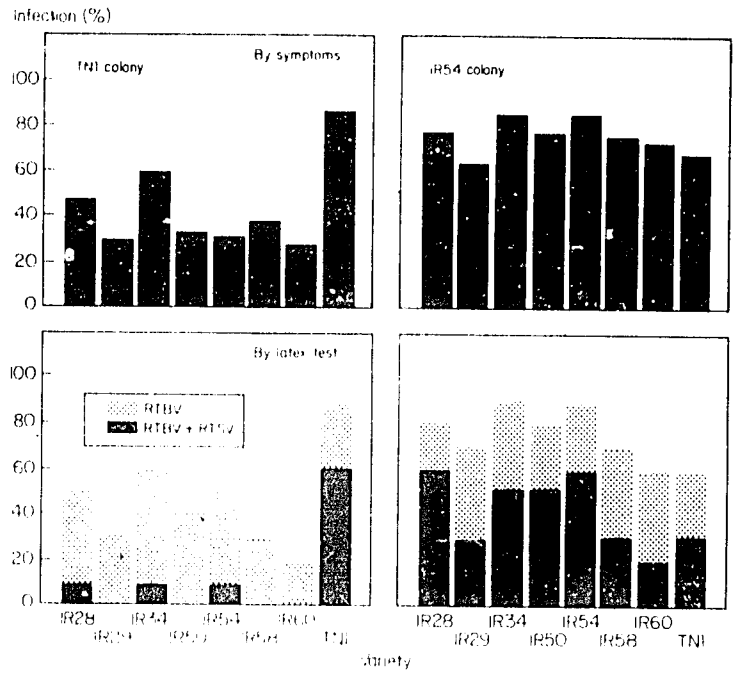
Planting date	Variety	Plants (%) infected[a] with		
		RTBV + RTSV	RTBV	RTSV
1 Aug 86	IR26	0	10	0
	IR30	0	30	0
	IR42	30	0	0
	IR54	10	20	0
	IR58	0	0	0
	IR60	0	0	0
	IR62	0	0	0
	IR64	0	0	0
	TN1	70	0	0
15 Aug 86	IR26	10	50	0
	IR30	20	40	0
	IR42	70	0	10
	IR54	70	0	0
	IR58	20	0	30
	IR60	10	0	0
	IR62	10	0	0
1 Sep 86	IR26	0	40	0
	IR30	30	10	0
	IR42	80	10	0
	IR54	30	10	0
	IR58	0	10	0
	IR60	0	0	0
	IR62	0	0	0
	IR64	10	10	0
	TN1	100	0	0

[a]Indexed by the latex test. Test plants were 10 for each variety.

Table 16. Incidence of RTBV and RTSV on rice varieties at 30 d after transplanting. Lanrang substation, MORIF, Indonesia, 1986.

Variety	Plants tested (no.)	Plants (%) infected[a] with		
		RTBV + RTSV	RTBV	RTSV
TN1	10	70	0	0
IR20	10	0	30	0
IR26	10	0	40	0
IR30	9	11	11	0
IR36	10	40	0	0
IR40	10	40	10	0
IR42	10	40	0	20
IR50	10	50	0	0
IR52	10	30	20	0
IR54	10	30	20	0
IR56	10	10	20	0
IR58	10	30	10	0
IR60	9	44	0	0
Kelara	7	0	14	0

[a]Indexed by the latex test.



8. RTV infection based on symptoms and RTBV and RTSV infection based on the latex test in rice varieties inoculated with TN1 and IR54 colonies that had fed on Cisadane plants infected with both RTBV and RTSV, MORIF, Indonesia, 1986.

Tungro and green leafhopper "biotypes" in the Philippines (*Plant Pathology*). During May 1985, about 50 GLH adults were collected from a ricefield planted to different IR varieties and lines in Koronadal, South Cotabato, Philippines. The GLH were reared on TN1 seedlings. Newly emerged first-generation adults were tested for their feeding behavior and transmission of RTV-associated viruses on IR26, IR36, IR54, and TN1. A GLH colony that had been maintained on TN1 for several years served as the control. The Koronadal colony excreted more basic honeydew on all varieties except on TN1 and transmitted RTBV+RTSV more efficiently in IR36 and IR54 than the TN1 colony (Table 17).

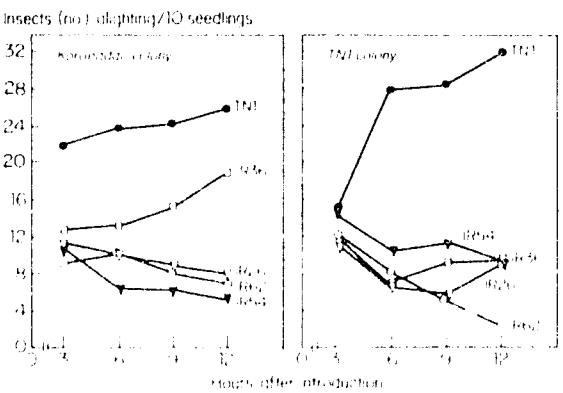
After having been reared for four to five overlapping generations on TN1, the young adults were subjected to the preference or free choice RTV

Table 17. Transmission of RTBV and RTSV and honeydew excretion during a 1-d inoculation access[a] on TN1 and 3 selected IR varieties by field and TN1 GLH colonies that had been exposed to RTV-infected TN1 plants for 3-4 d.[b] IRRI, 1986.

Variety	Koronadal colony						TN1 colony					
	Plants tested (no.)	Average area of honeydew spots (mm)		Plants (no.) infected with			Plants tested (no.)	Average area of honeydew spots (mm)		Plants (no.) infected with		
		Acidic	Basic	RTBV+RTSV	RTBV	RTSV		Acidic	Basic	RTBV+RTSV	RTBV	RTSV
IR26	20	92	33	0	18	0	31	201	7	0	5	0
IR36	20	99	58	7	3	0	25	194	8	1	9	0
IR54	20	115	22	9	3	4	30	210	0	0	4	0
TN1	20	123	68	13	1	0	25	146	90	16	3	1

[a]Inoculation access was given in a special feeding chamber. [b]The inoculated plants were indexed for the presence or absence of viruses by latex test about 1 mo after inoculation.

transmission tests. Ten 7-d-old seedlings of each variety (IR26, IR36, IR54, IR62, and TN1) were randomly transplanted in a plastic tray (28 × 36 cm), and 100 GLH adults that had been exposed to RTV-infected plants for 3-4 d were introduced. GLH alighting on seedlings of each variety were counted 3, 6, 9, and 12 h after the introduction. Seedlings were indexed by the latex test for the presence of the viruses at 1 mo after the infestation. The Koronadal and TN1 colonies showed similar preference for the test varieties, except that the Koronadal colony tended to prefer IR36 (Fig. 9). During the test, the Koronadal colony transmitted RTBV+RTSV or RTBV alone more efficiently than the TN1 colony (Fig. 10).

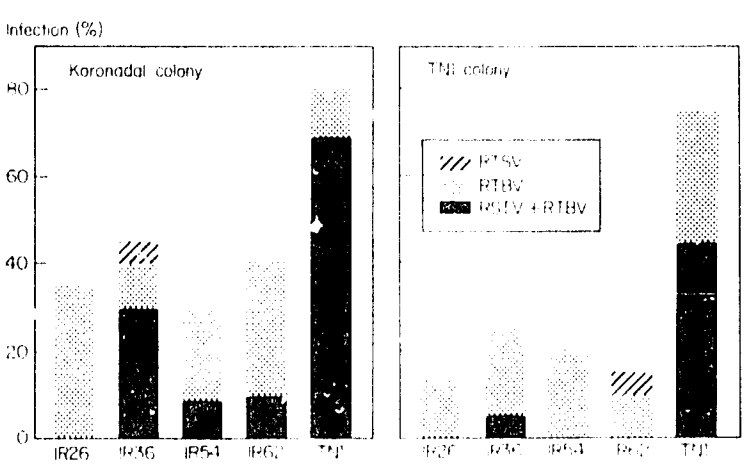


9. Number of green leafhoppers from the Koronadal or the TN1 colony alighting on 4 varieties at 3, 6, 9, and 12 h after introduction. IRRI, 1986.

Reactions of selected IR varieties to RTV-associated viruses were also tested by using the Koronadal and TN1 colonies, and an IR64 colony that was originally collected at Koronadal and had been maintained on IR64. Newly emerged adults were given a 4-d acquisition access to RTV-infected plants and then a 1-d inoculation access to 1-wk-old seedlings in test tubes. The Koronadal and IR64 colonies preferentially transmitted RTBV+RTSV in many varieties tested, while the TN1 colony preferentially transmitted RTBV alone in almost all varieties except IR42 and TN1 (Table 18).

Varietal reaction to tungro in the field (*Plant Pathology and Training and Technology Transfer*). IR varieties were tested for their reaction to RTV in Guimba, Nueva Ecija; Baybay, Leyte; and Koronadal, South Cotabato, Philippines, during 1986 DS. RTV had occurred in the previous crop at the sites except in Nueva Ecija, where the disease occurred in the 1983-84 croppings. Three-week-old seedlings of each variety were transplanted in 3- × 3-m plots. At 60 d after transplanting, RTV incidence was assessed by visual symptoms and by the latex test.

In Nueva Ecija and Leyte, where RTV incidence was very low or moderate, RTSV incidence was high. But in South Cotabato, where RTV incidence was high, incidence of RTBV+RTSV was high. IR56, IR60, and IR62 had very low infection rates with the viruses in South Cotabato and Leyte but relatively high infection rates with RTSV in Nueva



10. Percentage infection with RTBV and RTSV during the preference test. IRRI, 1986.

Table 18. Transmission of RTBV and RTSV to selected IR varieties by field or selected GLH colonies that had been exposed to RTV-infected TN1 plants for 3-4 d.[a] IRRI, 1986.

Variety	Koronadal colony				IR64 colony				TN1 colony			
	Plants tested (no.)	Plants (no.) with			Plants tested (no.)	Plants (no.) with			Plants tested (no.)	Plants (no.) with		
		RTBV+RTSV	RTBV	RTSV		RTBV+RTSV	RTBV	RTSV		RTBV+RTSV	RTBV	RTSV
IR8	20	6	2	0	28	2	9	0	30	1	10	1
IR20	20	0	12	0	19	0	9	0	29	0	19	0
IR26	20	0	12	0	20	0	13	0	30	0	12	0
IR30	18	0	4	0	18	0	6	0	29	0	12	0
IR36	20	3	6	2	30	7	8	1	25	2	9	1
IR42	20	5	3	1	27	6	9	1	30	6	11	2
IR50	16	4	4	0	27	5	6	1	25	1	3	0
IR54	20	5	7	0	25	6	7	1	27	0	5	0
IR56	19	3	3	1	30	2	4	0	28	1	9	1
IR58	20	5	1	0	22	11	8	0	29	0	5	0
IR60	19	1	3	0	27	10	7	0	30	0	11	0
IR62	18	5	2	2	26	2	2	4	29	1	7	0
IR64	18	2	2	1	29	3	8	0	29	0	7	1
TN1	39	20	10	2	25	14	5	0	27	14	8	0

[a]Seedlings were given a 1-d inoculation access at 1 leafhopper/seedling in test tubes.

Ecija (Table 19). IR50, IR54, and IR64 had high infection rates with RTBV + RTSV in South Cotabato but low infection rates with RTSV alone in Nueva Ecija. In South Cotabato, GSV incidence was 0-18%, depending on variety. The visual scoring might also have counted plants infected with GSV 2, which causes RTV-like symptoms and occurred in South Cotabato.

In 1986 DS, IR varieties and lines were tested in Libon, Albay, where RTV is endemic. RTV incidence was high in IR22, IR54, and IR56, but low in IR26, IR30, and several lines (Table 20).

The high infection rates with RTSV and RTBV in IR50, IR54, and IR64 indicate they had no more field resistance to RTV in Albay, Leyte, and South Cotabato.

Tolerance for tungro-associated viruses (*Plant Pathology*). Rice cultivar Balimau Putih (IRRI Acc. 17204) showed consistent resistant reaction to RTV infection in greenhouse mass screening tests.

Table 19. RTV incidence based on symptoms, and RTBV and RTSV incidence based on the latex test in IR varieties at 60 d after transplanting at 3 Philippine locations, 1986 DS.

Variety	Nueva Ecija[a]	Leyte				South Cotabato			
	RTSV incidence (%)	RTV incidence (%)	Virus incidence (%)			RTV incidence (%)	Virus incidence (%)		
			RTBV + RTSV	RTBV	RTSV		RTBV + RTSV	RTBV	RTSV
IR22	11	61	20	13	11	99	50	8	29
IR26	12	0	0	2	0	89	0	34	0
IR30	10	0	0	1	0	49	2	37	1
IR36	29	5	4	3	22	92	19	12	19
IR42	26	25	17	4	64	98	25	14	20
IR50	9	1	2	2	28	100	39	10	19
IR54	4	3	4	2	48	100	65	5	21
IR56	5	0	0	1	2	5	1	2	10
IR60	26	0	0	1	4	29	1	3	11
IR62	13	0	0	0	4	7	4	2	25
IR64	6	3	2	2	28	100	31	15	22

[a]No visual scoring was made. The latex test showed no incidence of RTBV + RTSV and RTBV.

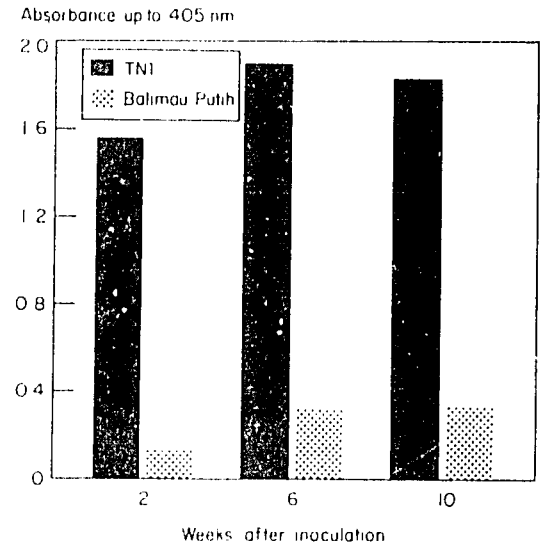
Table 20. RTV incidence based on symptoms and RTBV and RTSV incidence based on the latex test at 60 d after transplanting in IR varieties and lines in Albay, Philippines, 1986 DS.

Variety or line	Tungro incidence (%)	Virus incidence (%)		
		RTBV+ RTSV	RTBV	RTSV
IR22	70	31	12	8
IR26	2	0	1	1
IR30	7	0	3	1
IR36	8	3	1	18
IR54	38	11	1	40
IR56	47	22	1	29
IR22822-4-2-3-2	0	0	0	1
IR22822-8-12-3-1-1-2	0	0	3	0
IR32307-107-3-2-2	4	1	1	1
IR32429-47-3-2-2	7	1	1	6

The resistance of this variety to RTBV and RTSV was further evaluated. One hundred 27-d-old seedlings of Balimau Putih and TN1 were inoculated at 5 insects/seedling using GLH that had 4 d access to TN1 plants infected with both RTBV and RTSV. All inoculated seedlings were indexed by enzyme-linked immunosorbent assay (ELISA) 1 mo after inoculation. The tip (about 10 cm long) of the second youngest leaf was collected from each plant, and the relative amount of the viruses in the leaf tip was determined by ELISA based on absorbance value at 405 nm at 2, 6, and 10 wk after inoculation (WAI). Height and yield reduction due to infection with either RTBV or RTBV+RTSV were noted.

ELISA tests showed that Balimau Putih was susceptible to infection with the RTV-associated viruses just like TN1. However, Balimau Putih did not show symptoms typical of RTBV and RTBV+RTSV infection (Fig. 11). The relative amounts of RTBV and RTSV were constantly lower in Balimau Putih than in TN1 (Fig. 12). Apparently, the multiplication of RTBV and RTSV in Balimau Putih was limited to a tolerable level. Hence, infected plants showed no discernible symptoms, even when both viruses were present. Height reduction was 5% for Balimau Putih and 20% for TN1 when infected with RTBV alone, and 10% and 40% when they were infected with RTBV+RTSV. Consequently, Balimau Putih had a lower percentage of yield reduction (Table 21).

11. Tungro-infected Balimau Putih plants. The right-hand plant is healthy (check). The other plants are infected with (left to right) RTBV+RTSV, RTBV, and RTSV.



12. Relative amounts of RTBV in infected TN1 and Balimau Putih plants at 2, 6, and 10 wk after inoculation.

In another trial, five plants each of IR36, IR54, Balimau Putih, and TN1 that were infected with RTBV+RTSV were selected to compare virus concentration in the plants. At 5 WAI, whole

Table 21. Percentage of height and yield reduction in rice varieties TN1 and Balimau Putih infected at the seedling stage with RTBV or RTBV + RTSV. IRRI, 1986.

Variety	Height reduction (%)		Yield reduction (%)	
	RTBV	RTBV+ RTSV	RTBV	RTBV+ RTSV
TN1	21.3	41.6	50.0	90.0
Balimau Putih	5.0	11.4	7.6	18.4

Table 22. Relative amount of RTBV and RTSV in doubly infected plants of 4 varieties at 5 WAI. IRRI, 1986.

Variety	Absorbance at 405 nm[a]		Dilution end point	
	RTBV	RTSV	RTBV	RTSV
IR36	.65 ± .07	1.34 ± .04	1:128	1:512
IR54	.80 ± .05	.44 ± .04	1:64	1:512
Balimau Putih	.16 ± .07	.14 ± .09	1:32	1:32
TN1	.70 ± .14	1.00 ± .22	1:256	1:512

[a]Mean absorbance ± standard deviation of extracts (1:8 dilution) from 5 infected plants in ELISA.

plants excluding roots were separately homogenized, and the homogenates were serially diluted up to 1:1024 and tested by ELISA.

Absorbance values and dilution end points for positive ELISA varied with variety (Table 22). Balimau Putih had a low absorbance value and low dilution end point for both RTBV and RTSV. Infected IR36, IR54, and TN1 showed severe symptoms, while Balimau Putih showed no discernible symptoms.

RAGGED STUNT

Plant Breeding and Plant Pathology Departments

Evaluating Sitopas crosses for tolerance for ragged stunt virus (*Plant Breeding and Plant Pathology*). The Indonesian variety Sitopas was reported to have tolerance for RSV. We evaluated 523 F_3 lines from 5 crosses of Sitopas together with 3 check varieties: IR20, susceptible to brown planthopper (BPH) and intolerant of RSV; IR8234-OT-9-2, resistant to BPH biotype 1 but intolerant of RSV; and Sitopas, tolerant of RSV but susceptible to BPH biotype 1.

Seeds were soaked in petri dishes in five batches. Seedlings were artificially inoculated with RSV at 11 d after soaking by a standard mass screening method in the greenhouse, infected with RSV at 45 d after soaking, and then transplanted into the field in rows in a randomized complete block design with 2 replications.

N at 100 kg/ha was applied in 2 splits. Data on spikelet fertility were determined.

Sitopas confirmed its tolerance, while IR20 and IR8234-OT-9-2 were intolerant of RSV (Table 23). Crosses from IR43301 and IR46641 showed a significant number of fertile plants compared to other Sitopas crosses and check varieties IR20 and IR8234-OT-9-2. Crosses with Sitopas performed differently depending on other parents involved but, on the average, they were significantly better than the check varieties. They also had a comparatively high percentage of plots with fertility of at least 50%, showing that Sitopas was able to transmit its tolerance for RSV into some segregants. These findings hold promise for further selection of lines tolerant of RSV.

Tolerance for ragged stunt virus (*Plant Pathology*). Seedlings of 10 selected varieties were soaked for 7 d, inoculated with RSV, and then transplanted in 16-x-16-x-19-cm pots with fertile soil at 3 seedlings/pot. Other seedlings were also transplanted at 7 d after soaking and then inoculated at 15, 30, 45 or 60 d after soaking.

Table 23. Reaction of rice varieties and Sitopas progenies to RSV at IRRI, 1985.

Designation	Plots (%) with fertility >50%	Mean fertility (%)
Sitopas (check)	61.2	31.9 a
IR43301 (Sitopas//IR26702-52-3)	12.2	15.8 b
IR46641 (Sitopas/IR26702-52-3// IR8234-OT-9-2)	15.3	13.3 b
IR46630 (IR20/Sitopas//BR118-3B-17)	7.6	8.1 c
IR46733 (IR20/Sitopas//BR51-91-7)	4.2	2.8 d
IR46734 (IR20/Sitopas//New Sabarmati)	4.1	3.1 d
IR8234-OT-9-2 (check)	2.8	2.8 d
IR20 (check)	0.6	1.3 d

Uninoculated plants served as the control. Plant height, major symptoms, and grain yield were noted for each plant established in September 1984 and in November 1985. Each trial had three replications.

All inoculated seedlings developed symptoms characteristic of RSV at about 2 WAI when inoculated at 7 or 15 d after soaking. The emergence of new leaves in infected seedlings was delayed, and the leaves were short, ragged or twisted, and darker in color. At 1 mo after inoculation, newly developed leaves were less abnormal in all varieties. At 2 mo after inoculation, many varieties showed vein swelling and occasional ragged or twisted leaves but less stunting (Table 24). The recovery of infected plants was evident in Sitopas, Ptb 18, and Tetep more than in the other varieties. The symptoms were milder when plants were infected at 30 d after soaking. The symptoms were not clear except in Kirihara and TN1 when plants were infected at 45 d after soaking.

In the first trial, yield reduction was high in plants of almost all varieties infected at 7 or 15 d after soaking (Table 25). Sitopas, Ptb 18, Tetep, and Lemo had lower yield reductions than other varieties when infected at the seedling stage. In the second trial, where flowering was delayed but yield reduction was less than in the first trial yield reduction was higher in plants inoculated at 30 d after soaking than in plants inoculated at 7 or 15 d after soaking in many varieties. The varieties that had less yield reduction in the first trial also showed better yield in the second trial. Ptb 21 had significantly less yield reduction in the second trial.

In another trial, 7-d-old seedlings were individually inoculated with RSV and transplanted in pots. Uninoculated seedlings were similarly transplanted. For each cultivar, two batches of five RSV-infected and three uninoculated plants were randomly selected. At 30 and 45 DAI, plant height was measured, and the whole plant except the roots was separately homogenized with buffer solution; the sap at 1/5 dilution was directly tested by ELISA. A micro ELISA plate was coated with immunoglobulin against RSV at 2 μg/ml and immunoglobulin-alkaline phosphatase conjugate was diluted 300 times. The RSV concentration in the sap was indicated by the absorbance value at 405 nm. Absorbance of uninfected plant sap was below 0.05 throughout the tests.

Tolerant varieties Sitopas and Ptb 18 had ELISA absorbance lower than the other varieties, although the differences were not very significant (Table 26). Intolerant varieties, which showed higher plant height reduction, had higher absorbance except TN1 at 45 DAI. No correlation was found between plant height reduction percentage and RSV concentration in plants at 30 DAI; at 45 DAI, however, there was a correlation.

Table 24. Symptoms and plant height reduction at 30 and 60 DAI in 10 rice varieties inoculated with RSV at 7 d after soaking.[a] IRRI, 1986.

Variety	30 DAI		60 DAI	
	Symptoms	Height reduction (%)	Symptoms	Height reduction (%)
Sitopas	R^{+++}, V^{+}	24	R^{+}, V	7
Ptb 18	R^{+}, V^{+}	29	R^{+}, V^{++}	17
Tetep	R^{+}, V^{+}	29	R^{++}, V^{+}	22
Lemo	R^{+}	57	R^{++}, V^{+}	36
Ptb 21	R^{+}	59	V^{++}	20
Utri Rajapan	R^{+}	52	R^{+}, V^{+}	27
Khao Mali	R^{+}	43	V^{++}	21
Khao-Tah-Haeng	R^{+}, V^{+}	45	R^{++}, V^{+}	43
Kirihara	R^{+}, V^{+}	68	R^{+}, V^{++}	34
TN1	R^{+}, V^{+}	56	R^{++}, V^{+}	25

[a]DAI = days after inoculation; R = ragged or twisted leaves; V = vein swelling; +, ++, +++ = increasing severity.

Table 25. Percentage of yield reduction in 10 rice varieties infected with RSV at different days after soaking. IRRI, 1986.

Variety	Yield reduction (%)				
	7 d	15 d	30 d	45 d	60 d
Sitopas	41	55	28	35	3
Ptb 18[a]	38	65	28	21	–
Tetep	22	58	30	46	5
Lemo	57	–	33	-28	-21
Ptb 21	99	53	-10	-3	-22
Utri Rajapan	100	59	35	5	-39
Khao Mali	80	79	32	47	-16
Khao-Tah-Haeng	100	100	15	28	52
Kirihara	77	96	34	52	20
TN1	84	90	78	65	2

[a]Percentage yield reduction was calculated based on the yield of plants inoculated at 60 d after soaking.

Table 26. Plant height reduction and RSV concentration[a] at 30 and 45 DAI in plants of 10 rice varieties inoculated at 7 d after soaking. IRRI, 1986.

Variety	Absorbance at 405 nm		Height reduction (%)	
	30 DAI	45 DAI	30 DAI	45 DAI
Sitopas	0.86 ± 0.19	0.84 ± 0.01	34	2
Ptb 18	0.89 ± 0.09	0.87 ± 0.00	33	15
Tetep	1.13 ± 0.03	1.04 ± 0.09	35	16
Lemo	1.00 ± 0.02	0.95 ± 0.20	28	0
Ptb 21	0.94 ± 0.00	1.10 ± 0.13	24	11
Utri Rajapan	0.93 ± 0.08	1.01 ± 0.10	21	11
Khao Mali	1.06 ± 0.01	1.06 ± 0.01	21	8
Khao-Tah-Haeng	1.07 ± 0.17	1.20 ± 0.19	28	46
Kirihara	1.15 ± 0.06	1.10 ± 0.13	126	16
TN1	1.24 ± 0.03	0.94 ± 0.09	26	4

[a]Indicated by absorbance at 405 nm of sap at 1/5 dilution.

Sitopas, Ptb 18, and Tetep developed milder symptoms and had less damage when infected with RSV at the seedling stage. Their tolerance for RSV was due to their high ability to recover after severe infection at an early stage.

PATHOGEN GENETICS

Plant Pathology Department

Work was initiated to study the genetics of the Bl fungus *P. oryzae* and the BB pathogen Xco. In collaboration with several laboratories in developed countries, we began to develop genetic systems in both pathogens with the objectives of understanding the basis of pathogenesis and pathogenic variation and of developing genetic and molecular tools for epidemiological studies.

Pyricularia oryzae. The perfect stage of *P. oryzae* is *Magnaporthe grisea*, an ascomycete that produces asci with eight ascospores. Sexual compatibility is controlled by the mating type locus MAT, with two alleles MAT 1 (A) and MAT 2 (a). In general, isolates from rice are low in fertility and can function only as males, whereas isolates from many graminaceous weeds are more fertile and some are hermaphroditic. Mating type tests of 10 isolates from different grassy weeds in the Philippines showed that 6 were MAT 2 and 1 was MAT 1, but no viable asci were formed. To study the inheritance of pathogenicity, it is necessary to introgress fertility into rice isolates. We crossed nonpathogenic fertile testers with rice isolates and tested the progenies for pathogenicity on rice lines. Since the viability of ascospores was low (5-30%), whole germinated asci containing 1-4 ascospores were isolated. Among 563 asci derived from rice isolates No. 23 (CH40-1) and No. 25 (CH104-3), 20 (3.5%) produced susceptible lesions on rice lines. Conidia recovered from these plants were backcrossed to pathogenic rice isolates to generate strains for genetic analysis of cultivar specificity. Furthermore, rice lines susceptible to the hybrid progeny were crossed to conduct a parallel genetic analysis in the host.

In addition to improving the fertility of the rice isolates, various genetic markers including auxotrophy, isozymes, and morphological variants were incorporated into the rice isolates. Of particular interest is a morphological variant of the conidium that arose in the hybridization of two normal wild types (Fig. 13). The two terminal cells of a normally three-cell conidium were underdeveloped, resulting in either a single round cell or an irregularly shaped conidium. Genetic analysis suggested that two genes were involved in the abnormal development of the conidium (Table 27). For crosses with isolate 23, the significant deviation from the digenic 3:1 ratio appeared to be caused by the large number of nonsporulating progenies. The conidial mutant phenotype is being backcrossed to rice isolates as a potentially useful marker for epidemiological studies.

Xanthomonas campestris* pv. *oryzae. A variety of mutants was isolated from representative

13. Scanning electron micrographs of a) normal-cell, pyriform conidia, and b) irregular-shaped conidia of a conidial mutant. 1300X. IRRI, 1986.

Table 27. Genetic segregation of a conidial morphological variant of *Pyricularia oryzae*. IRRI, 1986.

Cross			Ascospores (no.)	Nonsporulating ascospore cultures (no.)	Conidial morphology of segregant (no.)		X^2 3:1[a]
Normal		Mutant			Normal	Deformed	
28	X	818	143	5	101	37	0.24
28	X	936	110	15	73	22	0.17
23	X	4186	58	21	20	17	8.65 **
23	X	4190	36	10	18	8	0.45
23	X	4170	21	6	7	6	3.09 *
23	X	4191	49	21	17	11	3.04 *

[a]Significant deviations from a 3:1 digenic model at the 0.05 (*) and 0.01 (**) levels.

isolates of different races of Xco in the Philippines. Spontaneous mutants resistant to spectinomycin, streptomycin, and rifampicin were recovered from PXO 61 (race 1), IRN793 (race 2), PXO 71 (race 4), and PXO 99 (race 6). These mutants will be useful in population studies by allowing the use of selective media. N-methyl-N'-nitro-N-nitrosoguanidine (NTG) was used to induce mutation in PXO 61 and IRN793. A number of white, antibiotic-resistant, auxotrophic mutants were isolated from the surviving colonies of these two isolates. The frequency of antibiotic-resistant mutants recovered from the NTG-treated cultures was about 10^5–10^6 times higher than that from spontaneous mutation. Seventy-one survivors of PXO 61 — 23 white and 48 yellow — were tested on 5 Philippine differentials: IR8, IR20, IR1545-339, Cas 209, and DV85. Ninety percent of these mutants had either completely lost or decreased virulence on the susceptible differentials IR8 and Cas 209; however, a few were found to become more aggressive on IR8 and Cas 209.

Another approach being used to generate mutations is transposon mutagenesis. Preliminary mating experiments between three Tn5-plasmids (kanamycin resistant) — pUW943, pJB4J1, and pSUP1011 — and PXO 61 did not yield any transconjugant. Through collaboration with the John Innes Institute and Kansas State University, more vector-Xco race combinations are being tested for effective transposon mutagenesis.

Genetic evaluation and utilization (GEU) program

Insect resistance

Entomology and Plant Breeding Departments and International Rice Testing Program

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SOURCES OF RESISTANCE

Entomology and Plant Breeding Departments and International Rice Testing Program

IRTP insect resistance trials. (*Entomology and International Rice Testing Program*). Insect resistance information was obtained from 1985 International Rice Testing Program (IRTP) trials (data received and analyzed in 1986). Entries that performed well across locations are indicated, as well as others that performed well at specific sites. Detailed results appear in the IRTP section of this report and in IRTP nursery reports.

Insect *Entries*

Stem borer

Vegetative stage: CO 18; IR13429-287-3, IR19735-5-2-3-2-1, IR19743-25-2-2, IR19743-46-2-3-3-2, IR19774-42-2-1-3-2, IR21015-80-3-3-1-2, IR56, IR5857-4-1E-3, IR8608-75-3-1-3, IR9129-169-3-2-3-3, Kalinga 2 (Acc. 39473), KAU1675, MTU15, RP825-71-4-10, Taichung sen 10, TKM6 (Acc. 237), TNAU(AD)103, TNAU9426-7, W1263 (Acc. 11057)

Heading stage: IR15314-43-2-3-3, IR15795-151-2-3-2-2, IR56, IR8608-75-3-1-3, IR9288-B-B-52-1, IR9830-26-3-3, Taichung sen 10

Brown planthopper: BG367-2, BG379-2, IR3540-56-3-2-1, IR25587-133-3-2-2-2, IR25603-20-2-1-3-2, IR27325-111-2-1, IR29692-65-2-3-3, IR35323-93-1-3-1, Ptb 19 (Acc. 6107), Ptb 33, Rathu Heenati (Acc. 11730), Sinna Sivappu (Acc. 15444)

Whitebacked planthopper: ARC10239, IR13475-7-3-2, IR15527-21-2-3, IR2035-117-3, IR25587-67-1-3-3-3, IR27316-6-2-2, Rathu Heenati (Acc. 11730), Sufaida 172 (Acc. 28298), WC1240 (Acc. 13742)

Resistance of CEU elite lines (*Entomology and Plant Breeding*). Seventy-nine lines and varieties were tested against 7 rice insect pests — brown planthopper (BPH) biotypes 1, 2, and 3; whitebacked planthopper (WBPH); green leafhopper (GLH); yellow stem borer (YSB); caseworm (CW); leaffolder (LF); and rice whorl maggot (RWM). Fifty-nine percent exhibited multiple resistance to BPH, GLH, and YSB; 26% were moderately resistant to WBPH (Table 1). None was resistant to CW, LF, or RWM.

Table 1. Reaction[a] of elite lines to insect pests. IRRI, 1986.

Variety or line	Reaction				
	BPH biotype			GLH	YSB
	1	2	3		
IR50	R	R	R	R	MR
IR58	R	R	R	R	R
IR64	R	R	R	R	MR
IR13146-45-2-3	R	R	R	MR	R
IR13149-71-3-2-3	R	R	R	R	MR
IR19083-22-2-2	R	R	R	R	MR
IR19382-42-3-3-2	R	MR	R	R	MR
IR28150-84-3-3-2	R	MR	R	R	MR
IR28222-9-2-2-2-2	R	MR	R	R	MR
IR28224-3-2-3-2	R	MR	MR	R	MR
IR28228-119-2-3-1-1	R	R	R	R	MR
IR29692-65-2-3-3	R	MR	R	R	MR
IR29692-99-3-2-1	R	R	R	R	R
IR29723-88-2-3-3	R	R	R	R	MR
IR29723-143-3-2-1	R	R	R	R	MR
IR29725-22-3-3-3	R	R	R	R	MR
IR29725-109-1-2-1	R	R	R	R	MR
IR31802-48-2-2-2	R	MR	R	R	MR
IR31868-64-2-3-3-3	R	MR	R	R	MR
IR32307-107-3-2-2	R	MR	R	R	MR
IR32429-47-3-2-2	R	R	R	R	MR
IR32429-68-3-3-3	R	MR	R	R	R
IR32429-122-3-1-2	R	R	R	R	MR
IR32453-20-3-2-2	R	R	R	MR	MR
IR32720-138-2-1-1-2	R	R	R	R	MR
IR32843-92-2-2-3	R	R	R	R	MR
IR33043-46-1-3	R	R	R	MR	MR
IR33059-26-2-2	R	R	R	R	MR
IR35293-125-3-2-3	R	MR	R	R	MR
IR35353-94-2-1-3	R	R	R	MR	MR
IR35361-59-3-3-2	R	R	R	R	R
IR35366-28-3-1-2-2	R	R	R	R	R
IR35366-40-3-3-2-2	R	R	R	R	MR
IR35366-90-3-2-1-2	R	R	R	R	R
IR37712-90-3-3-3-2	R	R	R	R	MR
IR37721-9-2-1-3	R	R	R	R	MR
IR37865-29-3-1-3	MR	MR	MR	R	MR
IR37873-16-2-3-3-3	R	R	R	R	R
IR38699-49-3-1-2	R	R	R	MR	R
IR39385-124-3-3-2-3	R	MR	MR	R	R
IR39423-124-3-3-1	R	MR	R	R	MR
IR41389-20-1-5	R	R	R	R	MR
IR41985-98-3-1-3-2	R	R	R	R	R
IR41986-12-2-2-3	R	R	R	MR	R
IR42068-22-3-3-1-3	R	R	R	MR	MR
IR44595-70-2-2-3	R	R	R	R	MR

[a]R = resistant, MR = moderately resistant.

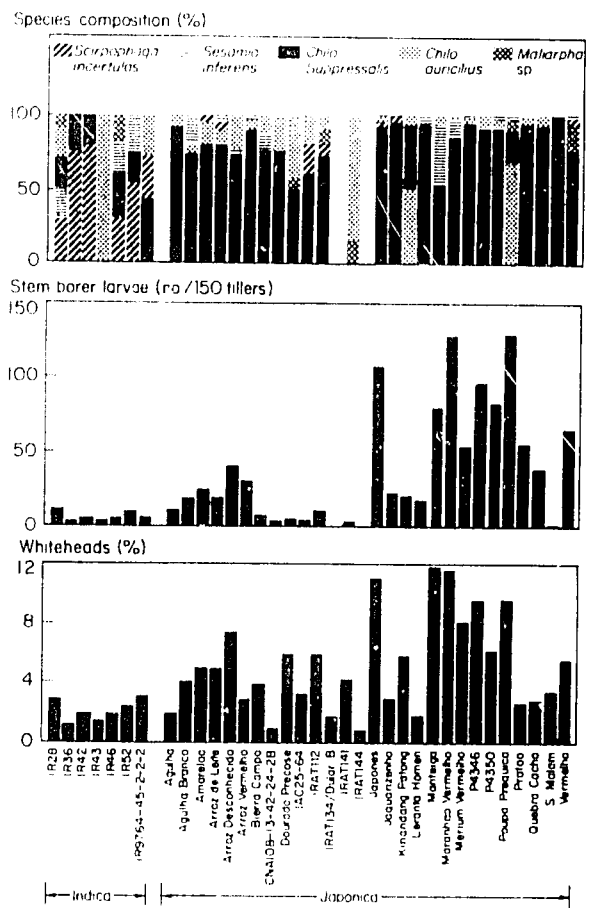
Screening methods for resistance to leaffolder (*Entomology*). Twelve varieties were evaluated for resistance to LF *Marasmia patnalis* larvae or adults by free-choice and no-choice tests. In free-choice tests, ten 3-wk-old potted plants of each variety were caged together and infested at a rate of two 1st-instar larvae/tiller or 10 pairs of adults/cage. In no-choice tests, 24 potted plants of the same variety were caged and also infested at a rate of 2 larvae/tiller or 2 pairs of adult/cage. Damage was scored when IR36 plants were rated 9 by the *Standard evaluation system for rice*. Damage ratings were comparable in both methods (Table 2). Choorapundy, GEB24, Darukasail, Kamalbhog, W1263, and Muthumanikan were moderately resistant under free-choice adult infestation, indicating insect nonpreference for oviposition. Choorapundy, Kamalbhog, and Muthumanikan also showed moderate resistance under no-choice adult infestation, indicating possible presence of oviposition inhibitors in these varieties.

Table 2. Reaction of selected varieties to *Marasmia patnalis* in free-choice (FC) and no-choice (NC) tests. IRRI, 1986.

Variety	Acc. no.	Damage rating: Adult infestation[a]		Damage rating: Larval infestation[b]	
		FC	NC	FC	NC
Vashaipoo samba	----	7	5	7	7
Choorapundy	49529	5	3	7	7
GEB24	5909	5	7	7	7
Ptb 33	19325	7	7	7	5
Darukasail	45493	5	7	7	7
Kamalbhog	46020	5	5	7	7
Karpur kanti	46078	7	7	7	7
W1263	11057	5	7	5	7
Muthumanikan	15379	5	5	7	7
ASD7	6303	7	7	7	7
TKM6 (resistant check)	237	3	5	7	7
IR36 (susceptible check)	30416	9	9	9	9
Mean		5.8	6.1	7	7
Difference		.36 ns		.50 ns	

[a]Adult infestation is used for initial screening to discard the bulk of susceptible screening materials. FC and NC were not statistically significant at the 5% level by DMRT.
[b]Larval infestation is used for retesting, to further confirm the resistance of different varieties. FC and NC were not statistically significant at the 5% level by DMRT.

Resistance of indica and japonica cultivars to stem borers (*Entomology*). We compared stem borer (SB) infestation on selected indica and japonica cultivars planted in adjacent irrigated wetland and dryland fields. SB infestations were based on 150 tillers/cultivar dissected 2 wk before harvest. In general, whitehead counts and borer larvae were higher on japonica than on indica cultivars (Fig. 1). Japones, Manteiga, Maranhao Vermelho, P4346, and Poupa Prequica had the highest borer infestations among the japonicas. The relative abundance of borer species in the indicas was *Scirpophaga incertulas* > *Chilo auricilius* > *C. suppressalis* > *Sesamia inferens* > *Maliarpha* sp.; in the japonicas, it was *C. suppressalis* > *C. auricilius* > *S. inferens* > *Maliarpha* sp. > *Scirpophaga incertulas*.



1. Relative abundance and infestation of 5 rice SB species. IRRI, 1986 WS.

Resistance to *Chilo auricilius* (*Entomology*). We evaluated 26 cultivars for resistance to the gold-fringed borer *C. auricilius*. Ten neonate larvae were placed on 35-d-old potted test plants, each having 10 tillers. No adult was recovered on Binundok, Biera Ocampo, CNA-108-8-42-24-2B, or IRAT121 (Table 3). Nine other varieties exhibited 7-13% adult recovery, and N22 had 77% recovery with a high growth index of 2.22.

Monitoring green leafhopper biotypes in the Philippines (*Entomology*). Tungro (RTV) incidence can increase if the vector (*Nephotettix virescens*) populations become adapted to resistant varieties. In a survey in the Philippines in 1979, there was hardly any evidence of widespread selection of GLH biotypes in farmers' fields, although IR36 was attacked by GLH and damaged by RTV in a few localities. But a survey conducted in several places in Luzon in 1984 showed that field colonies of GLH were far more virulent than the greenhouse colony. During 1985-86, IR64, a GLH-resistant variety, was severely infected with RTV in South Cotabato, indicating a shift in GLH biotypes.

We therefore compared the virulence of five GLH field populations with the greenhouse GLH colony on IR64, IR42, IR36, IR19670-263-3-2-2-1, IR28224-3-2-3-2, and IR22. The population increase of the Mindanao colony was consistently high on the resistant IR64; IR60, IR42, and IR19670-263-3-2-2-1 and on the susceptible IR22 (Table 4). In contrast, the Laguna, Bicol, Central Luzon, and the greenhouse colonies had much less population increase on resistant varieties. Fecundity showed a similar trend (Table 5). Monitoring with an electronic device showed distinct dif-

Table 3. Development of *Chilo auricilius* on selected rice cultivars.[a] IRRI greenhouse, 1986.

Cultivar	Origin	Survival[b] (%)	Growth index[c]
Binastian	Philippines	7 h	0.15 gh
Binerhin	Philippines	43 b-c	1.04 c-e
Dinolores	Philippines	13 gh	0.29 gh
Buluhan	Philippines	10 gh	0.23 gh
Dagi	Philippines	13 gh	0.27 gh
Milagrosa	Philippines	10 gh	0.23 gh
Binundok	Philippines	0 h	0 h
Kinandang Patong	Philippines	33 d-f	0.83 d-f
IR1917	Philippines	50 b-d	1.23 b-d
Tokyo	Korea	17 f-h	0.41 f-h
N22	India	77 a	2.22 a
Mushkan	India	57 bc	1.42 bc
Tondok	Indonesia	43 b-e	1.06 c-e
Godalki	Bangladesh	13 gh	0.34 gh
Jaguarizinho	Brazil	13 gh	0.30 gh
Japones	Brazil	10 gh	0.24 gh
Pratao	Brazil	60 b	1.54 b
Agulha	Brazil	50 b-d	1.28 b-d
Agulha Branco	Brazil	43 b-e	1.06 c-e
Biera Ocampo	Brazil	0 h	0 h
Arroz de Leyte	Brazil	40 c-e	0.99 c-e
Poupa Prequica	Brazil	40 c-e	1.06 c-e
CNA-108-8-42-24-2B	Brazil	0 h	0 h
IRAT121	Ivory Coast	0 h	0 h
IRAT141	Ivory Coast	10 gh	0.23 gh
IRAT112	Ivory Coast	27 e-g	0.62 e-g

[a] Av of 4 replications. Ten neonate larvae were placed on 35-d-old potted plants having 10 tillers each.

[b] $\text{Percent survival} = \frac{\text{emerged adults (no.)}}{\text{larvae (no.) placed on plant}} \times 100$

[c] $\text{Growth index} = \frac{\text{survival (\%)}}{\text{mean developmental period (d)}}$ was recorded upon moth emergence.

Table 4. Population buildup of *Nephotettix virescens* colonies on rice cultivars.[a] IRRI, 1986.

Variety or line	GLH (no./cage)				
	Laguna	Bicol	Mindanao	Greenhouse	Central Luzon
IR64	23.6 ab	22.1 ab	61.1 a	0 b	0.7 b
IR60	0 a	3.6 a	3.5 a	0 a	0 a
IR42	331.4 a	220.7 b	96.6 a	215 b	166.3 c
IR36	251.4 a	169.9 b	72.6 b	138.5 b	177.9 b
IR19670-263-3-2-2-1	9.2 b	13.1 b	142.1 a	0.1 b	2.2 b
IR28224-3-2-3-2	0 a	1 a	1.3 a	0 a	0 a
IR22	310.3 b	358.8 ab	194.4 a	308 b	218 c

[a]Av of 10 replications, each with 5 pairs of adults caged on 3-wk-old plants for 30 d. Means in a row followed by the same letter are not significantly different at the 5% level by DMRT.

Table 5. Fecundity of *N. virescens* colonies on rice cultivars.[a] IRRI, 1986.

Variety or line	Eggs (no./female)				
	Laguna	Bicol	Mindanao	Greenhouse	Central Luzon
IR64	11.9 a	39.5 a	50.4 a	12.1 a	29.5 a
IR60	11.2 a	11.5 a	18.3 a	11.2 a	1.4 a
IR42	402.6 a	209.3 b	248.2 b	363.6 a	371.4 a
IR36	275.3 a	174.1 b	265.8 a	303.3 a	171.4 b
IR19670-263-3-2-2-1	75	41.6	136.7	24.9	–
IR28224-3-2-3-2	20.0 a	8.9 a	25.9 a	10.8 a	1.4 a
IR22	501.5 b	325.8 c	445.2 b	524.4 b	683.9 a

[a]Av of 10 replications, each with 5 pairs of adults caged on 3-wk-old plants. Means in a row followed by the same letter are not significantly different at the 5% level by DMRT.

ferences in the feeding behavior on IR64 of GLH individuals from different colonies. Unlike members of other colonies, GLH individuals from the Mindanao colony were able to feed from the phloem of IR64 plants. This indicates a shift in GLH biotype and may explain why IR64 became susceptible to RTV in Mindanao.

Reactions of rice cultivars to green leafhopper and rice tungro virus (*Entomology*). At present, IR varieties derive protection from RTV infection mainly through resistance to the vector. Under high disease pressure most IR varieties become infected. To check this, we evaluated under natural conditions the reactions of 36 rice varieties and breeding lines to RTV at the IRRI farm and in South Cotabato, where RTV is rampant. Infected hills were counted at 30, 60, and 90 d after transplanting (DT). Entries were scored as resistant (0-30% infection), moderately resistant (31-60% infection), or susceptible (61-100% infection). The same entries were tested in a greenhouse at 7 and 14 d after sowing against GLH reared on TN1 plants.

The results of the field test are in Table 6; those of the greenhouse test are in Table 7.

NATURE OF RESISTANCE

Entomology Department

Nature of leaffolder resistance. Various behavioral and physiological responses of LF *M. patnalis* were evaluated on selected resistant varieties. Settling response, food intake, growth index, and fecundity were sensitive parameters for assessing the antibiosis effect on LF (Table 8).

Plant age and ovipositional preference of leaffolders. Twenty newly emerged adults were caged and allowed 3 d to oviposit on 10-, 15-, 20-, 25-, and 30-d-old potted IR36 plants. *M. patnalis* laid significantly more eggs on 30-d-old plants than on younger plants (Table 9).

Table 6. Incidence of RTV in selected rice entries evaluated in South Cotabato, Philippines, and on the IRRI farm, 1986 DS.[a]

Variety or line	Infected hills (%)					
	30 DT		60 DT		90 DT	
	IRRI	South Cotabato	IRRI	South Cotabato	IRRI	South Cotabato
Group I: R at IRRI and in South Cotabato						
IR28222-9-2-2-2-2	4	12	16	18	18	21
IR28224-3-2-3-2	5	2	9	13	10	15
IR28228-12-3-1-1-2	2	10	5	12	6	25
IR28228-119-2-3-1-1	11	9	14	15	20	20
Ptb 8	9	12	20	16	24	18
TAPL 796	4	9	5	16	13	24
ARC11554	1	8	5	13	7	16
ARC10980	0	10	4	12	12	15
Pankhari 203	0	5	5	10	6	17
Palasithari 601	0	5	4	5	8	11
Utri Rajapari	0	12	6	18	6	23
Group II: R at IRRI, R to MR in South Cotabato at 60 and 90 DT						
ARC10342	5	26	10	43	18	48
IR29725-109-1-2-1	14	22	14	30	16	54
IR56	8	18	20	23	28	51
Tilakkachari	12	13	18	29	19	36
Utri Merah	2	18	2	24	2	36
IR62	28	26	28	57	28	69
IR33043-46-1-3	15	26	22	33	23	39
Basmati	5	22	13	53	16	61
Group III: R to MR at IRRI, S in South Cotabato						
IR64	16	92	16	100	23	61
ASD7	1	64	21	100	23	100
TNAU658	9	73	21	84	25	84
MRC603-303	14	87	28	100	41	100
Gam Pai 30-12-15	2	68	12	71	36	77
IR32429-47-3-2-2	15	40	15	75	32	89
IR28118-138-2 3	10	57	18	100	20	100
IR21015-174-3-3-3-3	8	53	10	100	12	100
IR32307-107-3-2-2	8	60	10	81	15	97
Ptb 18	2	54	14	80	16	87
IR19670-263-3-2-2-1	24	87	44	100	44	100
IR29	11	67	45	100	54	100
Group IV: MR at IRRI, R in South Cotabato						
IR32453-20-3-2-2	35	12	38	12	38	14
Group V: S at IRRI and in South Cotabato						
IR8	46	81	100	100	100	100
IR42	11	76	96	100	99	100
TN1	82	96	100	100	100	100
Group VI: tested at IRRI						
IR36	29		72		89	
IR30	26		55		68	
IR50	15		16		28	
IR52	26		32		38	
IR54	12		24		25	
Naria Bachi	10		18		30	

[a]R = resistant, MR = moderately resistant, S = susceptible (on a 0-9 scale of GLH damage). RTV score: resistant (0-30% infection), moderately resistant (31-60% infection), susceptible (61-100% infection).

Cross resistance of varieties to leaffolder species. Thirty-day-old plants of the test varieties were infested with 1st-instar larvae of *Cnaphalocrocis medinalis* and *M. patnalis*. Larval survival and pupal weights of these species did not differ significantly on any variety (Table 10). Percent larval survival was, however, a better parameter than pupal weight for comparing resistance levels.

Table 7. Plant damage rating and RTV infection of selected rice cultivars in the greenhouse.[a] IRRI, 1986.

Variety or line	Plant damage rating	RTV infection (%)
Group I: R to MR to GLH and RTV		
Pankhari 203	3	0
IR33043-46-1-2	3	20
IR32453-20-3-2-2	3	20
IR29725-109-1-2-1	3	30
IR32429-47-3-2-2	3	30
IR32307-107-3-2-2	3	30
Tilakkachari	3	40
TNAU658	3	50
Gam Pai 30-12-15	3	60
IR21015-176-3-3-3-3	3	60
MRC603-3-3	5	60
IR29	5	40
Group II: R to MR to GLH and S to RTV		
ASD7	1	90
Ptb 18	1	70
IR28224-3-2-3-2	1	70
IR28222-9-2-2-2-2	3	100
IR28228-119-2-3-1-1	3	70
IR28118-138-2-3	3	70
IR19670-263-3-2-2-1	3	90
Palasithari 601	3	90
IR56	3	100
IR62	3	100
IR64	3	80
IR50	3	70
IR54	3	70
Ptb 8	5	90
TAPL 796	5	80
IR8	5	90
IR36	5	100
IR30	5	90
IR52	5	90
Group III: S to GLH and R to MR to RTV		
ARC11554	7	10
Utri Merah	7	0
Utri Rajapan	9	0
Naria Bachi	9	30
ARC10342	7	50
Basmati	7	60
Group IV: S to GLH and RTV		
ARC10980	7	70
IR42	7	80
TN1	9	100

[a]R = resistant, MR = moderately resistant, S = susceptible. Seven-day-old seedlings were infested with viruliferous *N. virescens* nymphs and rated for RTV and GLH damage at 7 d after infestation.

Plant age and susceptibility of variety Nira to thrips. Potted 20-, 30-, 40-, and 50-d-old plants of Nira were exposed to natural thrips infestation. Thrips infested all plants equally. Older plants with greater leaf area were appropriate for maintaining a high thrips density for insect culture.

Green leafhopper feeding behavior on resistant and susceptible varieties. Phloem feeding by GLH on rice plants is known to be conducive to increased RTV incidence. We therefore compared GLH feeding on 15- to 30-d-old plants of selected resistant (ASD7, IR60, and IR64) and susceptible (TN1) varieties, using an electronic recorder. There were 10 replications, each consisting of a fresh plant and a new GLH female reared on TN1 plants in the greenhouse.

Unlike that on susceptible TN1 plants, phloem feeding was negligible and xylem feeding was more on resistant plants (Fig. 2). The insects were restless on resistant varieties and spent less feeding time on IR64 than on ASD7 or IR60.

Virulence of field-collected brown planthopper. BPH samples collected from the Bicol region (Luzon), and Misamis Occidental (Mindanao), Philippines, were compared with a BPH biotype 2 culture in the greenhouse. Ten-day-old seedlings grown in seedboxes were infested with three 2d- to 3d-instar nymphs per seedling. Damage was scored when TN1 seedlings were killed at 26-29 d after infestation (Fig. 3). The Bicol BPH and BPH biotype 2 killed only IR26 with the *Bph 1* gene for resistance. When scoring was delayed, the Bicol BPH tended to kill IR42 with the *Bph 2* gene for resistance. The Mindanao BPH killed IR26 and IR42. None of the colonies damaged IR62 with the *Bph 3* gene for resistance.

Hatchability of brown planthopper, white-backed planthopper, and green leafhopper eggs on selected varieties. Gravid BPH, WBPH, and GLH females reared on TN1 plants were caged overnight on 30-d-old test plants. Emerging nymphs were removed and counted daily. After 15 d, unhatched eggs were counted by dissecting the plants under

Table 8. Response of *M. patnalis* on selected resistant rice varieties. IRRI, 1986.

Variety	Acc. no.	Response[a]						
		Food intake	Settling response 48 h after release	Fecundity	Egg hatchability	Larval survival	Growth index	Development period
Vashaipoo samba	------	0.6	0.5	0.6	0.9	0.7	0.6	1.0
Choorapundy	49529	0.5	0.6	0.5	0.9	0.7	0.5	1.0
GEB24	5909	0.6	0.5	0.6	0.9	0.7	0.5	1.0
Ptb 33	19375	0.5	0.5	0.6	0.9	0.7	0.5	1.0
Darukasail	45493	0.9	0.6	0.6	1.0	0.7	0.6	1.0
Kamalbhog	46020	0.7	0.6	0.6	0.8	0.6	0.5	1.0
Karpur kanti	46078	0.6	0.6	0.5	0.9	0.6	0.5	1.0
W1263	11057	0.7	0.4	< 4	0.9	0.6	0.5	1.0
Muthumanikan	15327	0.7	0.6	0.7	0.9	0.7	0.6	1.0
ASD7	6303	0.9	0.7	0.6	0.8	0.7	0.6	1.0
TKM6	237	0.5	0.5	0.5	0.9	0.7	0.6	0.9
IR36 (susceptible check)	30416	1.0	1.0	1.0	1.0	1.0	1.0	1.0

[a]Calculated as the ratio between the LF responses to a test plant and to the susceptible check IR36. The lower the number, the greater the resistance of the variety compared with IR36.

Table 9. *M. patnalis* eggs on IR36 at different plant ages.[a] IRRI, 1986.

Age of plant (d)	Eggs/plant (no.)
10	38 a
15	52 a
20	96 b
25	138 c
30	213 d

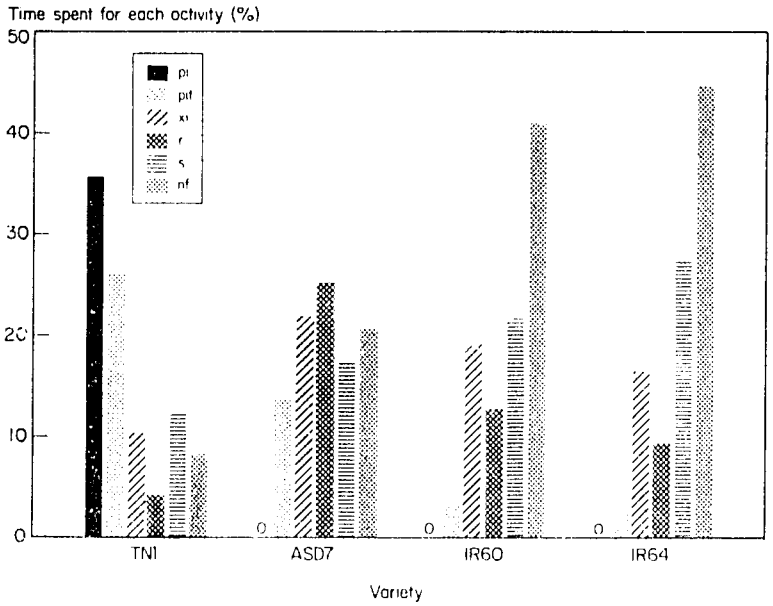
[a]Av of 5 replications, each consisting of 20 newly emerged moths.

a binocular microscope. Hatchability of the insects' eggs on their respective test varieties was not significantly different from that on TN1 (Tables 11-13). Hatchability was significantly lower on Ptb 21 and Rathu Heenati when BPH females were reared on 10-d-old test plants and then allowed to oviposit on 30-d-old TN1 plants (Table 14). Hatchability was not affected when a single BPH male was enclosed for 10 d on TN1 plants with 1, 3, 6, or 9 newly emerged females.

Table 10. LF survival and pupal weight.[a] IRRI, 1986.

Variety	Acc. no.	Survival (%)		Weight (mg)	
		C. medinalis	*M. patnalis*	*C. medinalis*	*M. patnalis*
Gora	49086	33	30	16	14
Choorapundy	49529	20	37	15	18
Ptb 33	19325	40	57	16	18
Darukasail	45493	30	47	15	17
Kamalbhog	46020	43	47	18	16
W1263	11057	20	53	16	13
Muthumanikan	15327	27	50	15	13
ASD7	6303	37	40	18	16
GEB24	5909	33	60	18	16
TKM6	237	33	40	12	9
IR36 (susceptible check)	30416	83	83	21	18

[a]*Cnaphalocrocis medinalis* and *M. patnalis* were not statistically different from each other; however, responses of varieties on larval survival are significantly different at the 5% level by DMRT.

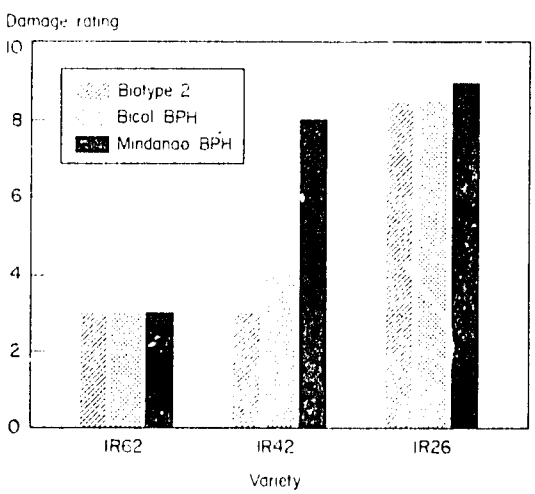


2. Feeding behavior of *Nephotettix virescens* on susceptible TN1 and resistant varieties ASD7, IR60, and IR64. IRRI, 1986. nf = not feeding, pi = phloem ingestion, pit = phloem ingestion trials, r = resting, s = salivation, xi = xylem ingestion.

CHEMICAL BASES OF RESISTANCE

Entomology Department

Brown planthopper biotype 1 biocidal factors. Dosage-mortality curves from bioassays of silica gel column fractions of IR8 (susceptible) and IR26 (resistant) showed that the most active fractions had relatively low relative mobility (R_f) values on thin layer chromatography on silica gel using 80:20:1 (by volume) hexane-diethyl ether-acetic acid. R_f was 0.15 for IR8 and 0.11 for IR26. Similar results were obtained with BPH biotype 2, although the dosages for 50% mortality were higher than for biotype 1. Chemical characterization of these fractions by scientists at the USDA



3. Damage caused by BPH biotype 2 and field-collected BPH colonies. IRRI, 1986.

Table 11. Hatchability of BPH biotype 2 eggs on selected varieties. IRRI, 1986.

Variety	Resistance genes	Eggs (no.)	Hatched (%)
Ptb 33	Digenic	1570 ab	94 a
Ptb 21	Digenic	1444 ab	94 a
Sinna Sivappu	Digenic	966 b	96 a
Babawee	*bph 4*	1467 ab	95 a
Ratnu Heenati	*Bph 3*	1095 b	94 a
IR60	*Bph 3*	1495 ab	98 a
IR62	*Bph 3*	1436 ab	96 a
IR64	*Bph 1*	1503 ab	96 a
Triveni	Minor genes	1775 a	97 a
TN1 (check)	None	1863 a	98 a

Table 12. Hatchability of WBPH eggs on selected varieties. IRRI, 1986.

Variety	Resistance genes	Eggs (no.)	Hatched (%)
ADR	*Wbph 3*	111 ab	97 a
ARC10239	*Wbph 2*	82 ab	93 a
Colombo	*Wbph 2* + 1 recessive (?)	139 a	90 a
IR2035-117-3	*Wbph 1* + *Wbph 2*	103 ab	90 a
Muskhan 41	*Wbph 1*	153 a	92 a
N22	*Wbph 1*	139 a	93 a
Cheriya chittari	*Wbph 2*	127 a	93 a
Podiwi A8	*wbph 4*	152 a	89 a
WC1240	*Wbph 1* + 1 recessive (?)	111 ab	94 a
TN1	None	155 a	97 a
Echinochloa sp.	–	49 b	49 b
Monochoria vaginalis	–	85 ab	82 a

Table 13. Hatchability of GLH eggs on selected varieties. IRRI, 1986.

Variety	Resistance genes	Eggs (no.)	Hatched (%)
Pankhari 203	*Glh 1*	53 b-d	99 a
ASD7	*Glh 2*	60 a-d	73 a
Godalki	*Glh 2*	52 b-d	88 a
Palasithari 601	*Glh 2*	120 ab	99 a
IR8	*Glh 3*	122 ab	99 a
Ptb 8	*glh 4*	85 a-c	99 a
ASD8	*Glh 5*	130 a	98 a
TAPL 796	*Glh 6*	35 cd	97 a
Moddai Karuppan	*Glh 7*	123 ab	87 a
TN1	None	131 a	99 a
Echinochloa sp.	–	0 d	–
M. vaginalis	–	10 cd	21 b

Table 14. Hatchability of Mindanao BPH eggs on TN1. IRRI, 1986.

Variety	Resistance genes	Eggs (no.)	Hatched (%)
Ptb 33	Digenic	948 cd	94 ab
Ptb 21	Digenic	647 d	83 b
Sinna Sivappu	Digenic	682 d	97 a
Babawee	*bph 4*	1290 c	97 a
Rathu Heenati	*Bph 3*	967 cd	84 b
IR60	*Bph 3*	823 cd	86 ab
IR62	*Bph 3*	540 d	90 ab
IR64	*Bph 1*	1935 b	91 ab
Triveni	Minor genes	1967 b	92 ab
TN1 (check)	None	2783 a	96 ab

Western Regional Research Center showed tha the main component was palmitic acid. The activ components are still being characterized.

Compound A from TKM6. The identification o "compound A" from SB-resistant rice variet TKM6 is reported now because of earlier paten restrictions. In a cooperative study with scientist at the Tropical Development Research Institute, United Kingdom, ether extracts of steam distillates of TKM6 rice plants were analyzed by gas chromatography with a simultaneous recording of electroantennogram response from a female striped SB. Only one major electroantennogram response peak was obtained, corresponding to a mean concentration of 100 μg/200 g rice leaves. The active fraction, purified by column chromatography on florisil and then silica gel with 20% $AgNO_3$, was identified as pentadecanal or 1-pentadecanal using chromatography-mass spectrometry and by comparison with the synthetic compound.

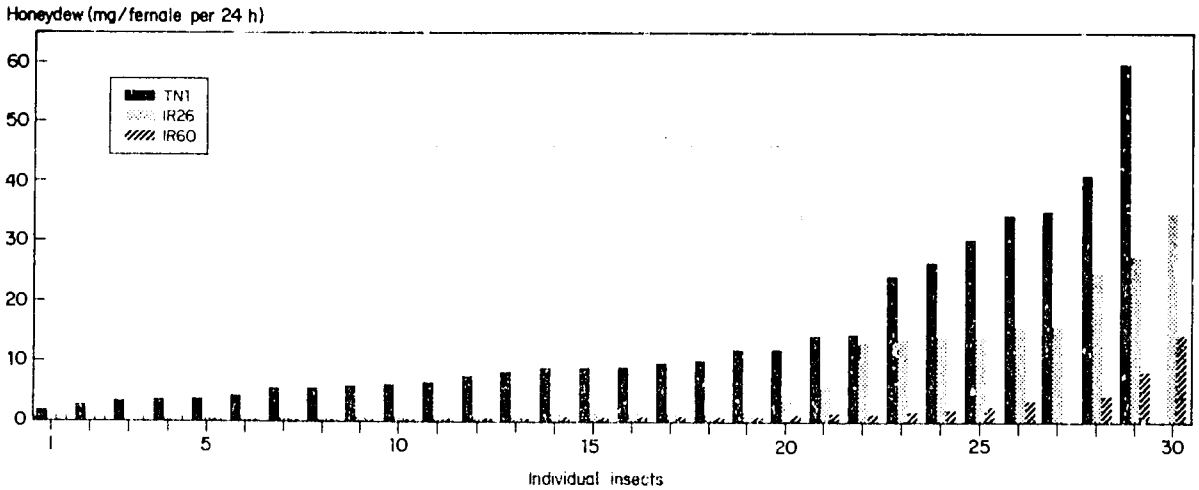
INSECT BIOTYPES

Entomology Department

Characterizing brown planthopper populations. To analyze shifts in BPH populations, we collected BPH from several sites in the Philippines. Using honeydew excretion measurements, we found that field populations had a highly variable response on different rice varieties. Also, within field populations, some individuals could feed quite well on varieties that are still considered to be resistant to BPH (Fig. 4).

Adult survival and fecundity in field populations were also highly variable among individuals and on different varieties. The highest mortality occurred on IR60 and the least on TN1. The BPH population survived well on IR26, which was once widely planted in the Philippines (Fig. 5), indicating that adaptation to genes for resistance used earlier is maintained in populations. Thus, gene rotation may not be very effective for BPH management.

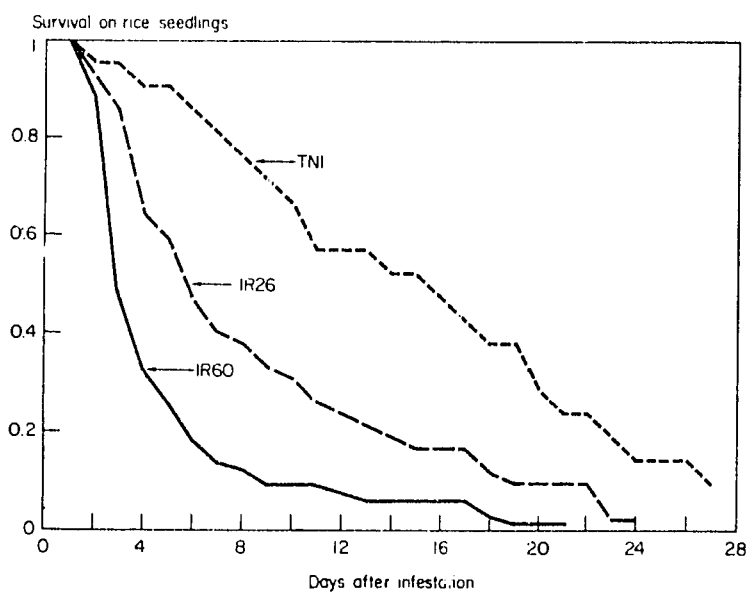
The survival and fecundity studies suggested how a local population becomes adapted to a newly introduced variety. Figure 5 shows that a small proportion of the population survived for several days on IR60 and contributed about 80% of the eggs to the next generation. With



4. Honeydew excreted on rice seedlings by brachypterous females of *Nilaparvata lugens* collected from the Bicol region, Philippines, 1986.

continued selection for long-surviving individuals, the population may eventually become permeated with virulent individuals. At that point, IR60 may become susceptible to the BPH field population. Such a population adapted to IR60 was selected in the greenhouse. Field populations of BPH therefore need to be monitored regularly.

Responses of rice- and grass-infesting brown planthopper biotypes. Recently, a population of *Nilaparvata lugens* was found thriving on *Leersia hexandra* Swartz, a weed grass common in rice-fields. We studied orientational and settling responses, feeding behavior, metabolism of ingested food, growth, adult survival, egg production, ovi-



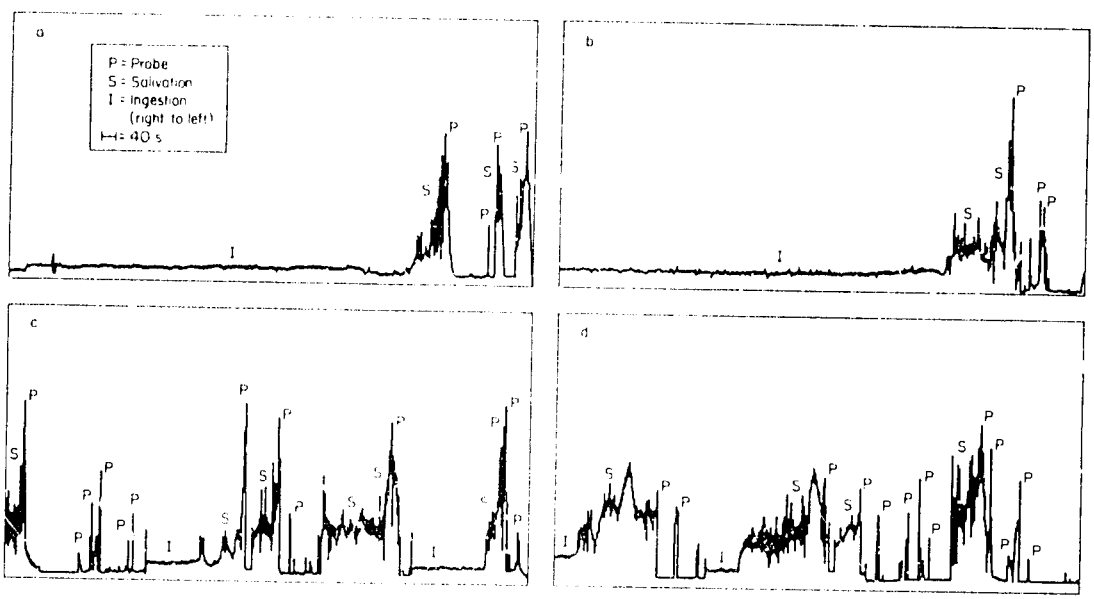
5. Survival of brachypterous females of *N. lugens* collected from Bicol, Philippines, 1986. IR60 is currently the dominant variety in the Bicol region.

position, and hatchability of eggs of the two *N. lugens* populations on TN1 rice plants and on *L. hexandra* grass. TN1 plants were most suited for the establishment of the rice-infesting population, as demonstrated by their feeding responses (Fig. 6). Individuals derived from one host did not thrive on the other host because of a significant reduction in feeding, assimilation of food, growth, longevity, and fecundity (Table 15).

Protein patterns of brown planthopper biotypes. Soluble proteins of newly emerged adults of rice-infesting BPH biotypes 1, 2, and 3 and the grass-infesting biotype were studied by polyacrylamide gel electrophoresis. Proteins were detected by staining with a 1% commasie blue: 12.5% trichloroacetic acid mixture (1:25 vol/vol). A general zymogram of each biotype was prepared by superimposing the bands found in replicates. The intensity of bands was noted.

Thirty bands were detected for the four biotypes. Biotypes 1, 2, and 3 had 24, 22, and 21 bands, respectively; the grass-infesting biotype had 21 bands (Fig. 7).

Similarity index values (Table 16) were com-



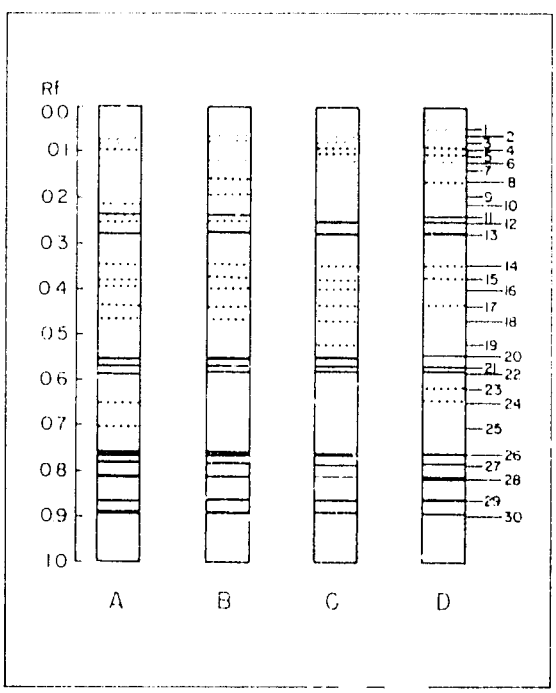
6. Electronically recorded waveforms during BPH feeding by a) rice-infesting females on TN1 plants, b) grass-infesting females on *L. hexandra* plants, c) rice-infesting females on *L. hexandra* plants, and d) grass-infesting females on TN1 rice plants. IRRI, 1986.

Table 15. Growth, longevity, and fecundity of rice- and grass-infesting *Nilaparvata lugens* adults on TN1 rice and *Leersia hexandra* grass plants. IRRI, 1986.

Plant	Becoming nymphs (%)	Longevity (d)		Fecundity (no. of eggs laid per female)
		Male	Female	
		Rice-infesting N. lugens		
TN1	97 ± 4.8	21.6 ± 1.6 a	24.9 ± 1.5 a	514 ± 133 a
L. hexandra	0.0	2.9 ± 0.5 b	2.6 ± 0.2 b	0 b
		Grass-infesting N. lugens		
TN1	0.0	2.0 ± 0.4 c	2.1 ± 0.3 c	0 b
L. hexandra	95 ± 7.1	18.3 ± 1.7 a	22.5 ± 1.9 a	356 ± 75 a

puted by dividing the number of similar bands by the sum of similar and dissimilar bands. The highest similarity was seen in proteins between biotypes 2 and 3, and the lowest between biotype 3 and the grass-infesting biotype.

Epicuticular wax of brown planthopper biotypes The epicuticular wax of BPH adults was examined to differentiate individuals of BPH biotypes reared on their respective hosts for 7 d. Hexane extracts after overnight soaking of either 200 males or 100 females of BPH biotypes 1, 2, and 3 and the biotype infesting *L. hexandra* were concentrated and injected into a column of 4% OV101 on Chromosorb W-HP 100-120 mesh. Biotypes could not be differentiated by variation in the elution time and height of chromatographic peaks.



7. Diagrammatic representation of soluble proteins in the different biotypes of BPH *N. lugens* (Stål). A = biotype 1, B = biotype 2, C = biotype 3, D = grass-infesting biotype. R_f = relative mobility.

Genetic polymorphism in green leafhopper. Genetic polymorphism in *N. virescens* was studied using horizontal starch gel electrophoresis. Out of 18 enzyme loci investigated, 14 were polymorphic. Other enzyme loci are being examined to estimate the extent of genetic differentiation within the species.

Soluble proteins of three green leafhopper species. Polyacrylamide gel disc electrophoresis showed 45 protein bands among *N. virescens*, *N. malayanus*, and *N. nigropictus* species (Fig. 8). *N. malayanus* and *N. virescens* each possessed 36 bands, and *N. nigropictus* had 28. Six bands (#19, 22, 31, 37, 38, and 39) were specific to *N. malayanus*, one to *N. nigropictus* (#17), and four to *N. virescens* (#12, 33, 34, and 35).

Similarity index values were computed (Table 17). The highest similarity was observed for proteins between *N. malayanus* and *N. virescens*, and the lowest that between *N. malayanus* and *N. nigropictus*.

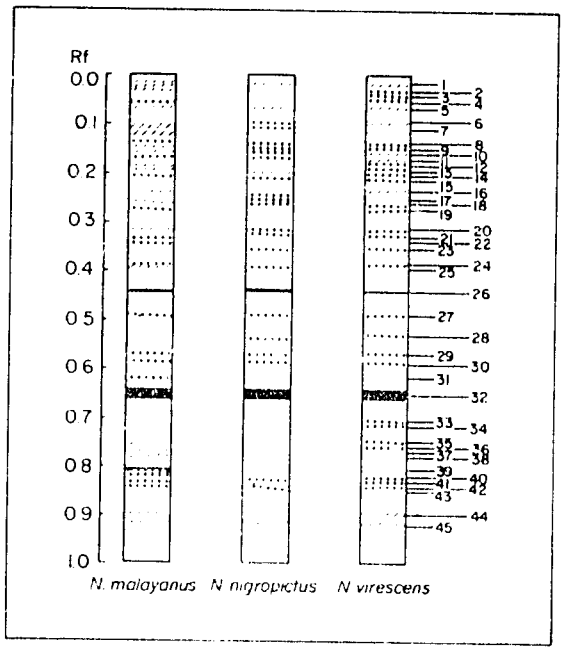
CYTOLOGY OF RICE INSECT PESTS

Entomology Department

Brown planthopper brain cells and chromosomes. Using the lacto-aceto-orcein staining technique, we observed mitotic brain cells of 4th-instar BPH nymphs (Fig. 9). Premetaphase chromosome counts established the normal diploid complement

Table 16. Similarity index of the soluble proteins among 4 biotypes of *N. lugens*. IRRI, 1986.

	Similarity index			
	Biotype 1	Biotype 2	Biotype 3	Grass-infesting biotype
Biotype 1	–	0.72	0.75	0.64
Biotype 2		–	0.78	0.67
Biotype 3			–	0.58
Grass-infesting biotype				–



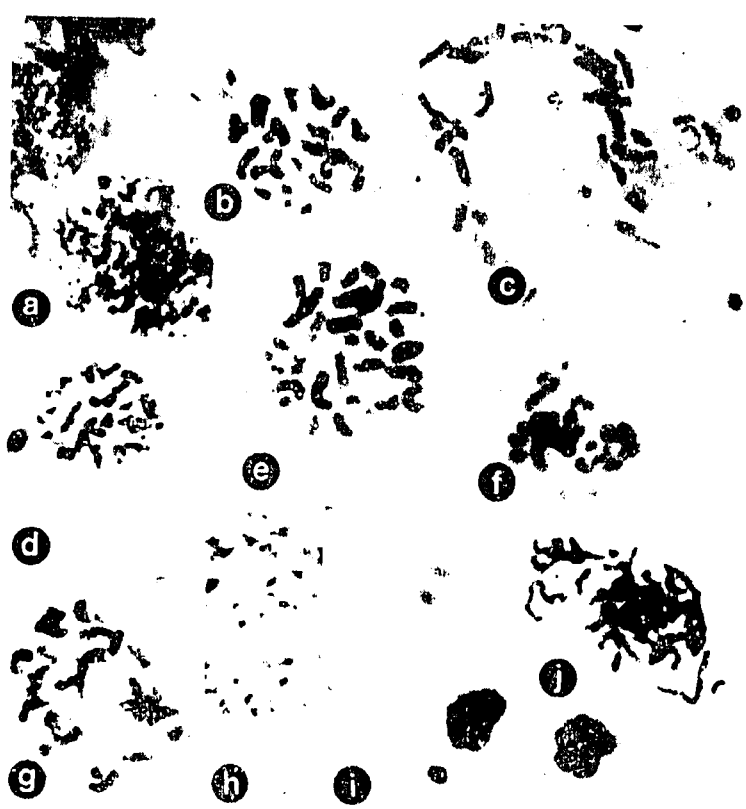
8. Diagrammatic representation of soluble proteins in GLH *Nephotettix* sp. IRRI, 1986.

Table 17. Similarity index of the soluble proteins among the 3 GLH *Nephotettix* spp. IRRI, 1986.

	Similarity index		
	N. malayanus	*N. nigropictus*	*N. virescens*
N. malayanus		0.5610	0.6591
N. nigropictus			0.6579
N. virescens			

at 2n = 30 (28 autosomes and an XX [female] or XY [male] sex chromosome system). The X and Y chromosomes had different shapes, the X-chromosome always being bigger than the Y-chromosome.

Early metakinetic chromosomes (Fig. 9b, c, e, f, g, and j) were short and rod-shaped; each chromosome had two chromatids. At metaphase, the holokinetic chromosomes occupied the spindle body. During anaphase and telophase, the chromatids segregated to opposite poles (Fig. 9i). Total chromatin was 11.9 μ in females and 5.74 μ in



9. Brain cells and chromosomes of *N. lugens* biotype 1. IRRI, 1986. Magnification 1000× (oil immersion)

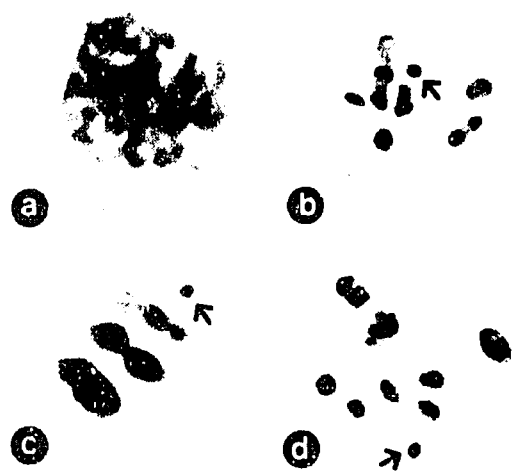
males. Females possessed longer chromosomes (Fig. 9c) than males (Fig. 9b and e). Later cytokinesis formed two daughter nuclei. During the regular mitotic cycle in BPH biotype 1, prophase was the longest stage, followed by telophase and metaphase; anaphase was the shortest. Some brain cells showed an increase (agmatoploidy) or decrease (hypoploidy) in chromosome number (Fig. 9f).

Chromosomes of *Nephotettix malayanus*. Study of spermatogenesis showed that *N. malayanus* has the normal diploid complement 2n = 13 (6HA + XO) (Fig. 10). During diakinesis, spermatocytes possessed six synapsed homologs plus a darkly stained univalent X-body, which was usually isolated from the bivalent autosomes (Fig. 10a). During metaphase I (Fig. 10d), the X-body fused with the autosomes at the equatorial plate. Spontaneous chromosomal aberrations were observed in about 15% of the spermatocytes during diakinesis (Fig. 10c).

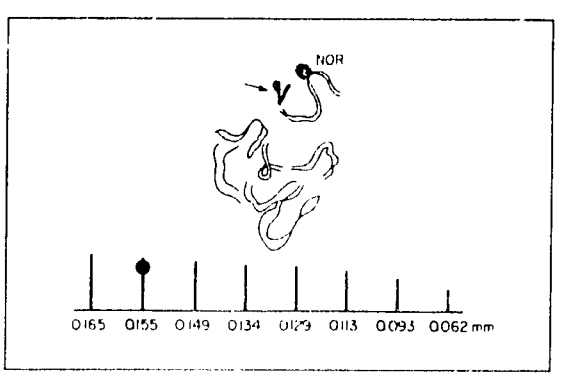
Chromosomes of *Nephotettix nigropictus*. Examination of primary spermatocytes at diakinesis showed that *N. nigropictus* has a genomic complement of seven bivalent autosomes and a univalent X-chromosome (Fig. 11). The diploid chromosome number is therefore 2n = 15 (7HA × XO). Pachytene analysis showed that the whole genome of males consists of eight linkage groups (Fig. 12). At diakinesis, 24% of the cells contained a reduced number of bivalents, and 5% possessed an increased number of chromosomes (Fig. 11d.)

Chromosomes of *Leptocorisa oratorius*. Examination of primary spermatocytes at dia-

10. Chromosomes of male *N. malayanus* at a) leptonema-pachynema, b) and c) diakinesis, d) metaphase I, and e) early anaphase I. IRRI, 1985-86. A normal cell (c) has 2n=13 (6HA + X). Spontaneous aberration may result in an agmatoploid cell (b) with 2n=19 (9HA + X). The arrow indicates the sex chromosome. Magnification 1500 × (oil immersion)



11. Chromosomes of male *N. nigropictus* at a) leptonema, b) diakinesis showing 2n=15 (7HA + X), and c) metaphase I. Spontaneous aberration may result in d) an agmatoploid cell with 2n=19 (9HA + X). IRRI, 1985-86. The arrow indicates the sex chromosome. Magnification 1500× (oil immersion)



12. Camera lucida drawing of pachytene chromosomes of *N. nigropictus* and their idiogram. IRRI, 1985-86. The arrow indicates the sex chromosome. NOR = nucleolar organizing region. Magnification 1250× (oil immersion)

kinesis showed that the rice bug possesses 7 bivalent autosomes plus a univalent X-body, the genomic complement being 2n = 15 (7IIA + XO). In addition to the standard genomic chromosomes, a short, open, ring-like fragment was consistently observed near the nuclear periphery. Based on its heterochromaticity and size, it was considered as a supernumerary (S) chromosome. It is nonhomologous and does not pair with standard chromosomes.

Chromosomes of *Sitophilus oryzae* and *S. zeamais*. An examination of primary spermatocytes at diakinesis showed that the rice weevil *S. oryzae* possesses 19 chromosomes — 2n = 19 (9IIA × XO) — while the maize weevil possesses 21 chromosomes — 2n = 21 (10IIA + XO).

Genetic evaluation and utilization (GEU) program

Drought tolerance

International Rice Testing Program, Agronomy Department, and Upland Rice Breeding Program

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VARIETAL SCREENING AND FIELD EVALUATION

International Rice Testing Program, Agronomy Department, and Upland Rice Breeding Program

Drought tolerance in 1985 IRTP nurseries (*International Rice Testing Program*). Entries listed in Table 1 were identified as being drought tolerant in the 1985 International Rice Testing Program (IRTP) nurseries. Detailed results appear in the annual IRTP nursery reports.

Field drought screening, 1986 dry season (*Agronomy*). In the 1986 dry season (DS), 6,224 rices from the International Rice Germplasm Center, IRTP, and the Germplasm Evaluation and Utilization (GEU) program were screened for drought tolerance and recovery ability in the field. Drought reaction was scored 5 times at 4- to 6-d intervals, once at 2 bars soil moisture tension (SMT) at 15-cm soil depth, and twice each at 5 and 10 bars SMT.

Twenty-one varieties and lines exhibited less than 50% leaf desiccation at 10 bars SMT and at least 80% stand recovery upon availability of soil moisture (Table 2). They were better than the Philippine drought-tolerant check variety Salumpikit, which had similar 80% stand recovery but 60% leaf desiccation. At 2 bars SMT, 9 of the 21 rices showed no symptoms of soil moisture deficit, and 12 others had slight leaf tip drying like Salumpikit. Nineteen rices, including those that did not exhibit effects of soil moisture deficit at 2 bars, were better than Salumpikit at 5 bars SMT.

Thai deepwater rices DWCT114-1-0-1-1-1-0-1 and SPR7295-53-2-1-2, Moroberekan progeny IR47686C-6-2-B, and RD19 progeny IR42569-579-2-1 had 90% stand recovery upon reirrigation.

Of the 21 outstanding rices, 11 were IRRI breeding lines, 5 of which were selections from cross IR47686, a descendant of drought-tolerant Guinea variety Moroberekan. Moroberekan is also the progenitor of the outstanding entry IRAT140 from the Ivory Coast. Moroberekan, 2 lines from descendant IR47691, and 1 line from IR47686 had less than 50% leaf desiccation at 10 bars but 60% stand recovery.

The rest of the outstanding selections were six germplasm bank (GB) accessions and four IRTP materials, three of which were deepwater rices.

For five seasons including 1986 DS, IR5178-1-1-4 showed consistent tolerance for severe soil moisture deficit and very good stand recovery upon availability of soil moisture.

Field screening for drought resistance (*Upland Rice Breeding*). We continued to screen the germplasm collection as well as breeding lines from

Table 1. Drought-tolerant entries in 1985 International Rice Testing Program nurseries, 1986.

Rainfed lowland, drought tolerant	Upland		Deep water, drought tolerant
	Drought tolerant	Good recovery	
BH2	B3622f-Tb-14-4	B2997c-Tb-60-3-3	BKN6986-1
BKN6721-5-7-4	BR160-2B-4-8-HR16	B3622f-Tb-14-4	BKNFR76024-100-1-5-1
BRB11-448-1-4	Farox 298	B3913B16-20ST-28	BKNFR76026-3-2-2-3
BRB32-75-4	Farox 302	B922c-Mr-118	BKNFR76035-112-1
BRB34-74-3	INIAP415	C4-1-5	BKNFR876045-85
GEU77042-0-4K-28	IRAT111	INIAP415	BKNFR76055-166-4-1
IR13259-153-5E-P2-3	IRAT140	IRAT138	DWCT114-1-0-1-1-1-0-1
IR13358-16-3-2	IRAT170	IR12979-24-3-4	DWCT156-1-2-0-1
IR21586-R-31-1	ITA186	IR3646-9-3-1	HTA7403-110-1-1-3-0
IR26716-12-2-1-3	M55	IR43	IR11185-R-0-7
IR26724-246-1-1	TOX475-NIB1-NK1-LS3-B1	Kabra (62-68)	Jalamagna
IR4422-480-2-3-3-IE-P1	TOX906-67-1-1	MRC172-S	RD19
MRC4B37-3144		NDR97	
RTN90-4		P1288-1-4M-2-18	
TCA178		Rohini	
TCA180-4		SI-2	
		UPLRi-5	

Table 2. Drought tolerance and recovery scores of outstanding selections in field drought screening.[a] IRRI, 1986 DS.

Variety or line	Drought-tolerant progenitor	Drought scores[b]					Recovery score[c]
		2 bars SMT	5 bars SMT		10 bars SMT		
			1st	2d	1st	2d	
IR5178-1-1-4	Leb Mue Nahng III	1	2	3	4	4	3
IR21085-38-1-3-3-1	Leb Mue Nahng III and Nam Sagui 19	0	0	3	4	4	3
IR33355-39-1-1-3	Nam Sagui 19	1	2	3	4	4	3
IR42221-2-2-3-1	Nam Sagui 19	0	1	3	4	4	3
IR42569-579-2-1	RD19	1	2	4	4	4	1
IR43582-176-3-2-2	Nam Sagui 19	1	2	3	4	4	3
IR47686C-5-12-B	Moroberekan	0	2	2	4	4	3
IR47686C-6-2-B	Moroberekan	1	1	2	4	4	1
IR47686C-6-10-B	Moroberekan	1	1	3	4	4	3
IR47686C-9-8-B	Moroberekan	0	1	2	4	4	3
IR47686C-13-2-B	Moroberekan	0	1	2	4	4	3
IRAT140	Moroberekan	0	1	1	3	3	3
DWCT114-1-0-1-1-1-0-1		0	1	3	4	4	1
Bavalabou (Acc 66225)		1	2	4	4	4	3
Habiganj Aman II		1	1	2	3	4	3
Muthumanikum (Acc 66253)		1	2	3	4	4	3
Pawm (Acc 64580)		1	2	3	4	4	3
SPR7295-53-2-1-2		1	1	2	4	4	1
13A (Acc 14833)		1	2	3	4	4	3
24A (Acc 14843)		0	1	2	4	4	3
270 (Acc 14914)		0	1	1	4	4	3
Salumpikit (tolerant check)		1	2	4	5	6	3
IR442-2-58 (tolerant check)		2	4	6	7	7	3
IRAT9 (susceptible check)		4	6	8	8	9	7
IR20 (susceptible check)		3	4	7	8	8	5

[a]SMT = soil moisture tension. [b]0 to 9 scale, where 0 = no symptoms, 5 = half the leaves fully dried, 9 = all plants apparently dead. [c]1 = at least 90% stand recovery, 5 = 40-69% stand recovery, 9 = 0-19% stand recovery.

various nurseries for field resistance to drought with the aim of identifying diverse resources that have higher levels of drought resistance, especially in the reproductive phase, and thus broadening the genetic base.

A total of 6,260 entries consisting of GB accessions, *O. glaberrima* strains, and breeding lines from both the upland and rainfed lowland nurseries were screened (Table 3). The field drought reactions of 4,043 GB accessions varied greatly. However, only 5% of the total population screened showed a high level of drought resistance in the vegetative phase, and very few accessions showed a high level of drought resistance in the reproductive phase. Eight generally early-maturing varieties from Taiwan, China, Ecuador, and Bangladesh showed drought scores of 3-4 (Table 4).

Four hundred fifty-nine *O. glaberrima* strains were scored in the vegetative phase and 328 in the reproductive phase. Only 3% showed a score of 2-3 in the vegetative phase, but 4.6% were found to have a similar level of resistance in the reproductive phase.

Among the upland breeding nurseries, about 18% of the entries showed an intermediate reaction (score = 5) to drought, and 2% had scores of 3-4. Breeding lines from the upland yield trial were highly sensitive to severe water stress in the reproductive phase. Other lines from the upland observational nurseries did not head by the cut-off date of 135 d after sowing (DAS).

From the rainfed lowland nurseries, 9% showed an intermediate reaction to drought in the vegetative phase. None of the lines in these nurseries headed by 135 DAS.

Table 3. Field screening for drought resistance under upland conditions. IRRI, 1986 DS.

Group	Entries (no.)	Plants (no.) showing a given drought score[a]								
		1	2	3	4	5	6	7	8	9
						Vegetative phase				
Germplasm bank (GB) accessions	4043	3	0	90	112	1083	1171	1395	0	189
Advanced upland breeding lines	390	0	0	4	4	122	180	80	0	0
Upland pedigree lines	274	0	0	3	3	87	142	39	0	0
F_7 breeding lines previously selected for deep and thick roots	101	0	0	1	4	25	43	28	0	0
Upland composites	316	0	0	0	1	11	148	148	0	8
Rainfed lowland breeding nurseries										
Observational yield trial	408	0	0	0	0	49	156	182	0	21
Drought-prone area observational trial	223	0	0	0	1	15	91	106	0	10
Drought-prone area yield trial	56	0	0	0	0	1	25	28	0	2
Oryza glaberrima strains	459	0	0	2	13	194	207	42	0	1
						Reproductive phase				
GB accessions	2046	0	0	7	1	51	9	476	2	1500
Advanced upland breeding lines	41	0	0	0	0	0	0	6	0	35
O. glaberrima strains	328	1	0	14	0	59	0	205	0	49

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

Table 4. Outstanding GB accessions having field drought resistance in the reproductive phase and some of their basic agronomic traits. IRRI, 1986 DS.

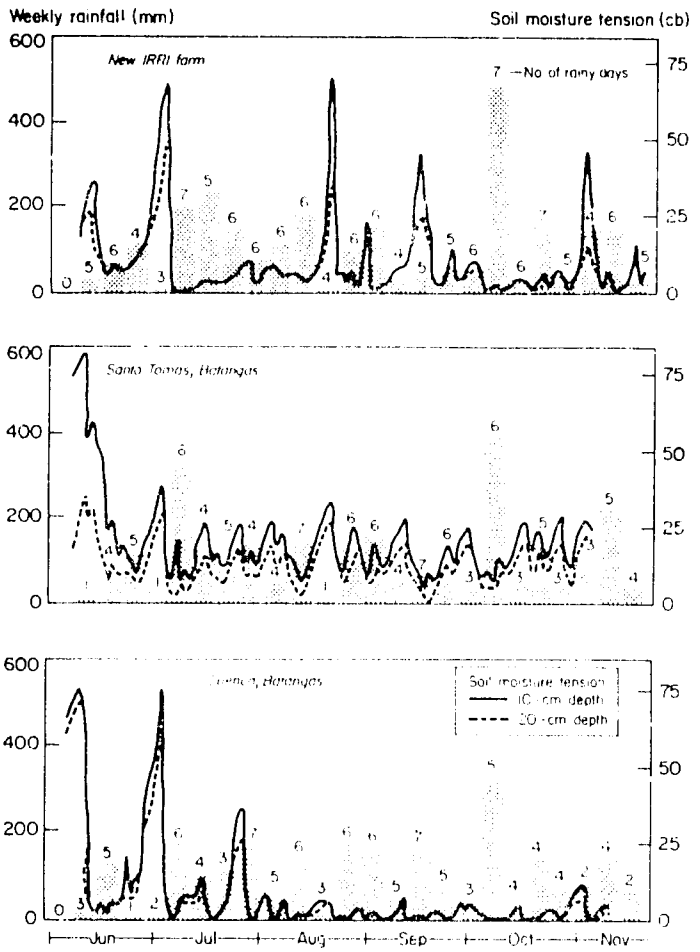
Acc. no.	Variety	Origin	Maturity[a] (d)	Plant height[a] (cm)	Panicle length[a] (cm)	Drought score	
						Vegetative phase	Reproductive phase
1270	Ai Kwoh 4	China	104	93	22	3	4
1441	Tsi Ta Hei/Tuoh Ying Shuei	China	105	94	23	3	3
3393	PI 190192	Ecuador	110	113	32	3	3
3396	Dharial	Bangladesh	108	113	22	3	3
3397	Hashikalmi	Bangladesh	106	81	21	5	3
4790	Ban-Oh	China	110	99	24	3	3
5591	Paiauru	Taiwan, China	115	109	29	3	3
5592	Nutsuriwai	Taiwan, China	101	105	25	3	3

[a]GB basic data.

Although we have identified parental sources for reproductive stage drought resistance from the GB accessions in the present experiment, a search for more resistant sources and further refinements in methodology are needed.

Upland rice yield trial, 1986 wet season (*Agronomy*). The 1986 wet season (WS) upland rice yield trials were conducted at IRRI; in farmers' fields in Cuenca and Santo Tomas, Batangas; and in Philippine Bureau of Plant Industry experiment stations in Ilagan, Isabela, and in La Granja, Negros Occidental. Trials consisted of a 36-entry group of drought-tolerant selections and promising lines from the IRRI upland rice breeding program and two 18-entry (early- and medium-maturing) groups from IRTP.

The weather was generally favorable throughout WS at the IRRI and Batangas sites. The SMT at 10- and 20-cm soil depths was high only in early June and early July at all 3 sites (Fig. 1), but it did not visibly affect the experimental crops. The SMT rose beyond 30 cb at IRRI for 2 d each in late

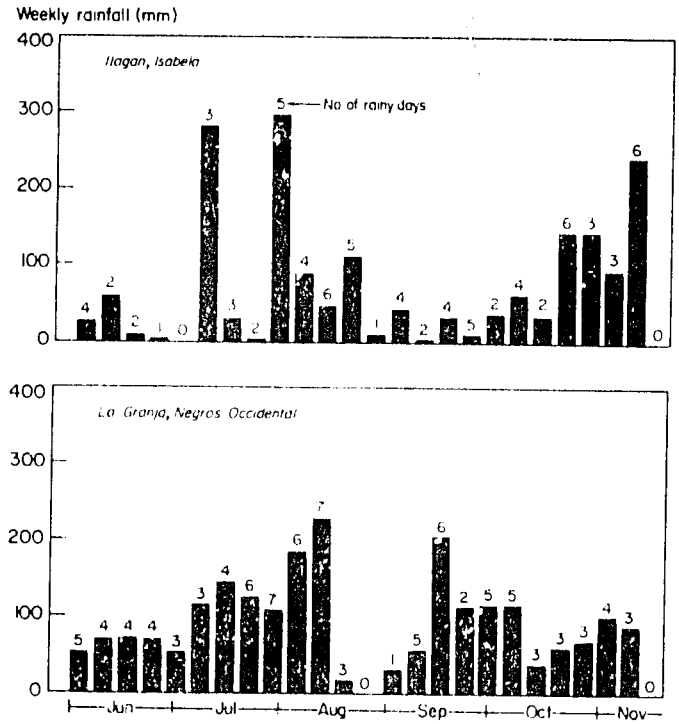


1. Weekly rainfall and daily soil moisture tension at the IRRI and Batangas, Philippines, upland rice experimental sites, 1986 WS.

August and late September and likewise did not affect the appearance of the IRRI crop. Dry spells lasting for 11 d in Ilagan and 16 d in La Granja occurred from late August to early September (Fig. 2), causing low and highly variable yields (Table 5, 6).

Grain yield of the test entries ranged from 0.2 t/ha for IR10198-66-2 in droughty Ilagan to 4.4 t/ha for IR9852-53-2 at the relatively wet Cuenca site. Leaf and neck blast lowered the yield of NDR84 to 0.3 t/ha in relatively wet Santo Tomas soil.

Except for the short-statured IR9560-2-6-3-1, all medium-maturing entries that had significantly better grain yield performance than the semidwarf check variety IR43 or were similar to it (Tables 5, 6) were intermediate-statured (Tables 7, 8), indicating the existence of rices with high yield potential and better weed competition capability than IR43. Short-statured IR9560-2-6-3-1 (Table 5), with a yield similar to that of IR43 at IRRI and in Batangas, was significantly better in soil moisture-deficient Ilagan and La Granja. It produced the highest average grain yield among all test entries at all sites. Intermediate-statured IR13754-5-2 was superior in yield to IR43 in the 23 May seeding in Santo Tomas but was inferior at IRRI, although it had the second highest average yield of 2.9 t/ha. A



2. Weekly rainfall in Ilagan and La Granja, Philippines, upland rice experimental sites, 1986 WS.

Table 5. Grain yield of selected entries in upland rice yield trials at 5 Philippine sites, 1986 WS.

Variety or line	Grain yield (t/ha)							
	IRRI	Santo Tomas		Cuenca		Ilagan	La Granja	Mean
	30 May	23 May	28 Jun	19 May	1 Jul	19 Jun	10 Jun	
IR9560-2-6-3-1	3.4 ab	2.9 b	3.0 a	3.0 bc	2.8 b	2.6 a	3.1 a	3.0
IR13754-5-2	2.8 bc	4.0 a	2.5 ab	4.3 a	2.6 b	1.9 bc	1.9 bcd	2.9
IR13754-5-10	3.2 abc	3.0 b	2.8 ab	3.5 ab	2.6 b	1.9 bc	2.1 bc	2.7
UPLRi-5	3.3 ab	3.2 b	2.3 b	3.9 ab	2.5 b	1.8 bc	2.1 bc	2.7
IR12721-5-1-1-3	2.6 c	2.9 b	2.7 ab	3.6 ab	2.7 b	1.9 bc	2.6 ab	2.7
IR7790-18-1-2-5	2.6 c	3.0 b	2.6 ab	4.0 ab	3.4 a	2.2 ab	1.0 d	2.7
IR43 (check)	3.5 a	3.2 b	2.5 ab	3.6 ab	2.4 b	1.7 c	1.4 cd	2.6
Kinandang Patong (local check)	1.4 d	2.0 c	1.8 c	2.1 c	1.7 c	0.9 d	1.2 d	1.6
Group mean	2.5	2.9	2.3	3.2	2.3	1.2	1.5	
CV (%)	13	13	12	15	12	23	36	

sister line, IR13754-5-10, and UPLRi-5 had yields statistically similar to that of IR43 at all test sites but had higher average grain yields of 2.7 t/ha.

The early-maturing entries that performed better than the early check Kinandang Patong (Table 6) were all semidwarfs (Table 8). The top entry was IR2588-7-3-1, which had significantly higher yield than Kinandang Patong at all sites except during the 23 May seeding in Santo Tomas, where yields were similar.

Table 6. Grain yield of selected entries in the International Upland Rice Yield Nursery – Early (IURYN-E) and International Upland Rice Yield Nursery – Medium (IURYN-M) at 4 Philippine sites, 1986 WS.

Variety or line	Grain yield[a] (t/ha)					
	IRRI	Santo Tomas		Cuenca	La Granja	Mean
	30 May	23 May	28 Jun	1 Jul	10 Jun	
		IURYN-E				
IR2588-7-3-1	2.8 a	2.3 a	2.1 a	2.8 a	2.8 a	2.6
IRAT110	2.4 ab	2.2 a	1.5 ab	1.8 b	2.8 a	2.1
IR10198-66-2	1.7 cd	1.4 b	1.4 ab	2.9 a	2.5 a	2.0
CR222-MW10	2.0 bc	2.3 a	1.5 ab	2.0 b	1.9 a	1.9
Kinandang Patong (check)	1.3 d	2.2 a	0.9 b	1.8 b	0.5 b	1.3
Group mean	1.4	1.6	1.1	2.2	1.9	
CV (%)	23	20	33	13	31	
		IURYN-M				
IR12979-24-1 (brown)	3.2 a	3.4 ab	2.9 a	2.8 a	1.4 a	2.7
IR13754-5-2	2.6 a	4.1 a	2.0 b	2.7 ab	1.2 a	2.5
BR319-1	2.4 a	3.1 bc	2.9 a	2.8 a	0.7 a	2.4
IR5931-113-1	2.6 a	3.1 bc	2.3 ab	2.5 abc	1.1 a	2.3
C894-7	2.8 a	2.7 bc	2.8 a	2.0 c	1.2 a	2.3
IR7835-28-2-4	2.5 a	2.3 c	2.7 ab	2.3 abc	1.5 a	2.3
IR7805-22-3-1	2.5 a	2.8 bc	2.5 ab	2.1 bc	1.3 a	2.2
B2992B-TB-73-4-2-3-3-3-2	2.8 a	2.6 c	2.6 ab	2.4 abc	0.8 a	2.2
IR43 (check)	3.2 a	3.4 ab	2.4 ab	2.2 abc	0.9 a	2.4
Group mean	2.3	2.5	2.1	2.2	1.4	
CV (%)	20	17	17	14	40	

[a]In a column within a group, entry means having a common letter are not significantly different at the 5% level by DMRT.

Table 7. Average grain yield and other agronomic characters of selected entries in upland rice yield trials at 5 Philippine sites, 1986 WS.

Variety or line	Average grain yield (t/ha)	Heading (DE)[a]	Plant height (cm)	Panicles (no./m²)	Drought reaction[b]		Important diseases[c]
					Hagan	La Granja	
IR9560-2-6-3-1	3.0	95	78	269	2	4	LSc, LSm, ShR
IR13754-5-2	2.9	95	106	248	2	3	LSm, ShR
IR13754-5-10	2.7	96	110	221	1	5	LSm, ShR
UPLRi-5	2.7	92	104	188	1	4	BB, ShR
IR12721-5-1-1-3	2.7	96	106	253	2	5	ShR
IR7790-18-1-2-5	2.7	92	113	215	3	4	BB, ShR
IR43 (check)	2.6	94	78	235	1	4	BB, LSm, NBLS, ShR
Kinandang Patong (local check)	1.6	87	126	160	3	2	BB, ShR

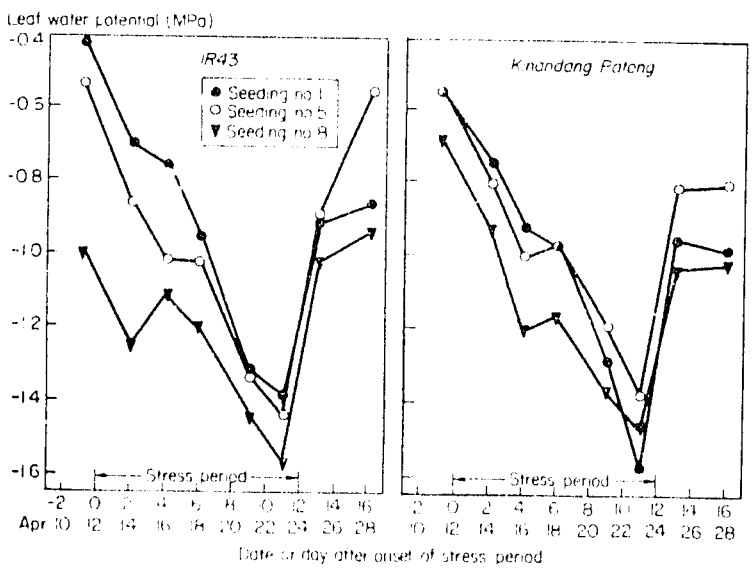
[a]DE = d after emergence, [b]0 to 9 scale, where 0 = no symptoms, 1 = slight leaf tip drying, 5 = 50% of leaves fully dried, and 9 = all plants apparently dead, [c]BB = bacterial blight, LSc = leaf scald, LSm = leaf smut, NBLS = narrow brown leaf spot, ShR = sheath rot.

Sheath rot (ShR), which was prevalent at IRRI and the Batangas sites, infected all the selected entries; only ShR infected the selected lines IR12721-5-1-1-3 and IR7805-22-3-1 (Tables 7, 8). Leaf and neck blast seriously affected the late-seeded (28 Jun) early group in Santo Tomas. Bacterial blight and bacterial leaf streak were common at IRRI, while leaf scald and leaf smut affected many entries at the Batangas sites. Narrow brown leaf spot was most prevalent in Hagan.

Table 8. Average grain yield and other agronomic characters of selected entries in IURYN-E and IURYN-M at 4 Philippine sites, 1986 WS.

Variety or line	Average grain yield (t/ha)	Heading (DE)	Plant height (cm)	Panicles (no./m²)	Important diseases[a]
		IURYN-E			
IR2588-7-3-1	2.6	70	75	248	BB, NBI, NBLS, ShR
IRAT110	2.1	66	85	191	BB, LSm, ShR
IR10198-66-2	2.0	71	75	255	NBI, NBLS, ShR
CR222-MW10	1.9	74	71	246	BB, BLS, NBLS, ShR
Kinandang Patong (check)	1.3	85	130	166	BB, BLS, ShR
		IURYN-M			
IR12979-24-1 (brown)	2.7	78	98	222	BB, BLS, ShR
IR13754-5-2	2.5	94	107	232	LSc, ShR
BR319-1	2.4	83	97	226	BB, BLS, NBI, ShR
IR5931-113-1	2.3	85	102	214	BB, ShR
C894-7	2.3	91	104	250	BB, NBLS, ShR
IR7835-28-2-4	2.3	92	112	208	BLS, ShR
IR7805-22-3-1	2.2	92	107	212	ShR
B2992B-TB-73-4-2-3-3-3-2	2.2	79	104	200	BB, ShR
IR43 (check)	2.4	92	78	249	BB, BLS, NBLS, ShR

[a]BB = bacterial blight, BLS = bacterial leaf streak, LSc = leaf scald, LSm = leaf smut, NBI = neck blast, NBLS = narrow brown leaf spot, ShR = sheath rot.



3. Midday leaf water potential of check varieties IR43 and Kinandang Patong during the stress period. IRRI, 1986.

Drought resistance screening of upland rice at flowering (*Agronomy*). In previous years, a staggered planting schedule had limited success in synchronizing flowering for reproductive phase drought resistance screening. In this field experiment, seven planting dates at 7- to 14-d intervals and a single drought period were used to improve the chance of having stress during flowering of each of 26 varieties. The objectives were to identify varieties and lines with superior drought resistance

at the reproductive phase and to determine the relationship between vegetative and reproductive phase drought resistance. The 7 planting dates were main plots and the 26 varieties subplots in a split-plot design.

Water was applied by a whole-plot overhead sprinkler system; the amount was gradually increased from seeding to the full canopy stage. Thereafter, irrigation was applied 3 times a week at a rate equivalent to 1.2 × pan evaporation. The last full irrigation before the stress period was applied on 12 Apr (day 0). No irrigation was applied until 24 Apr. The midday leaf water potential of check varieties IR43 and Kinandang Patong decreased after stress imposition and was lowest on the 11th day of stress. Kinandang Patong had a relatively higher midday leaf water potential than IR43 on the 11th day of stress (Fig. 3)

The multiple seeding date strategy greatly improved the chance of each variety being stressed during flowering. About 85% of the entries flowered during the 12-d stress period. Only entries that flowered 3-7 or 8-12 d after stress onset are presented in Table 9, because those that flowered during the first few days after stress onset may represent drought escape rather than tolerance. Grain yield was not significantly correlated with filled spikelets or drought score for varieties flowering at any time during the stress period. On the other hand, there was a significant correlation between days to flowering after stress onset and filled spikelets for all entries that flowered 3-12 d after stress onset ($r = -0.508^*$), and between days to flowering and grain yield only for entries that flowered 8-12 d after stress onset ($r = -0.635^*$).

A graph of grain yield versus flowering date for all varieties and planting dates (Fig. 4) shows great variation among varieties when stressed at any growth stage. In addition, there was a significant declining yield trend with later planting (and flowering) date.

Drought tolerance under limited rooting depth (*Agronomy*). A total of 105 GEU elite and selected entries from the 12th International Upland Rice Observational Nursery were screened in the greenhouse for drought tolerance at limited rooting depth (45 cm) and the ability to recover from drought stress.

Table 9. Grain yield, spikelet fertility, and drought scores of genotypes that flowered during the drought stress period. IRRI, 1986 DS.

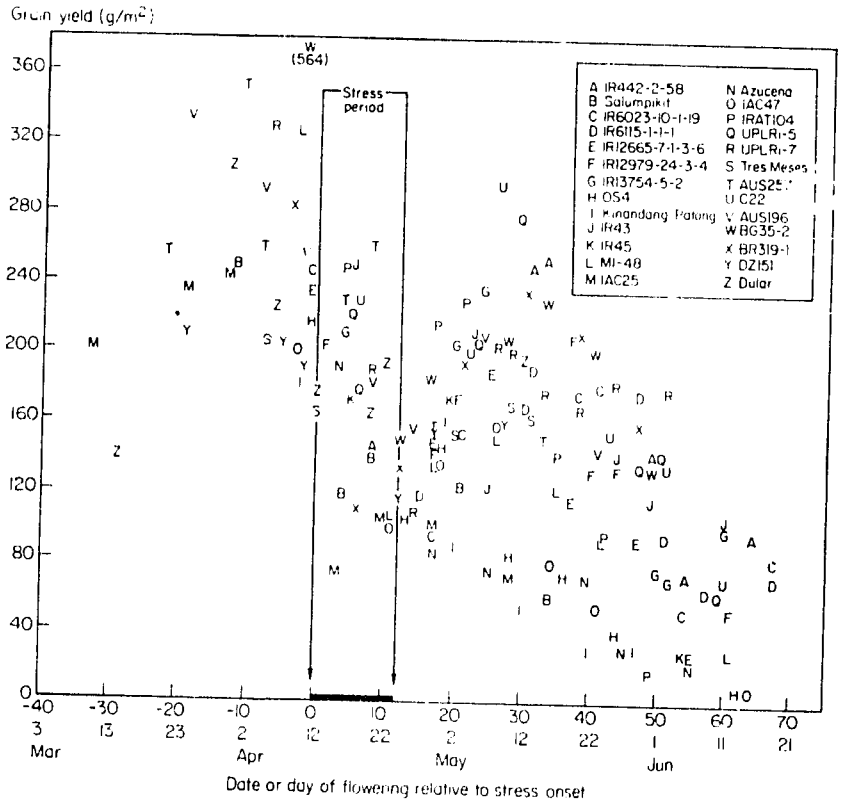
Variety or line	Days to flowering after onset of stress	Grain yield (g/m²)	Filled spikelets at maturity (%)	Drought score[a]
Flowered 3-7 d after onset of stress				
IR43	5	250	57	2.46
IRAT104	4	249	74	1.93
AUS257	4	231	62	2.81
C22	6	230	53	2.57
UPLRi-5	5	222	60	2.61
IR13754-5-2	4	212	48	2.64
Azucena	3	192	74	2.68
IR45	5	174	69	2.32
Tres Meses	3	172	58	3.00
Salumpikit	4	119	65	1.58
BR319-1	6	111	64	3.11
IAC25	3	75	67	2.00
Flowered 8-12 d after onset of stress				
AUS257	8	261	65	2.81
UPLRi-7	8	209	48	2.61
AUS196	8	183	55	3.00
Dular	9	180	57	2.75
BG35-2	12	150	61	2.82
IR442-2-58	8	147	53	2.89
Salumpikit	8	141	54	1.58
BR319-1	12	134	64	3.11
DZ151	12	118	51	2.80
MI-48	11	106	29	2.43
IAC25	10	105	59	2.00
IAC47	11	102	36	2.29

[a]Taken on the last day of stress period (day 12). Scale based on SES for Rice (1980): 0 = no symptoms, 9 = all plants apparently dead.

Three rices, including the drought-tolerant check Leb Mue Nahng, were seeded in dry soil in steel drums and watered regularly up to 30 DAS. Then water was withheld and the soil allowed to dry by evapotranspiration. When Leb Mue Nahng was apparently dead, plants were scored for drought tolerance. The soil was then sampled for moisture content before rewatering.

Soil moisture contents just before relief from stress were 7.6% at 10 cm depth and 12.1% at 20 cm. These values were much above 15 bars SMT.

Table 10 shows the comparative performance of some promising entries. IR36 and IR13761-113 recovered well in DS, as did IR26760-76-2-1-2-3 and IR39385-124-3-3-2-3 in WS. The tolerant



4. Grain yield of 26 upland rice cultivars at different flowering days relative to drought stress onset IRRI, 1986.

check Leb Mue Nahng did not recover; neither did the traditional upland variety Kinandang Patong and the promising upland line UPLRi-5, both previously found to be good performers in field drought screening. The limited rooting depth in this experiment might have restricted their extraction of soil moisture.

Results indicate that several breeding lines and varieties can be used as gene sources for drought tolerance and recovery ability in rainfed lowland culture or in upland culture with a shallow soil surface and an impervious layer.

Screening rainfed lowland rices in drought-prone areas (*Agronomy*). During 1985 WS, yield trials were conducted at Guimba, Nueva Ecija; IRRI, Laguna; and Liloan, Cebu, to evaluate promising breeding lines for their yield and reaction to water deficit under rainfed shallow wetland conditions. Entries consisted of very early-, early-, medium-, and late-maturing genotypes.

Guimba, Nueva Ecija. The crop grown in a farmer's field in Nueva Ecija received evenly distributed rainfall (763 mm) from transplanting to harvest (Fig. 5). Average yield was 3.2 t/ha.

Yields of very early and early genotypes ranged from 1.2 t/ha for IR26894-37-2-1-3 to 4.2 t/ha for IR21567-9-2-2-2-1. IR21567-9-2-2-2-1 outyielded the check varieties IR36 and IR54.

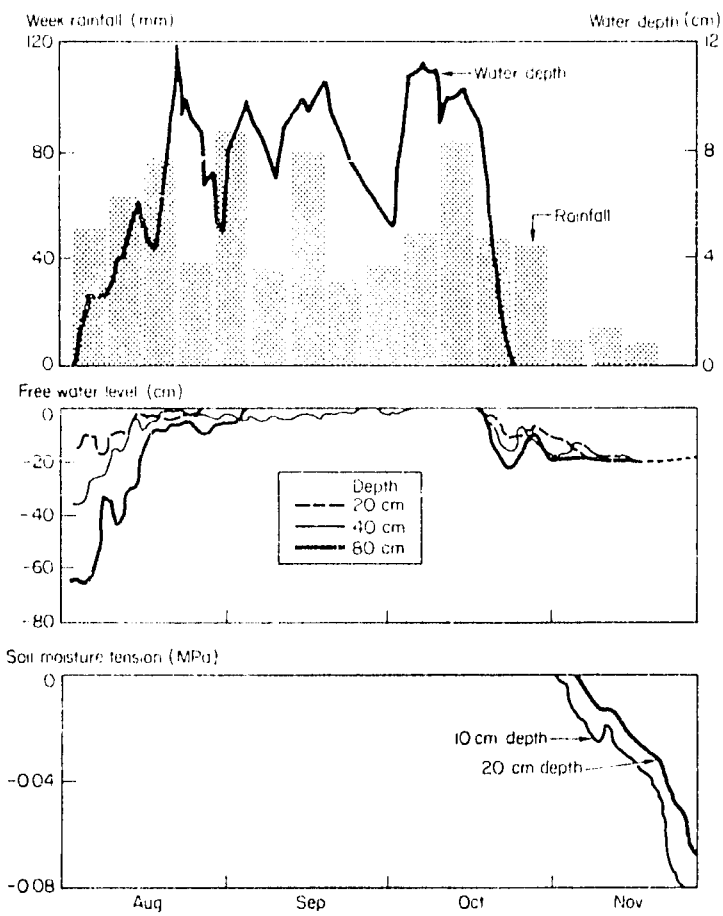
Yields of medium- and late-maturing genotypes ranged from 2.4 t/ha for IR27050-15-2-3-3-2 to 3.6 t/ha for B4259-39-2-3.

IRRI, Laguna. In a well-drained field on the IRRI farm, yields were lower than in a farmer's field in Guimba because of erratic rainfall distribution (Fig. 6) and a short period of water deficit during the reproductive phase. Rice tungro virus also contributed to low yields.

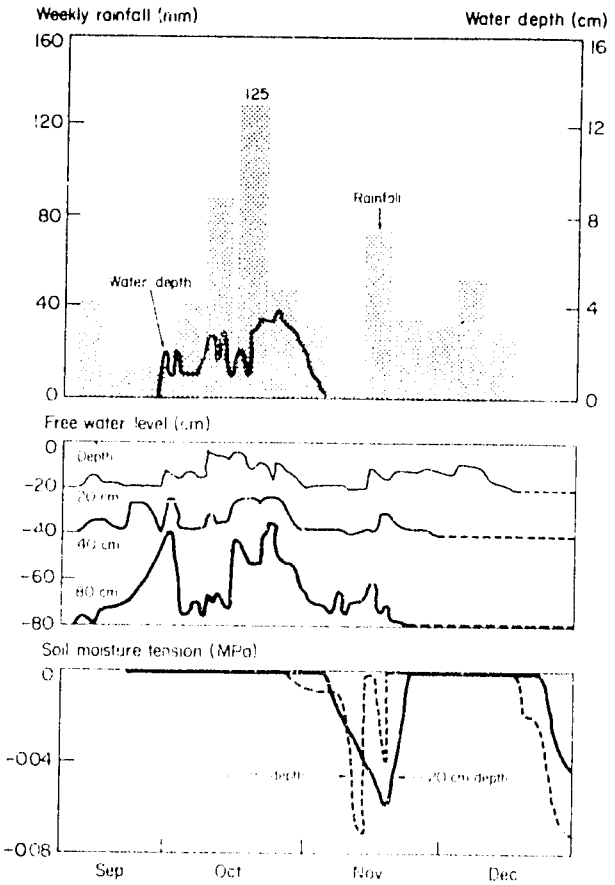
Table 10. Drought tolerance rating of promising entries during the vegetative phase and recovery of entries after relief from stress. IRRI greenhouse, 1986.

Variety or line	Drought tolerance rating[a]	Tillers (%) that recovered after relief from stress[b]			Variety or line	Drought tolerance rating[a]	Tillers (%) that recovered after relief from stress[b]		
		1 wk	2 wk	3 wk			1 wk	2 wk	3 wk
	Dry season					*Wet season*			
IR36	6	28	56	131	IR26760-76-2-1-2-3	6	18	18	73
IR13761-113	5	13	18	68	IR39385-124-3-3-2-3	8	13	24	53
RP1140-28-3-3-6	7	11	15	50	RR20-5	6	3	6	44
CRM14-BE/26	6	25	28	43	CR314-5-18	6	19	27	42
CR222-MW10	7	13	23	40	IR5931-113-1	7	8	17	33
IR29723-143-3-2-1	9	3	7	31	IR28228-12-3-1-1-2	6	6	12	29
Dular	7	6	10	19	IR43	7	6	19	26
Palghar 31-1-3	6	7	11	18	SI-2	7	6	11	17
Kinandang Patong	8	0	0	0	UPL Ri-5	8	0	0	0
Leb Mue Nahng	9	0	0	0	Leb Mue Nahng	9	0	0	0

[a]0 = no visible effect, 9 = all plants apparently dead. [b]Includes tillers arising from primary and secondary tillers.



5. Water level (piezometer at 20, 40, and 80 cm), field water depth, rainfall, and soil moisture tension in Guimba, Nueva Ecija, Philippines, 1985 WS.



6. Water level (piezometer at 20, 40, and 80 cm), field water depth, rainfall, and soil moisture tension at IRRI, 1985 WS.

Yields of very early- and early-maturing genotypes ranged from 1.6 t/ha for KKN7205-39-3-SKN-1-1-1 to 3.4 t/ha for IR21567-9-2-2-2-1 and 3.7 t/ha for IR21567-9-2-2-3-1-3. Because the latter two are early maturing (110 d), they probably escaped from reproductive phase stress.

Yields of medium- and late-maturing genotypes ranged from 1.1 t/ha for IR27050-15-2-3-3-2 to 3.3 t/ha for IR19431-72-2.

Liloan, Cebu. At Liloan, water did not appear to limit growth, and yields were relatively high. Cebu had well-distributed rainfall and high water level except at the end of the season (Fig. 7).

Yields of very early- and early-maturing genotypes ranged from 1.3 t/ha for IR28128-45-2 to 4.4 t/ha for IR46. Yields of medium- and late-maturing genotypes ranged from 2.1 t/ha for IR27050-15-2-3-3-2 to 4.7 t/ha for IR19431-72-2.

Table 11 summarizes grain yields for the top 10 entries of the integrated performance trials for drought-prone shallow wetland environments at the 3 locations.

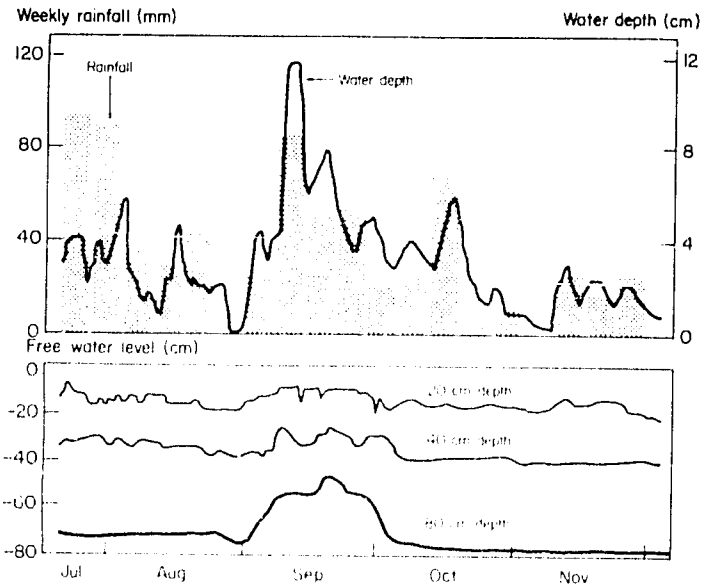
SOIL-PLANT WATER RELATIONSHIPS

Agronomy Department and Upland Rice Breeding Program

Comparison of methods for screening rainfed lowland rice for drought resistance (*Agronomy*). In the past, screening of rainfed lowland rice for drought resistance was conducted largely on an ad hoc basis. Nurseries were planted in drought-prone areas and evaluated for drought resistance if water deficit occurred during the season. In this field trial, we not only attempted to impose a systematic water deficit, but also maintained a continuously flooded control. Four groups of drought resistance screening indices were tested with 30 breeding lines and varieties: grain yield, visual scoring according to the *Standard evaluation system for rice*, uprooting force after severing the lateral roots to a depth of 15 cm, and infrared thermometry. We assumed that the best agronomic index of drought resistance is grain yield of stressed plots, and so all other indices were compared with grain yields to determine the usefulness of the screening methods. Because one variety in the test is photoperiod sensitive and did not flower, only 29 genotypes were used for screening method comparisons. A second objective of the study was to determine

Table 11. Grain yields for top 10 entries of the integrated performance trials for rainfed shallow wetland environments, Philippines, 1985 WS.

Line	Grain yield (t/ha)		
	IRRI	Nueva Ecija	Cebu
IR21567-9-2-2-2-1	3.73	4.23	4.20
IR21567-9-2-3-1-3	3.44	3.98	4.36
IR19431-72-2	3.34	3.47	4.67
IR13240-108-2-2-3	2.79	3.79	4.08
IR19083-22-2-2	2.36	3.46	4.35
IR33355-39-1-1-3	2.62	3.86	3.63
IR28941-164-1-5	2.45	3.30	3.96
IR9217-58-2-2	2.74	3.61	3.27
IR26933-16-2-3	2.61	3.58	3.26
IR21363-13-2-2-1-1	2.47	3.56	3.21



7. Water level (piezometer at 20, 40, and 80 cm), field water depth, and rainfall in Cebu, Philippines, 1985 WS.

whether drought resistance of rainfed lowland rices might be predicted from observation in continuously flooded (unstressed control) plots.

All drought resistance indices studied were significantly correlated with grain yield under stress (Table 12), and the most and least drought resistant genotypes according to grain yield under stress were also generally ranked among the most and least resistant genotypes for the other indices (Table 13). Relative grain yield — the ratio of stress and control yields — offers no insight into these results, although relative yields have proven useful to other researchers. The fact that all genotypes in our study had high yields under the continuously flooded treatment reduced the usefulness of relative yields here.

Three drought indices — Idso's, Jackson's, and one developed at IRRI — based on infrared thermometry and other micrometeorological data — showed no apparent advantage over canopy temperatures or canopy-air temperature differences. Although infrared thermometry-based indices showed no advantage over visual scoring under stress, they do allow greater physiological interpretation, as canopy temperature is generally inversely proportional to stomatal conductance. For example, two of the least drought-resistant varieties (IR52 and KKN7205-39-3-SKN-1-1-1) had very low canopy temperatures. A very cool canopy suggests high stomatal conductance and therefore excessive transpiration, leading to severe internal plant water deficits.

Table 12. Simple linear correlation coefficients between grain yield and drought resistance index for 29 rainfed lowland varieties and breeding lines. IRRI, 1986 DS.

Factor	Yield		Uprooting force	Visual score		Canopy temperature	Canopy-air temperature	Drought water stress index		
	Control	Relative		Control	Stress			Idso	Jackson	Modified
Stress yield	.395**	.818**	.296**	-.251**	-.664**	-.626**	-.633**	-.631**	-.634**	-.551**
Control yield		-.181	-.091	-.075	-.278**	-.085	-.101	-.096	-.095	-.220*
Relative yield			.368**	-.238*	-.526**	-.578**	-.572**	-.572**	-.578**	-.448*

Table 13. Drought resistance indices and ranks (in parentheses) for the 5 most and 5 least drought-resistant rainfed lowland varieties and breeding lines. IRRI, 1986 DS.

Variety or line	Grain yield			Uprooting force (kg)	Visual score		Canopy temperature (°C)		Canopy-air temperature (°C)	
	Stress (t/ha)	Control (t/ha)	Relative		Stress[a]	Control[b]	Stress	Control	Stress	Control
Most drought resistant										
IR29723-143-3-2-1	6.0 (1)	7.0 (2)	.851 (5)	13.2 (8)	4.0 (6.5)	4.3 (20.5)	32.6 (3)	28.5 (20)	.39 (2)	−3.67 (24)
IR48	5.7 (2)	7.2 (15)	.795 (9)	12.7 (9)	5.3 (19)	3.0 (3.5)	32.8 (5)	28.4 (17)	.89 (5)	−3.74 (20)
IR13146-13-3-3	5.6 (3)	5.9 (1)	.942 (1)	12.4 (11)	5.0 (15)	3.7 (10.5)	33.4 (10.5)	28.0 (7)	1.54 (14)	−4.06 (9)
IR13146-45-2-3	5.2 (4)	5.7 (20)	.912 (2)	11.7 (13)	4.0 (6.5)	3.7 (10.5)	32.8 (4)	28.1 (10)	.92 (6)	−4.02 (11)
IR29725-109-1-2-1	5.2 (5)	6.8 (3)	.762 (8)	11.1 (15)	2.7 (1)	3.7 (10.5)	32.8 (6)	28.4 (18)	.8[illegible] (4)	−3.74 (19)
Least drought resistant										
IR12979-24-1	2.7 (25)	4.1 (28)	.667 (17)	10.7 (17)	6.0 (22)	4.7 (23.5)	33.1 (9)	28.2 (12)	1.34 (9)	−3.87 (13)
IR11418-15-2	2.7 (26)	5.7 (21)	.474 (26)	12.0 (12)	6.3 (24.5)	3.0 (3.5)	34.8 (25)	28.4 (19)	2.81 (25)	−3.74 (18)
IR52	2.2 (27)	6.1 (13)	.355 (28)	11.1 (16)	6.3 (24.5)	3.0 (3.5)	34.4 (23)	27.6 (1)	2.32 (20)	−4.48 (2)
KKN7205-39-3-SKN-1-1-1	1.8 (23)	4.[illegible] (27)	.369 (27)	9.0 (27)	7.3 (27)	4.3 (20.5)	34.4 (22)	27.8 (3)	2.47 (2[illegible])	−4.24 (5)
IR5931-110-1	1.8 (29)	5.4 (24)	.331 (29)	10.2 (20)	8.0 (29)	5.0 (28.5)	34.2 (20)	28.4 (28)	2.35 (22)	−3.45 (28)

[a]0 = no apparent stress, 9 = dead. [b]Phenotypic acceptability score for control treatment, 0 = good, 9 = poor.

For drought resistance screening trials in which water deficit occurs, the visual scoring system appears to be the best estimate of yield, but it may be improved by also measuring canopy temperature and uprooting force (Table 14). For trials in which no water deficit occurs, control yield seems to be the best estimate of yield under stress, and this estimate may be much improved by also measuring uprooting force (Table 14).

All screening tools have their limitations. Most indices measure drought resistance at a single time, whereas water deficit occurs and affects crop growth across a span of time. Uprooting force can be measured only under well-watered conditions. Infrared thermometry is limited to clear sky conditions. Although grain yield integrates stress effects across time, it is expensive to measure and responds to stresses other than water deficit. Thus, although we may select a "best" index for drought resistance, until we fully understand the interactions among soil, crop, and atmospheric factors, research should continue on all available indices.

Water deficit and N fertilization effects on water relations of rainfed lowland rice (*Agronomy*). Because both water and N availability strongly affect rice growth and development, a field experiment was conducted to determine how N fertilization affects rice water relations in a simulated rainfed lowland field. The experiment, in

Table 14. Selected multiple linear correlation coefficients for various drought resistance indices vs grain yield under stress for 29 rainfed lowland varieties and breeding lines. IRRI, 1986 DS.

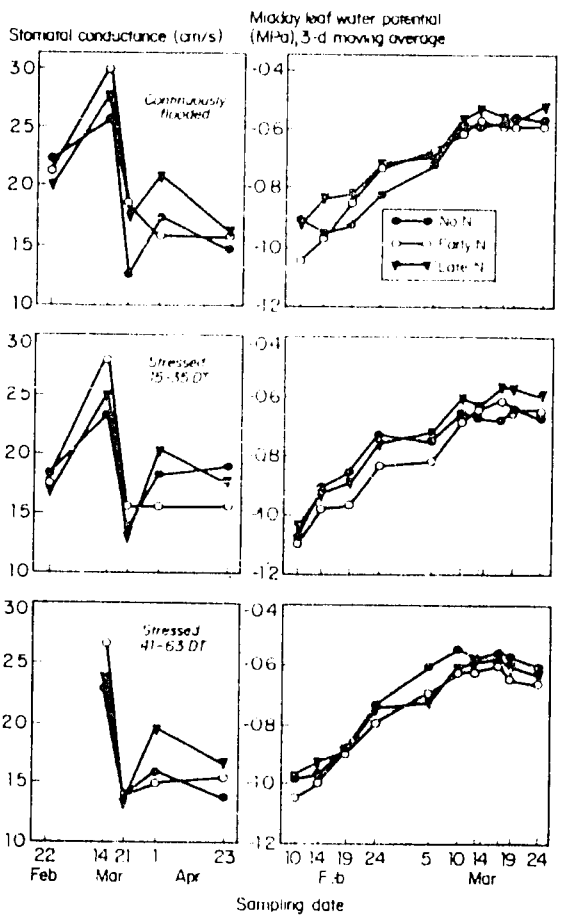
Drought resistance indices	*R*
If drought can be imposed	
Uprooting force + visual score	.705
Visual score + canopy temperature	.706
Uprooting force + canopy temperature	.529
Uprooting force + canopy temperature + visual score	.732
If no drought can be imposed	
Control yield + uprooting force	.516
Control yield + visual score	.453
Control yield + canopy temperature	.409
Uprooting force + visual score	.368
Uprooting force + visual score + canopy temperature	.386
Control yield + uprooting force + visual score + canopy temperature	.560

a split-plot design with four replications, was planted on 20 Jan 1986 in a farmer's field in Pila, Laguna, selected for low native N. Three irrigation treatments were imposed as main plot treatments: continuously flooded, unirrigated from 15 to 35 d after transplanting (DT), and unirrigated from 41 to 63 DT. Three N fertilization treatments were imposed as subplots: no-N, early split N of 40 kg/ha at both 0 and 37 DT, and late split N of 40 kg/ha at both 11 and 65 DT.

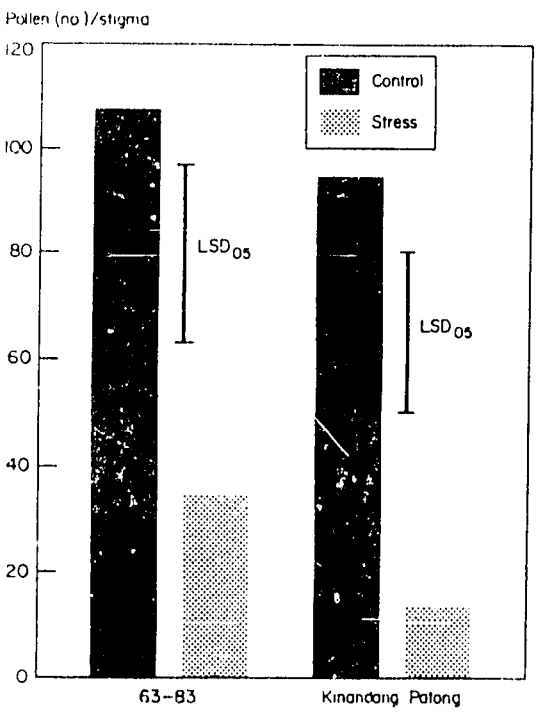
Graphs of stomatal conductance and leaf water potential during water deficit periods are shown in Figure 8. Seasonal or crop developmental effects appeared stronger than N fertilization and irrigation treatments on stomatal conductance and leaf water potential. Irrigation treatment effects were small, primarily because of a shallow water table, even though yield effects were significant (see Management of Soil and Fertilizer Nitrogen).

Still, it is clear that early N fertilization led to higher stomatal conductance in March regardless of irrigation treatment, and late split N treatment led to higher stomatal conductance in April regardless of irrigation treatment. Thus, N application appeared to have a very strong impact on stomatal conductance. Treatment effects on leaf water potential at midday were not as clear-cut.

Water deficit effects on pollination and spikelet fertility (*Agronomy*). Because rice yields are most sensitive to water deficit when stress occurs during flowering, a greenhouse experiment was conducted to determine the effects of water deficit on pollen shedding and germination in the traditional upland rice cultivars 63-83 and Kinandang Patong after a 7-d stress. Water deficit reduced pollen shed on stigma threefold in 63-83 and sevenfold in Kinandang Patong over well-watered plants (Fig. 9). In vivo pollen germination was also



8. Stomatal conductance and midday leaf water potential as affected by water deficit and N fertilization. Pila, Laguna, Philippines, 1986 DS. DT = days after transplanting.



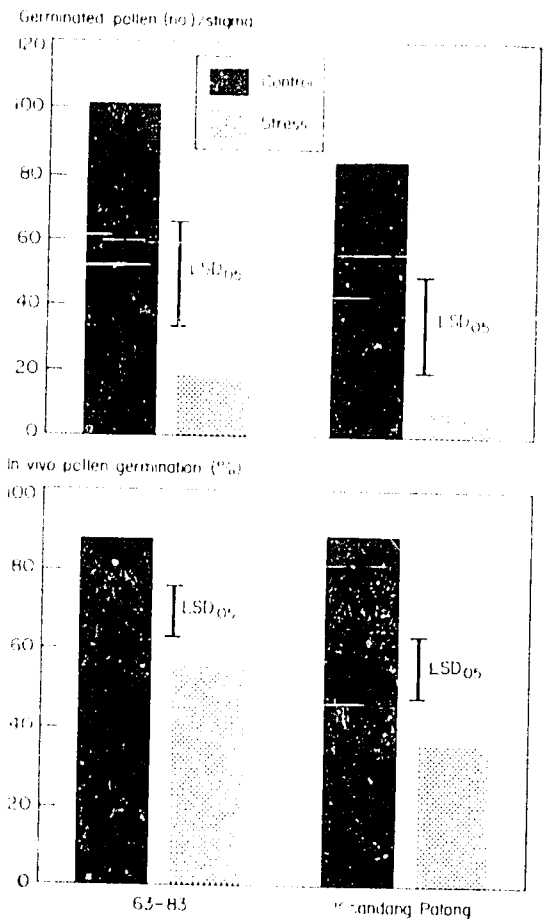
9. Total number of pollen grains on stigma as affected by stress treatment in 63-83 and Kinandang Patong. IRRI, 1986.

severely retarded (Fig. 10), and, based on pollen germinability, only about 45% of the spikelets in 63-83 and 23% in Kinandang Patong could produce fertile spikelets (Fig. 11). Correlation coefficients showed significant associations among pollen shedding, germination, and spikelet sterility. Poor panicle exsertion also contributed to spikelet sterility.

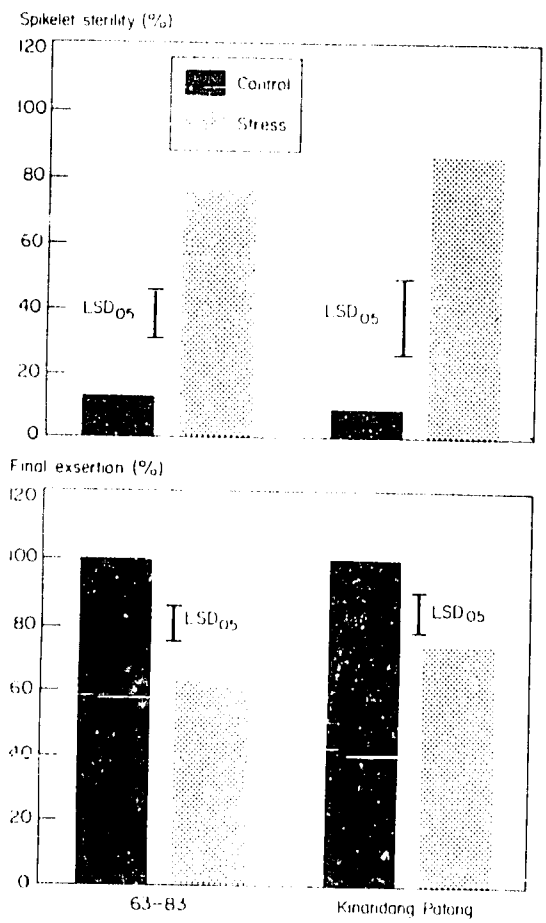
In a second greenhouse experiment, flowering characteristics were measured at leaf water potentials from -0.3 to -2.8 MPa after a 7-d stress period during anthesis using moderately drought-tolerant IRAT13. Anther dehiscence, pollen shedding, pollen germination, and pollen tube growth were measured on randomly selected spikelets on the final day of stress. At maturity, final panicle exsertion and unfilled spikelets were determined (Table 15). Water deficit drastically affected all flowering characteristics and increased the number of unfilled spikelets. The flag leaf water potential (X_1), final panicle exsertion (X_2), total pollen grains per stigma (X_3), and spikelets with more than 20 pollen grains per stigma (X_4) significantly contributed to the variation in unfilled spikelets. Among nine linear models fitted to predict unfilled spikelets, the best predictor equation was

$$Y = -0.28\,X_1 + 5.26\,X_2 + 0.71\,X_3 + 0.89\,X_4 \quad R^2 = 0.9538$$

Genotypic variability of the sterility response of rice induced by water deficit at anthesis (*Agronomy*). Twelve rice cultivars varying in



10. Effect of water stress on in vivo pollen germination (total number and percentage) in 63-83 and Kinandang Patong. IRRI, 1986.



11. Effect of water stress at flowering on a) spikelet sterility and b) final panicle exsertion in 63-83 and Kinandang Patong. IRRI, 1986.

Table 15. Effect of water deficit on flag leaf water potential and flowering characters of IRAT13 at anthesis and maturity.[a] IRRI, 1986.

	Flag leaf water potential (MPa)	Total pollen/ spikelet (no.)	Spikelets with >10 germinated pollen (no.)	Anther dehiscence score[b]	Pollen tube growth (%)	Spikelets with >20 pollen (%)	Panicle exsertion (%)	Unfilled spikelets (%)
	−0.2 a	136 a	100 a	1.2 a	22 a	100 a	99 a	4 a
	−0.8 b	123 a	78 b	1.7 b	18 b	90 b	85 b	9 b
	−1.1 c	92 b	77 b	1.8 b	18 b	70 cd	84 bc	43 c
	−1.4 d	77 c	64 c	1.7 b	17 b	69 d	71 cde	38 c
	−1.7 e	50 d	49 d	3.4 c	10 c	72 c	82 bcd	73 d
	−2.0 f	50 d	45 e	4.0 d	8 d	60 e	80 bcde	71 d
	−2.3 g	36 e	21 f	5.7 e	6 e	21 g	67 ef	69 d
	−2.5 h	29 f	19 f	8.2 f	3 f	30 f	70 def	82 e
	−2.8 i	12 g	19 f	8.7 g	1 g	22 g	53 g	87 f
F value	1221**	283**	1449**	2520**	244**	1000**	233**	491**
Degrees of freedom	24	24	24	24	24	24	24	24

[a]In a column, means followed by a common letter are not significantly different at the 1% level by DMRT. ** = significant at 1% level. [b]1 = 90-100% dehiscence, 9 = 0% dehiscence.

hydrological origin, maturity days, and drought tolerance levels (Table 16) were grown under well-watered control, mild, moderate, and severe SMTs to evaluate their genotypic performance after a 21-d slow soil-drying period. Growth parameters such as plant height, leaf area, and leaf rolling, and flowering traits such as panicle exsertion, spikelet desiccation, and total flowering were noted on the last day of stress. Grain yield, sterility components based on model characterization, and panicle exsertion were measured on mature plants. The cumulative stress index, based on midday leaf water potentials and stress duration, was significantly correlated with SMT and flag leaf water potential at flowering.

Moisture stress intensity and genotype response showed interaction effects on leaf rolling. However, drought stress affected the rolling response of all cultivars. At severe stress levels, all cultivars showed tight leaf rolling (Table 17). At moderate stress levels, the IR9669 selection, N22, and Azucena exhibited relatively less rolling (score

Table 16. Origin, agronomic characteristics, and drought scores of the test rice cultivars. IRRI, 1986.

Cultivar	Country of origin	Variety group	Hydrological origin	Plant type	Maturity (d)	Drought score[a] A	Drought score[a] B
IRAT140	Ivory Coast	Indica	Upland	Tall	105	–	–
IRAT110	Ivory Coast	Intermediate	Upland	Semidwarf	105	–	–
N22	India	Indica	Upland	Tall	91	7	2
IR9229 selection	Philippines	Intermediate	Lowland	Semidwarf	122	–	–
Azucena	Philippines	Intermediate	Lowland/upland	Tall	108	7	7
IRAT13	Ivory Coast	Indica	Upland	Tall	99	6	5
Kinandang Patong	Philippines	Indica	Upland	Tall	125	5	3
IR43	Philippines	Intermediate	Upland	Semidwarf	120	–	–
IR36	Philippines	Intermediate	Lowland	Semidwarf	105	8	–
IR8	Philippines	Intermediate	Lowland	Semidwarf	125	9	–
IR20	Philippines	Intermediate	Lowland	Semidwarf	121	8	9
IR5	Philippines	Intermediate	Lowland	Semidwarf	130	9	–

[a]Drought score: A = at the vegetative stage (at −0.9 to −1.0 MPa SMT), B = at the reproductive stage (1 = tolerant, 9 = susceptible to drought stress).

Table 17. Effect of moisture regime at flowering on leaf rolling score on last day of stress. IRRI, 1986.

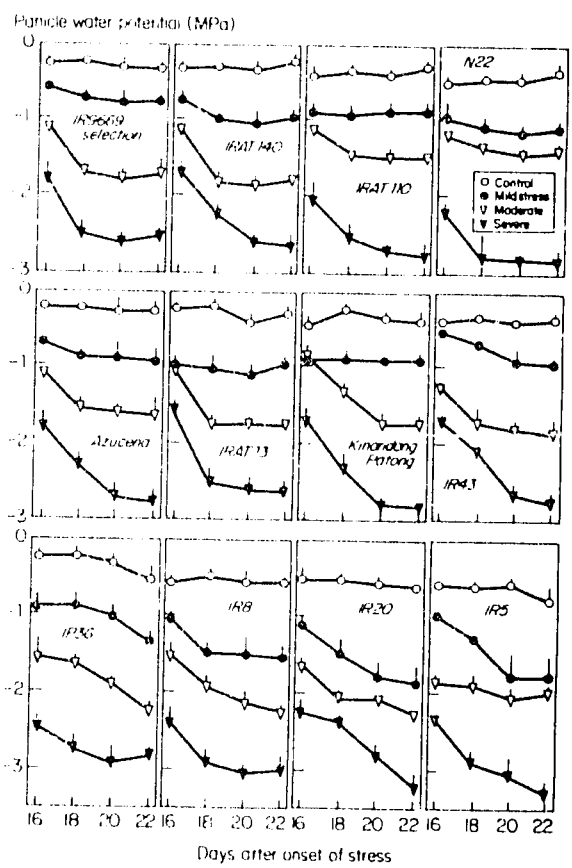
Cultivar	Leaf rolling score[a]				
	Control	Mild stress	Moderate stress	Severe stress	Mean
IR9669 selection	1	1.3	4.0	5.0	2.8 c
IRAT140	1	2.3	4.7	5.0	3.3 ab
IRAT110	1	2.7	4.7	5.0	3.3 ab
N22	1	2.0	4.0	4.0	3.0 bc
Azucena	1	1.7	4.0	5.0	2.9 bc
IRAT13	1	2.7	4.7	5.0	3.3 ab
Kinandang Patong	1	2.0	4.7	5.0	3.2 abc
IR43	1	2.2	4.7	5.0	3.2 abc
IR36	1	2.3	4.7	5.0	3.3 ab
IR8	1	2.3	4.3	4.7	3.1 abc
IR20	1	3.0	5.0	5.0	3.5 a
Mean	1 d	2.2 c	4.5 b	5.0 a	3.2

[a] In a row or column, means followed by a common letter are not significantly different at the 5% level by DMRT. Mean of 3 replications. Leaf rolling score: 1 = no rolling, 5 = tight rolling.

of 4). The IR9669 selection, with very slight leaf folding, performed better than this genotype.

Genotypes most tolerant of stress were the IR9669 selection, IRAT140, IRAT110, IRAT13, and N22; IR5 and IR20 were strongly sensitive. IRAT140 and IRAT110 yielded better than the other test cultivars. N22, the IR9669 selection, IR43, and Kinandang Patong also recorded moderately high yields. Panicle exsertion determined the extent of sterility, since spikelets in the unexserted sections of the panicles were completely sterile. The lower the exsertion, the higher was the sterility. Under mild or moderate stress conditions, the lack of anthesis contributed more to sterility. IR8, IR20, and IR5 panicles experienced more severe stress levels than the other cultivars (Fig. 12). Panicle water potentials of the IR9669 selection, IRAT13, and IRAT140 were higher at most stress levels and dates. IR36, IR43, N22, and Kinandang Patong experienced moderately severe stress conditions. N22 had high yield under stress and less sterility due to nonexsertion of the panicle. In most flowering and yield traits, the IR9229 selection proved superior to others. In general, the IRAT lines, N22, and Kinandang Patong can be recommended as genotypes tolerant of drought at flowering.

Pressure-volume water relations of rice panicles in response to water deficits (*Agronomy*). Pressure-volume (P-V) analysis of plant tissues allows the

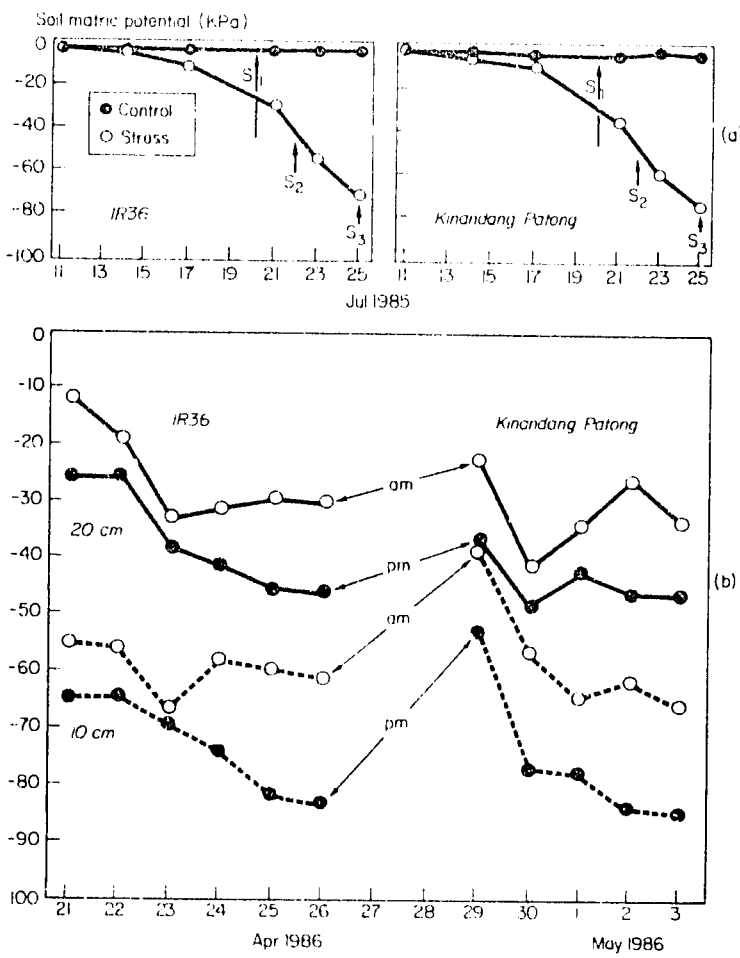


12. Trends in midday water potential of 12 rice cultivars exposed to mild, moderate, or severe soil moisture stresses and control conditions during the last 7 d of stress (mean ± SD). IRRI, 1986.

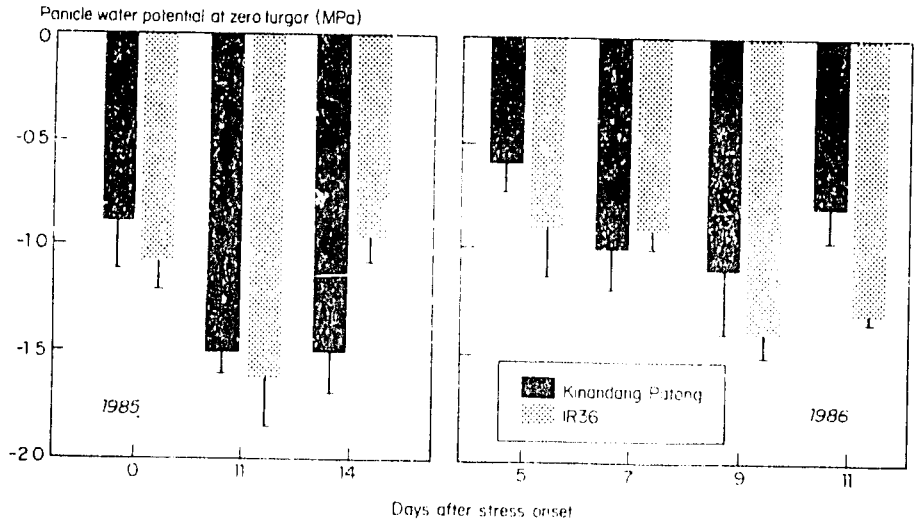
determination of physiological and physical parameters that characterize plant responses to water deficit. Although P-V techniques have been applied widely to the study of leaf-water relationships, they have been little used for studying the water relationships of floral organs.

Because rice yields are highly susceptible to reduction by water deficit during flowering, two greenhouse studies were conducted to evaluate the effects of flowering-stage water deficit on the P-V water relationships of rice panicles. Kinandang Patong and IR36 were grown in 112-liter barrels containing autoclaved Maahas clay. In 1985, the soil was allowed to dry naturally until it reached about 0.15 MPa SMT; P-V measurements were made at 3 times during stress development (Fig. 13), and only panicles that were 50% exserted were studied. In 1986, the soil was allowed to dry to about 0.06 MPa and was then maintained at that moisture level through daily watering (Fig. 13); panicles of various degrees of exsertion were used.

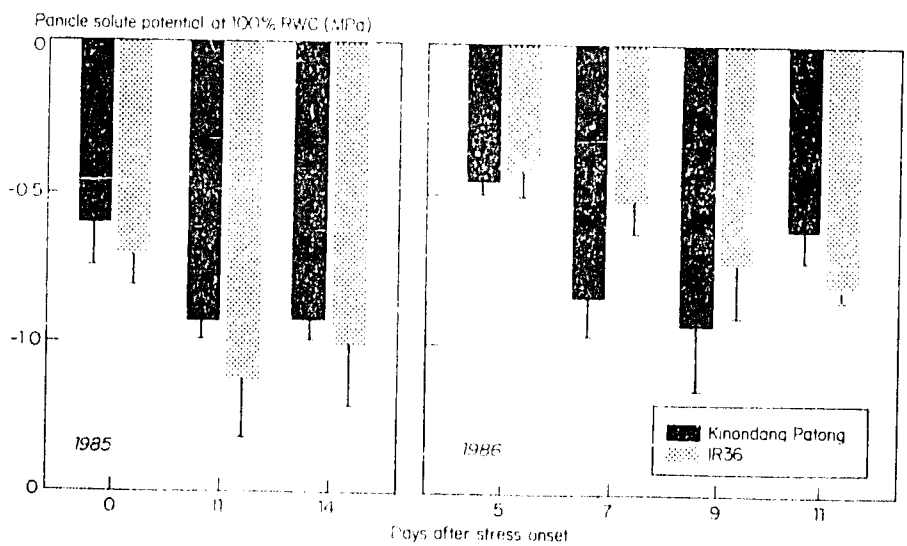
The panicle water potentials at zero turgor (Fig. 14) and solute potential at 100% relative water content (Fig. 15) declined as stress became more severe, suggesting osmotic adjustment in the rice panicles. In addition, the modulus of elasticity in the 1986 study appeared to increase in response to water deficit for IR36, but not for Kinandang Patong (Fig. 16). The increase in modulus of elasticity indicates that cell walls became less stretchable but more resilient. An increase in modulus of elasticity may indicate that cells were



13. Soil matric potential during water deficit periods for pressure-volume analysis of rice panicles. IRRI, 1986. S_1, S_2, and S_3 = sampling times.



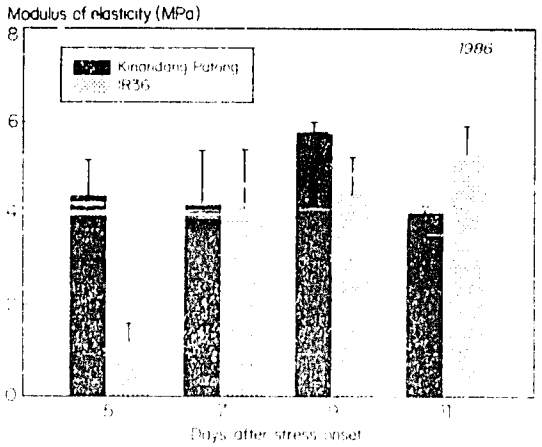
14. Panicle water potential at zero turgor from pressure-volume analysis in response to flowering-stage water deficit, IRRI, 1985-86.



15. Panicle solute potential at 100% relative water content (RWC) from pressure-volume analysis in response to flowering-stage water deficit, IRRI, 1985-86.

smaller or cell walls more rigid in response to the stress.

Although IR36 generally appeared more responsive to stress through reduction of solute potential than Kinandang Patong, the results were not consistent. One problem with P-V techniques as applied to rice panicles is that there appears to be a very high apoplastic water fraction in rice panicles (Table 18). Previous studies with leaves of rice and other crops have shown that the apoplastic water fraction is generally about 0.3-0.5. Our studies of rice panicles, however, showed an apoplastic water fraction of 0.56-0.79. A possible explanation for these high values is that for leaves, the sap expressed during the P-V analysis has a solute potential near zero, whereas the sap expressed from rice panicles may have significant amounts of dissolved solutes. Future studies must



16. Modulus of elasticity of rice panicles in response to flowering-stage water deficit. IRRI, 1986

Table 18. Apoplastic water fraction (Va) and relative water content at zero turgor (RWC, P = 0) for rice panicles.[a] IRRI, 1986.

Year	Variety	Va	RWC, P = 0 (%)
1985	Kinandang Patong	0.79	93
	IR36	0.69	90
	Significance	**	ns
1986	Kinandang Patong	0.59	93
	IR36	0.56	82
	Significance	ns	**

[a] ** = significantly different at P < .01 by t-test.

account for the solute potential of expressed sap to improve estimates of the apoplastic water fraction.

The high apparent level of apoplastic water may have also led to the high relative water content at zero turgor. Leaves generally tolerate a reduction of relative water content to about 0.7-0.8 before losing turgor, whereas rice panicles lost turgor at around relative water content of 0.9 (Table 18). If a large fraction of the panicle water is in the apoplast, then a very small reduction in symplastic water potential could have a very great effect on the turgor.

These P-V analyses show that rice panicles appear to respond to water deficits by reducing solute potentials and through changes in physical structure, and that there are differences between the more drought-resistant Kinandang Patong and the less resistant IR36. It is not yet clear which of these factors may confer resistance to water deficits at flowering. Furthermore, although P-V analysis may help elucidate the response of rice panicles to water deficits, the technique must be further refined.

Root characters in aeroponic culture (*Upland Rice Breeding*). Twenty-eight selected breeding lines from the upland replicated yield trial were screened for desired root characters in aeroponic culture. Moroberekan was the resistant check and IR20 the susceptible check. Eleven breeding lines had root length equal to or longer than that of Moroberekan. The most outstanding lines were IR11397-1-8-1, IR13754-6-3, IR27078-11-6, IR27078-20-6, and IR30716-B-8-B-5-4, which have a traditional upland parent such as OS4, LAC23, E425, Rikuto Norin 21, Palawan, and Azucena.

The roots of all breeding lines were thicker (0.51-0.74 mm) than those of IR20 (0.35 mm) but did not approach those of Moroberekan (0.87 mm). The breeding lines, however, have higher root to shoot ratios (0.353-0.518) than Moroberekan (0.349), except for 2 lines whose ratios were slightly lower (0.343 and 0.335).

A deep-and-thick root system is a drought avoidance mechanism. Moreover, thick roots are positively correlated with the number of xylem vessels and xylem vessel area. These traits are vital to the conductance of water from the soil to the upper parts of the plants to meet the evaporative demand.

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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SCREENING FOR TOLERANCE FOR CHEMICAL SOIL STRESSES

Soils Department

In 1986, screening for tolerance for chemical stresses was continued. Of a total of 12,792 entries screened, 1,528 were found tolerant (Table 1). Performance trials with promising rices were intensified, with greater emphasis on P deficiency in both flooded and acid upland soils.

SALINITY

Soils, Plant Physiology, and Plant Breeding Departments and International Rice Testing Program

Screening for tolerance (*Soils*). Of 8,056 rices from the various components of the GEU program and from the anther cultures of the Tissue Culture Facility screened in the greenhouse, 619 were tolerant at a salinity stress of 9 dS/m.

The 35 entries of the International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON) were tested in a salinized field. During the dry season (DS), only Bhurarata 4-10 and IR19743-40-3-3-2 were rated tolerant. When conditions were rendered milder by the rains in the wet season (WS), A69-1, IR26916-13-1-1, IR28228-119-2-3-1, IR32307-107-3-2, IR9808-9-2, and the resistant check Pokkali were rated tolerant.

In a salinized field, 239 entries from the GEU elite lines and those rated tolerant and susceptible in greenhouse tests were evaluated. Only 13 were rated tolerant during DS and WS: IR31906-67-1-1-2, IR41985-16-2, IR31906-67-1-1-2-2, IR41985-16-2-2-1, IR28228-28-1-3-3-2, IR32429-47-3-2-2, IR33043-46-1-3, IR39357-133-3-2-2-2, IR35293-125-3-2-3, IR13146-45-2-3, IR28228-119-2-3-1-1, IR21567-9-2-2-2-1, and IR31361-8-3-1-1.

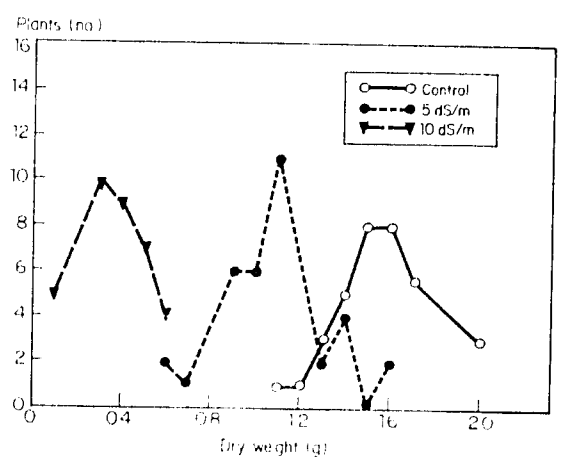
Table 1. Summary of screening for chemical stress tolerance, IRRI, 1986.

Stress	Entries tested (no.)	Tolerant (no.)
Salinity	8794	645
Alkalinity	1293	274
Acid sulfate soil	89	7
Peat soil	144	13
P deficiency	875	304
Zn deficiency	1346	234
Al Mn toxicity	145	29
B toxicity	106	22

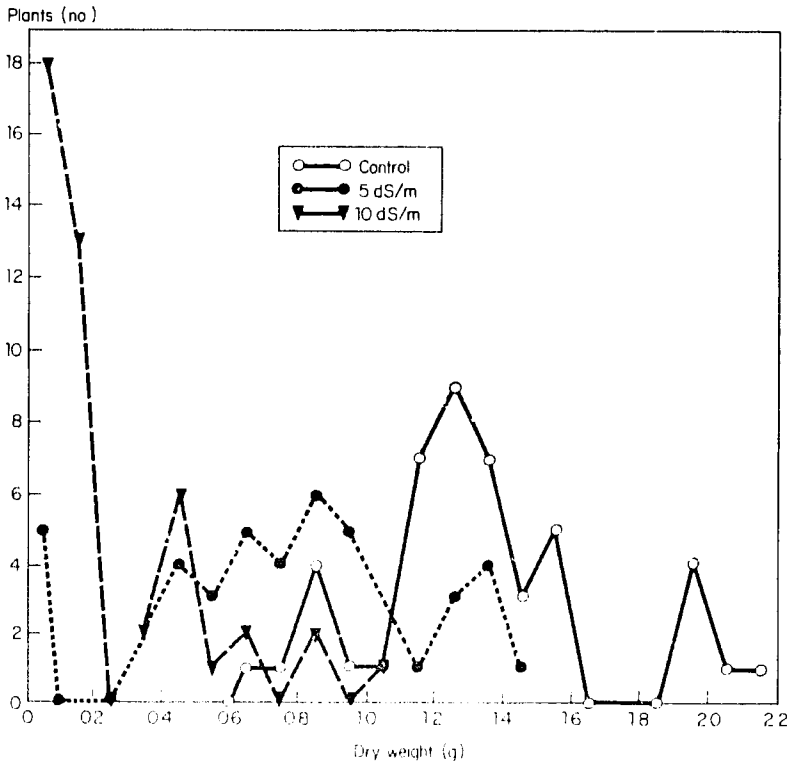
In farmers' fields in Bulacan (salinity 4-9 dS/m) and Pampanga (9 dS/m), Philippines, where salinity is caused by inundation with brackish water from a tidal creek, 464 entries were tested. The eight entries that showed tolerance for saline soil conditions were BG367-4, IR19743-40-3-3, IR32307-107-3-2, IR8073-231-3, IR28909-2-0-1, Banih Runtai Putih (Acc. 17233), Bayar Putih (Acc. 48500), and Lemo Besar (Acc. 19999).

Plant factors affecting salt tolerance (*Plant Physiology*). *Intravarietal variation.* Large variability in salt tolerance is often observed within rice varieties. To explain this phenomenon, the seedling weight of 45 plants grown for 30 d in normal and saline (5 and 10 dS/m) nutrient solutions was determined individually (experiment 1).

In each variety, marked variation in seedling growth was observed under both normal and saline conditions (Fig. 1, 2). Genetically pure cultivars such as Pokkali showed a normal frequency distribution of seedling weight under nonsaline conditions. However, some varieties and lines were far from normal and showed multimodal patterns under normal conditions with corresponding peaks under saline conditions (Fig. 2). Intravarietal variation of seedling tolerance for salinity is thus governed by two factors: differences in embryo



1. Frequency distribution of dry weight of Pokkali under normal and saline conditions, IRRI, 1985.



2. Frequency distribution of dry weight of IR4595-4-1-13 under normal and saline conditions. IRRI, 1985.

weight, which are inevitable intravarietal variations even within pure cultivars, and genetic impurity.

If intravarietal variation is partly caused by genetic impurity, the continuous selection of materials under salt stress conditions should efficiently select tolerant variants from a given variety or line and identify resistant individuals from varieties that already possess many desirable agronomic traits. However, the percentage of tolerant plants under a stress condition from a given variety that was once selected under salt stress conditions is apparently not always better than the original material (Table 2). These results do not exclude the possibility of selecting tolerant material from an impure cultivar. However, the chances of selecting highly tolerant variants from already released modern high-yielding cultivars through this method will be low.

Growth rate. Results from experiment 1 showed that, in the same cultivar, plants obtained from the heavier portion of the distribution curve have higher relative dry weights at 5 and 10 dS/m (Table 3) and lower Na content (Table 4) than smaller plants. In another experiment using 18 rice varieties grown at full and 20% nutrient levels at pH 5 and pH 9, and salinized at 5 and 10 dS/m, varieties differed in the amount of Na absorbed by the shoot; Na uptake was negatively correlated with relative growth (Fig. 3). A higher growth rate under saline conditions would therefore indicate lower Na uptake into the shoot, higher salt exclusion ability, and, consequently, higher salinity tolerance. Na content was negatively related, although loosely, to dry weight in the control (Fig. 4), which also indicates that the lower specific Na content of tolerant cultivars is due to their faster growth rate.

Besides relative growth, another criterion that can be used in evaluating salt tolerance is survival percentage. Since in extreme cases salinity causes plant death, survival percentage is a better characteristic for evaluating seedling salt tolerance from the agronomic point of view. Survival can be

Table 2. Survival of rice cultivars after one generation of selection using salinized culture solution. IRRI, 1986.

Variety or line	Days of salinization[a] (no.)	Survival (%)	
		Parent	R_2
ADT4	13	40	14
MI-48	13	18	18
IR36	16	13	18
IR56	16	20	28
Taichung 65	17	28	36
IR8	19	5	25
IR52	19	39	22
ADT28	20	20	27
IR32	20	17	22
IR4595-4-1-13	20	47	27
IR9884-54-3	20	20	23
IR31375-3-3-1-1	20	20	42
Jhona 349	20	25	38
KR1-24	21	37	59
IR4563-52-1-3-6	22	11	36
BR4-10	23	52	16
Getu	23	27	25
IR4630-22-2-5-1-3	23	34	29
M242	23	33	23
Kharai Ganja	24	10	32
Nona Bokra (International Rice Germplasm Center)	24	55	37
Pokkali	24	40	40
Nona Bokra (Plant Breeding)	25	52	43

[a]Concentration and duration of salinization: 15 dS/m for the first 10 d, 20 dS/m from the 11th to the 15th day, then 25 dS/m from the 16th to the 25th day.

Table 3. Relative dry weight of plants located in each peak of the distribution curve. IRRI, 1985.

Variety or line	EC (dS/m)	Relative dry weight			
		Peak 1	Peak 2	Peak 3	Peak 4
KR1-24	5	0.75	0.76	0.57	
	10	0.80	0.63	0.47	
IR4595-4-1-13	5	0.69	0.54	0.49	0.41
	10	0.44	0.41	0.32	0.12
IR8	5	0.93	0.92	0.66	

evaluated either by the day of 50% death (D_{50}) or by the EC level resulting in D_{50}. To determine the varietal differences in the survival percentage of 15 rice varieties, 1-wk-old seedlings were grown at different EC levels (1, 6, 8, 10, 12, and 14 dS/m). Twenty plants were scored daily for survival percentage and sampled 30 d after salinization. The electric conductivity giving D_{50} was found to be closely related to initial dry weight (Fig. 5). Cultivars with low growth rate in the control rarely showed high tolerance. Thus faster growth rate is one of the prerequisites for higher survival under salt stress, although cultivars having a faster growth rate are not always tolerant because of other limiting factors.

Survival percentage is often considered to be proportional to relative growth under salinized conditions. However, remarkable differences appeared when comparing the relationship between survival percentage and relative growth under salinized conditions among rice cultivars. Some cultivars showed higher survival under similar growth reduction (Fig. 6). This may be explained by the dilution of Na because of higher growth rate or by a difference in the ability to localize Na^+ from the actively growing part in tolerant cultivars, which is also related to growth rate.

Ethylene as an indicator of salt tolerance (*International Rice Testing Program*). Growing salt accumulation in cultivated and cultivable riceland and other cropland poses a serious threat to irrigated agriculture. The development of cultivars with high salinity tolerance and of a methodology to monitor and rapidly screen for salt tolerance may ameliorate the problem. Because of the involvement of ethylene in growth responses under stress, its potential as an indicator of salt tolerance in rice was investigated. Little ethylene was detected in rice seed in the presence or absence of 0.1 M NaCl with up to 6 d of soaking. When 1-aminocyclopropane-1-carboxylic acid (ACC) was used, alone or in combination with salt, ethylene production began on the 3d day of soaking, reached a maximum at 4-5 d, and then declined. A parallel increase in ethylene production and shoot growth occurred in the presence or absence of salt with an increase in ACC concentration, reaching a maximum at 1-2 mM; at 5-50 mM both processes were inhibited. ACC-derived ethylene production and shoot growth are inhibited to varying extents in rice genotypes by the addition of 0.1 M NaCl. At the saturating dose of ACC (2 mM), ethylene production depended on the activity of the ethylene forming enzyme because of CO^{2+}, not aminovinylglycine, inhibited

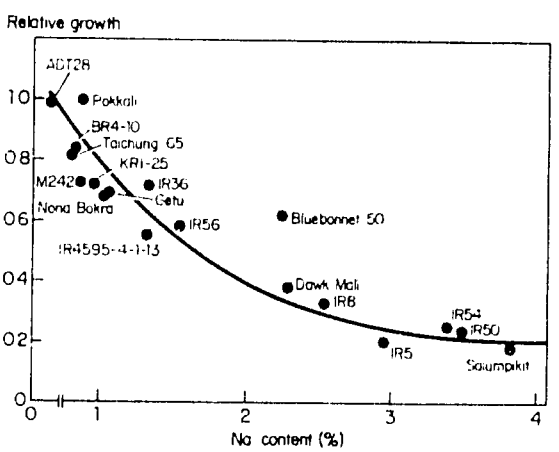
Table 4. Na and K contents of plants located in each peak[a] of the distribution curve. IRRI, 1985.

Variety or line	EC (dS/m)	Plant part	Contents (%)							
			Peak 1		Peak 2		Peak 3		Peak 4	
			Na	K	Na	K	Na	K	Na	K
KR1-24	5	Shoot	2.27	1.84	2.29	1.72	2.83	1.78		
		Root	2.34	0.70	2.50	0.70	2.66	0.70		
	10	Shoot	3.63	2.76	2.96	2.61	4.22	2.95	4.33	2.05
IR4595-4-1-13	5	Shoot	1.27	1.99	1.52	1.97	1.69	1.84	2.02	1.75
		Root	2.30	0.95	2.29	1.06	2.33	1.12	2.64	1.03
	10	Shoot	3.70	2.68	4.31	2.68	4.83	2.63	5.05	1.53

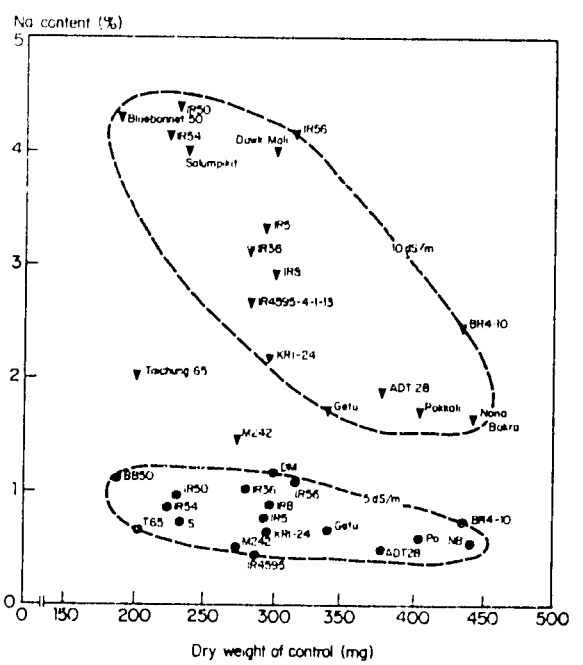
[a]Weight of plants in increasing order: peak 1 > peak 2 > peak 3 > peak 4.

shoot growth and ethylene production. The capacity of rices to produce ACC-dependent ethylene is a varietal trait and correlated well ($r = 0.91$) with salt tolerance at the seedling stage. The data indicate that ethylene could serve as biochemical marker for mass screening of large breeding populations of rice for salinity tolerance at early seedling establishment.

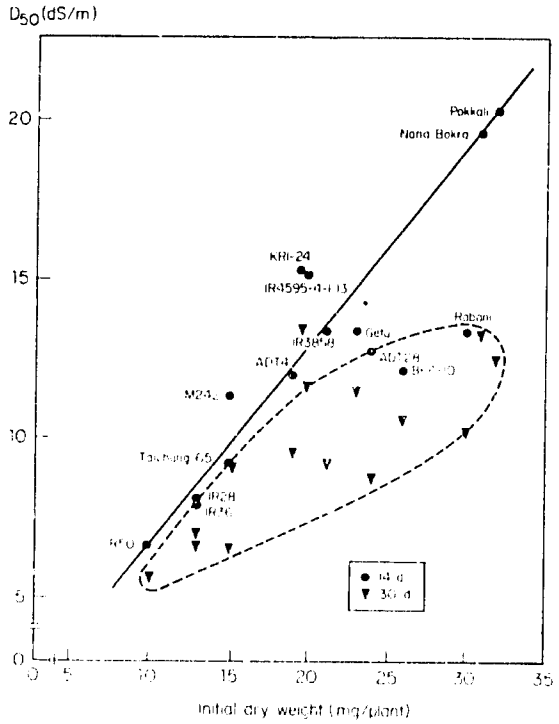
Effect of Na:Ca and Na:K in saline culture solution on growth and mineral nutrition (*International Rice Testing Program and Soils*). Two experiments were conducted in saline culture solution to find the causes of rolling and bleaching of young rice leaves, previously observed in experiments on coastal saline-sodic soils. Symptoms were observed on young leaves of KS282 in saline culture solution with Na:Ca of 100 or greater. These symptoms were due to Ca deficiency, not Cu deficiency, since Cu concentration was higher in saline shoots of the test plants than in the control. The decreasing Na:K or Na:Ca in the saline solution decreased Na and Cl concentration in the shoot. In addition to salinity, the Na:Ca and Na:K of the growth medium significantly influenced rice shoot and root growth.



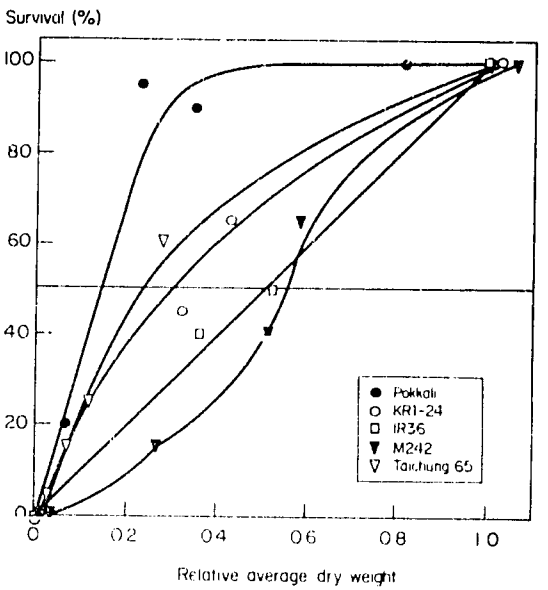
3. Na content in the shoot and relative growth of varieties grown at pH 5, 20% N, and NaCl at 5 dS/m. IRRI, 1985.



4. Relation between dry weight of control and Na content of shoot. IRRI, 1985.



5. Relation between initial dry weight and survival ratio. IRRI, 1985.



6. Relationship between survival percentage and relative average dry weight after 30 d of salinization using full concentration and pH 5. IRRI, 1985.

Effect of ionic composition (*Plant Breeding and Soils*). We studied the effect of various ionic compositions chloride-sulfate (CS) with sulfate dominance, $SO_4^{-2}/Cl^- = 7$; sulfate-chloride (SC) with chloride dominance, $Cl^-/SO_4^{-2} = 2$; and chloride (CL), which were comparable to those in natural saline soils on rice plant growth. In each composition, 4 levels of salinity expressed as electrical conductance (EC) 2, 4, 6, and 8 dS/m were used. Salt-tolerant Pokkali and salt-sensitive IR5929-12-3 were grown in Maahas clay salinized by the three ionic compositions at four EC levels.

Plant height at different growth stages and culm height after panicle initiation responded differentially. CL was the most harmful and CS the least harmful composition, irrespective of varietal tolerance. Lower salinities (2 and 4 dS/m) enhanced growth and higher salinities (6 and 8 dS/m) suppressed it.

CS at 2 dS/m advanced flowering in Pokkali. SC and CL at that level were comparable to the control; the rest of the treatments delayed flowering (except for CS up to 6 dS/m). In IR5929-12-3, all treatments except CS at 2 dS/m, delayed flowering.

Panicle emergence was not altered by any of the treatments except for CL at 8 dS/m in Pokkali. In IR5929-12-3, this parameter was comparable to the control only at 2 dS/m. The differential effects of the different ionic compositions were also observed. Harmful effects followed the order CL>SC>CS.

The lowest EC of CS and SC significantly increased the panicle length of Pokkali. Only SC and CL at 8 dS/m produced significantly shorter panicles. The pattern in IR5929-12-3 was similar to that in Pokkali except for the absence of an enhancement of panicle length in CS and SC at 2 dS/m and a significantly shorter panicle in CL at 6 dS/m.

The number of productive tillers of Pokkali was not affected by either level or type of ionic composition. However, that of IR5929-12-3 decreased with increasing salinity. CL gave the lowest number of productive tillers and CS the highest at a given salinity level. SC was intermediate.

Other yield components studied were total number of spikelets on the main panicle, sterility percentage of the main panicle, and 1,000-grain

weight. Irrespective of varietal tolerance, lower salinities did not adversely affect the total number of spikelets on the main panicle. Exceptions were CS and SC at 2 dS/m in Pokkali, where the number significantly increased; and CL at lower salinities in IR5929-12-3, where spikelet number was significantly reduced. Producing the lowest spikelet number, CL was more harmful than CS and SC on both varieties, especially on IR5929-12-3.

The sterility percentage in Pokkali did not change with type or level of salinity, although this parameter was significantly higher than the control in all treatments except for CS at 2 dS/m. The pattern in IR5929-12-3 was entirely different from that in Pokkali. Increasing salinity increased the sterility percentage. Differential effects of different ionic compositions were observed from 2 dS/m up to 8 dS/m. In IR5929-12-3, sterility percentage followed the order CL>SC>CS.

The response of 1,000-grain weight to salinity was similar in both varieties. CS did not alter the 1,000-grain weight in either variety at any EC level. With SC, 1,000-grain weight in both varieties was comparable to the control up to 6 dS/m. Only at 8 dS/m did SC reduce the 1,000-grain weight in both varieties. CL produced the lightest seed at all levels.

Lower salinities could increase the yield of the tolerant variety, depending on the ionic composition. However, all treatments reduced the yield of the sensitive variety.

Except for the highest salinity level of CL, the salt treatments did not adversely affect the straw yield of Pokkali. In IR5929-12-3, the adverse effect of salinity on straw yield was restricted to the higher salinities (SC at 8 dS/m and CL at 6 and 8 dS/m).

The grain-to-straw ratio decreased with increasing salinity, irrespective of variety. However, low salinities (2 and 4 dS/m for Pokkali and 2 dS/m for IR5929-12-3) did not change the ratio except for CL at 2 dS/m in IR5929, which had a lower ratio than the control.

Total milled rice (TMR) and head rice (HR) recovery were not affected adversely by the lower salinities, irrespective of the composition of the ionic media and the tolerance of the varieties, but were reduced by higher salinities. A striking difference between the two varieties was in hull percentage. In Pokkali, hull percentage gradually increased with increasing salinity, but in IR5929-12-3, it did not respond to any treatment.

The effect of salinity on brown rice protein was not very pronounced. In Pokkali, CS at 8 dS/m and SC and CL at 8 and 6 dS/m increased protein. In IR5929-12-3, no significant difference was observed in any treatment.

Lower salinities did not alter the amylose content of Pokkali, but higher salinities did. In IR5929-12-3, only CL at 4 and 6 dS/m reduced amylose content. The gelatinization temperature of Pokkali did not change under any treatment. However, SC at 8 dS/m and CL at all levels changed the gelatinization temperature of IR5929-12-3 from intermediate to low.

The two varieties differed in the distribution of Na in their grains. The Na content of the hull was more than that of the kernel in Pokkali; it was the opposite in IR5929-12-3. Increasing salinity increased the Na content in both milling fractions of both varieties, keeping the pattern of distribution unchanged; however, accumulated Na due to increased salinity concentrated mainly in the hulls.

Effect of heterosis on soil salinity (*Plant Breeding and Soils*). Increased vegetative and root vigor are useful for adaptation to soil and climatic stresses. Generally, F_1 hybrids express these traits. Therefore, as a preliminary investigation, we evaluated a number of F_1 rice hybrids and their parents for survival under saline soil conditions at IRRI in 1986 DS. Although the parents of these hybrids are not known to be tolerant of salinity, our objective was to test the usefulness of hybrid vigor under stresses such as soil salinity.

Five-week-old seedlings of 12 hybrids and their parents grown on a wet seedbed were transplanted in a field where salinity of 7 dS/m was induced by adding common salt. The salinity level was maintained throughout the experiment. Each entry was planted on 50 hills. Check varieties were IR28 (salt-sensitive) and IR9884-54-3 (salt-tolerant). Plant survival was recorded at 6, 12, and 15 wk after transplanting.

Salinity prolonged the growth of all varieties tested. Parents and hybrids that are very early under normal conditions flowered about 100 d after seeding.

Six of the 12 hybrids evaluated showed strikingly increased survival compared to their

parents. In three cases, hybrids and parents were comparable; in two, hybrids were inferior to the better parent. One hybrid was superior to its parents at the early stages but subsequently became comparable to them. Some F_1 hybrids could thus be superior to their parents in adaptability to salinity because of increased root and shoot vigor.

Physiological aspects of salt tolerance (*Plant Physiology and Soils*). Our collaborative research program with the University of Sussex on the mechanism and physiological aspects of salt tolerance in rice entered its third phase. In the first phase, we found that no single factor is a fully representative marker for salt tolerance as judged by seedling survival, that there is enormous individual variability for tolerance within lines, and that shoot Na content is the best single marker although it accounted for only half of the variance in survival.

The second phase revealed that salinity resistance is not the consequence of one, but of many plant processes. A wide-ranging examination of the basic physiology of the plant identified many traits that could contribute to salt tolerance, e.g., low permeability of the root system to salt, the preferential localization of Na in the older leaves, and differential tolerance of the leaf tissue itself for salt. The main conclusions of this phase were that variation does exist in several processes that could be components of overall salt tolerance, and that the best prospect for increasing tolerance is to select for the components individually and then combine them in a single variety.

The third phase of our collaboration is the beginning of practical breeding. We identified varieties and lines with different mechanisms for salt tolerance and made crosses in an attempt to pyramid together the genes for these mechanisms into a single variety. Table 5 shows some of the parents we used, along with their score for various tolerance traits.

ALKALINITY

Soils Department

Screening for tolerance. Mass screening of 1,067 entries from the Plant Breeding Department showed that 259 were tolerant of alkalinity at pH 8.5 and Na absorption ratio of 40.

Table 6. Rice plant samples from an acid upland soil, Caliraya, Laguna, Philippines, 1986 WS.

No.	Variety	Plant type	Growth response to P
1	LAC23	Japonica	None
2	Chianan	Japonica	None
3	Azucena (C)	Japonica	None
4	B2997C-TB-4-2-1	Indica	Slight
5	INIAP415	Indica	Slight
6	B3622F-TB-14-2	Indica	Slight
7	B3623G-TB-46	Indica	Intermediate
8	C171-136 (selection)	Indica	Intermediate
9	IR47691-11-9-1	Japonica	High
10	IR47701-11-5-1	Japonica/indica progeny	High

Table 5. Scores for vigor, survival, Na transport, tissue tolerance, and leaf-to-leaf compartmentation of some known salt-tolerant varieties and lines, IRRI, 1986.

Variety or line	Vigor	Survival	Na transport[a]	Tissue tolerance[b]	Leaf-to-leaf compartmentation[c]
Cheriviruppu	1	1	2	7	8
Damodar	4	3	2	7	8
IR36	7	5	4	5	9
IR4595-4-1-13	6	3	3	5	7
IR4630 22-2-5-1-3	7	2	2	1	4
IR10167-129-3-4	8	5	6	2	3
Nona Bokra	2	1	1	7	6
Pokkali	1	1	3	9	8

[a] 1-9 scale: 1 = low shoot sodium, 9 = high shoot sodium. [b] 1-9 scale: 1 = high tissue tolerance, 9 = low tissue tolerance. [c] 1-9 scale: 1 = high compartmentation, 9 = low compartmentation.

Of the 29 entries of IRSATON tested in an alkali plot during DS and WS, 5 were found tolerant: IR4422-480-2-3, IR8073-231-3-3, IR8608-75-3-1, IR21820-154-30-6, and IR22083-105-3.

The elite breeding lines were tested in an alkalized field; 15 were scored tolerant, with IR20, IR26468-36-2, 2 IR28228 lines, IR31868-64-2, IR33059-26-2, IR33059-26-2-2, and IR37873-16-2-3 being outstanding.

IRON TOXICITY

Soils Department

Screening for tolerance and yield trials. Field mass screening for tolerance for Fe toxicity on an acid sulfate soil was done in Albay, Philippines, during DS. Seven of 89 rices from International Rice Testing Program (IRTP) nurseries were rated tolerant: B2791B-MR-196-2-3-1-8-KP-3, B2791B-MR-196-2-3-3-5, B3063C-PN-151-2, BR51-74-6-J1, IR13146-45-2, IR22082-41-2, and IR31238-474-3-p4.

In DS, a mean yield of 3 t/ha was obtained from an evaluation of 16 rices. The highest yielder was IR4683-54-2-2-3, with 3.6 t/ha. The line IR9764-45-2-2, repeatedly confirmed as having multiple stress tolerance, had a comparable yield of 3.5 t/ha.

Highly significant differences in grain yield were observed among the rices tested. Tissue analysis at maximum tillering showed the rices had adequate amounts of P, K, Mg, Mn, Cu, and Si; toxic contents of Fe and Al; and deficiencies of N, Ca, and Zn.

PHOSPHORUS DEFICIENCY

Soils Department

Screening for tolerance. Of 875 rices screened, 30% were found efficient in utilizing small amounts of P. Among the most efficient were IR5657-33-2, IR32453-20-3-2, IR32843-92-2, IR35361-59-3, IR35366-40-3, IR35366-90-3, IR39357-133-3, IR39423-124-3-3, and three tissue culture-derived rices.

Yield trials. Of 32 rices tested in a performance trial in a P-deficient farmer's field, the 20 that produced yields greater than 4 t/ha were medium- to late-maturing. Among them were IR62, IR65, IR19672-155-2, IR25588-7-3-2, IR25604-99-13, IR28222-9-2, IR29723-17-3, IR32453-20-3, and IR25361-9-2.

The addition of 25 kg P/ha conferred a mean yield advantage of 1.7 t/ha on 10 rices.

Effect of P fertilization on mineral nutrition of upland rice. Ten-week-old plants exhibiting different growth responses to P fertilization (Table 6) were sampled for chemical analyses in the 1986 WS acid upland screening trial of the Plant Breeding Department at Caliraya, Laguna. The soil is a Palehumult (clay = 66%, pH = 4.0, organic C = 2.5%, total N = 0.23%, Olsen P = 1.2 mg/kg, CEC = 23.6 mol/kg).

Besides N, Ca, K, and Mg, P is the major limiting nutrient. Fertilization with 40 kg P/ha increased the P content in all plants but did not raise it above the critical level.

P addition resulted in a corresponding increase in plant Mn.

Plants with no or slight growth response revealed Fe and Al contents of more than 300 mg/kg in control plots, while plants with intermediate or high response showed less than 300 mg/kg.

With P addition, the P-to-Fe ratio increased and the Fe-to-Mn ratio decreased in plants with no or slight growth response; the opposite was observed in plants with intermediate and high response (Fig. 7, 8).

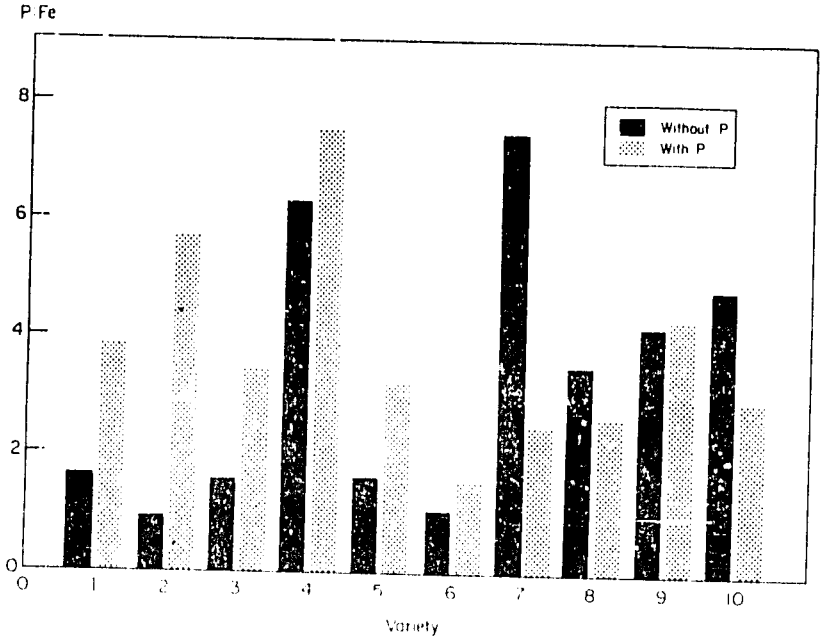
Observed varietal differences in growth response to P fertilization may thus be explained by different plant nutrient interactions.

ZINC DEFICIENCY

Soils Department

Screening for tolerance. In a Zn-deficient field in Bay, Laguna, Philippines, 234 of 1,346 rices screened were found tolerant. IR36, IR1552, and four tissue culture-derived rices were outstanding.

Performance trials. The performance of 40 rices was tested in a farmer's field. Fifteen with grain yields of 4-5 t/ha were considered efficient users. Highest yielders with 5 t/ha each were the cultivar IR38 and IR lines IR21567-9-2-2 and IR40757-11-3.



7. Effect of P fertilization on P/Fe in tissues of rice grown on an acid upland soil. Laguna, Philippines, 1986. Varieties keyed in Table 6.

The moderately susceptible IR40 and IR19743-25-2-2-3-1 responded significantly to Zn dip treatment. Resistant rices IR20, IR22, IR38, and IR25588-7-3-1 gave comparable yields with and without Zn treatments, confirming earlier reports that in marginally Zn-deficient soils, the use of a resistant variety is an inexpensive remedy.

MULTIPLE STRESSES

Soils and Plant Breeding Departments and International Rice Testing Program

Peat soil problems (*Soils*). Field mass screening of 144 entries from the 1986 DS and WS elite lines and the 1986 WS rainfed breeding lines was continued at Calauan, Laguna. Rated moderately tolerant in the presence of N, P, K, and Zn were IR28228-28-1-3-3-2, IR29692-65-2-3-3, IR29692-99-3-2-1, IR29723-143-3-2-1, IR32429-47-3-2-2, IR13146-13-3-3, IR13146-45-2-3, IR19318-1-2-1-1-2, IR21188-87-3-3-2-2, IR28526-44-1-1, IR33238-25-3-2, IR36974-13-3-3-3, and IR38699-49-3-1-2.

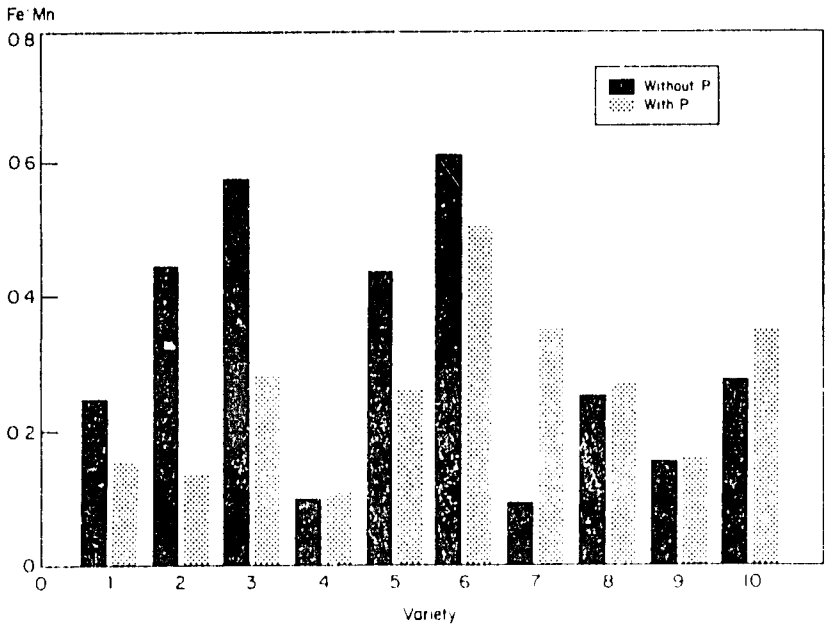
In concrete beds, the tolerance of IR34, IR46, IR64, and IR28150-84-3-3-2 was confirmed.

In tests with ZnO, and using entries previously rated as moderately tolerant, IR60 gave the highest yield in DS (3.6 t/ha) and in WS (2.2 t/ha). IR21848-65 gave a yield of 3.6 t/ha in DS but performed poorly in WS. IR13540-56 gave the same yield during both DS and WS.

Saline and acid sulfate soil conditions (*Soils, Plant Breeding, and International Rice Testing Program*). Twenty-five traditional tidal wetland varieties, 75 modern semidwarfs with adverse soils tolerance, 418 advanced breeding lines, and 90 entries in the IRSATON were evaluated at three locations in Iloilo, Philippines. The traditional tidal wetland varieties, modern semidwarfs, and F_3 populations were used in DS and the others in WS.

The fields were strongly saline because of tidal influence, and the soil has acid sulfate conditions. Salinity ranged from 3 to 27 dS/m, being generally higher in DS. The soils had low pH (3.7 in dry soil), low available P (3.8-5.0 ppm), high active Fe (1.2-1.8%), high acetate-soluble sulfates (0.26-0.35%), and high exchangeable Al (120-160 ppm). In WS the fields were also affected by floods (2-3 times/season), in which case the plants remained submerged for 2-7 d.

Pokkali performed best at all sites. Among the traditional varieties, Dudmona, Nizersail, Sulai, and Wagwag were comparable to Pokkali. Aliwee,



8. Effect of P fertilization on Fe:Mn in tissues of rice grown on an acid upland soil. Laguna, Philippines, 1986. Varieties keyed in Table 6.

AT69-5, BW295-5, IR4630-22-2-5-1-3, IR31361-8-3-2-2, IR31375-5-2-1-3, IR33451-12-1-1-1-2, IR33552-12-1-2-1-2-3, IR39537-27-5-1-3, and Mahsuri also showed tolerance for adverse conditions, but the degree was not as high as in Pokkali or other traditional varieties.

Of the advanced breeding lines and IRSATON entries, some that showed tolerance were ITA7414-10-2, IR4422-480-2-3-3, IR4427-28-3-2, IR4432-52-6-4, IR13149-45-2, IR13419-113-3, IR13426-19-2, IR30146-26-3-2-3, IR31432-5-4, IR33238-25-2-3-2, IR3306-93-6-3-3-3, IR33352-59-3-1-3, IR33360-5-1-3-2-2-3, IR33360-5-1-3-2-1-1, IR37119-4-3-2-3, and RP975-109-2.

Acid upland soils (*Soils, Plant Breeding, and International Rice Testing Program*). *Screening* (*Soils, Plant Breeding, and International Rice Testing Program*). About 650 rices were screened under acid upland soil conditions in a farmer's field in Bagacay, Iloilo, in WS. Soil in the test field was acidic (pH 4.2-4.9), low in available P (5.7 ppm), low in CEC (4-6 meq 100 g), and high in Al saturation (30-65%). The test rices were obtained from IRTP (361 entries) and the Plant Breeding Department. Varieties that showed tolerance for combined stresses were Berlin, B3016b-Tb-260-3-2-1-1-3, B2976b-Tb-60-3-3, Dhariwal, IR43, IR3646-9-3-1, IR3646-13-3-2-2-14-2, IR3646-13-3-2-2-15-2, IR3880-2-3, IR6023-10-1-1, IR10018-7-1-6-3, IR10147-113-5-1-1-5, IR26957-55-4, ITA116, Kinandang Patong, Ku-62, Mahsuri, IR165-28-14, TKM9, UPLRi-5, UPR103-80-1-2, and UPR231-28-1-2.

Screening and yield trials (Soils). Of 145 IRTP entries tested during DS and WS in an acid upland soil in Malinao, Albay, Philippines, 29 were rated tolerant of Al toxicity. Outstanding were INIAP415, IR1552, IR29723-17-3-2-1, IR9171-60-2-2, IR13539-100-2-2-3, ITA231, PAN50-B-25-1, and TOX955-104-1-1.

Three rice races were tested during DS in an acid upland area in Laguna. The japonica entries were found less susceptible to Al and Mn toxicities and had better vigor than the indica and the aus entries. Besides having tolerance for Al and Mn toxicities, upland rice varieties must be P efficient. Observed to have good general vigor in the absence of P were eight japonicas, five aus rices, and two indicas. None showed complete tolerance for brown spot disease.

In a drained acid sulfate soil (pH 3.9, organic C = 1.74%, exchangeable Al = 11.1 mmol/kg) in

Malinao, the effects of different rates of P fertilization (25 and 40 kg P/ha as solophos) under low N fertilization (20 kg N/ha) were evaluated using the 3 rice races. Highly significant differences in varietal reaction to the adverse soil factors were manifested by visual symptoms at 8 wk after sowing and by straw and grain yields at harvest. P treatment did not affect the scores or the dry matter yield. Application of 40 kg P/ha and low N rates did not alleviate Al toxicity, which was the main adverse factor in this soil. Of the six rices, IRAT109 (japonica) was the most P-efficient and Dular (aus) was the most P-responsive.

The performance of 15 rices previously rated tolerant was compared in a fertilized acid soil in Laguna. IR10781-75-3-2-2, UPLRi-7, IR9761-19-1, and IRAT104 each gave a yield of 2.5 t/ha. Although an entry exhibited symptoms of Mn toxicity, the main growth-limiting factor was P deficiency.

The performance of 12 drought-tolerant rices was tested under 2 levels of acidity (pH 4.4 and 3.7). Plant growth and yield were better under the more acid soil (1.7-3.8 t/ha at pH 3.7, 1.0-3.0 t/ha at pH 4.4). IR9761-19-1, BR319-1, and UPLRi-7 had high tolerance for soil acidity.

Inland iron-toxic and phosphorus-deficient soils (*Soils, Plant Breeding, and International Rice Testing Program*). In an inland Fe-toxic soil with low pH (3.8-4.2), available P (3.8 ppm), exchangeable K (0.02 meq/100 g), and organic matter (0.96%), and high active Fe (2.3%), 815 rice varieties were evaluated for their performance in a farmer's field in San Dionisio, Iloilo, in WS. The test rices were obtained from IRTP (669 entries) and the Plant Breeding Department (146 entries). About 40 selected varieties that are known to be tolerant of either P deficiency or Fe toxicity were further evaluated in DS.

Some of the rices that showed tolerance for these soil conditions included Bg 367-4, Bg 379-2, BR51-282-8, BC16-128-4-1, Bw 85, Bw 295-4, Bw 295-5, Bw 297-2, Cabayasi, CR1002, H-4, IR2307-247-2-2-3, IR5741-73-2-3, IR8192-166-2-2-3, IR8192-200-3-3-1-1, IR9764-45-2-2, IR9884-54-3, IR13423-17-1-2-1, IR21015-196-3-1-3, IR21820-154-3-2-2-3, IR24632-145-2-2-2-3, IR24637-38-2-2-1, IR25909-11-2-2-3-2, IR26821-200-3-1-1-1, IR27325-27-3-3, IR28222-23-1-3-3-2, IR28222-9-2-2-2-2, IR28228-12-3-1-1-2, IR29341-85-3-1-3, IR29706-94-1-3-2, IR29723-143-3-2-1, IR32358-122-2-1-2, Kuatik Putih, Layang, Mat Candu, MI 273, M28D-79-3, R114-2-1-1-1, Seribu Gantang, Suakoko (sel.), and UPR254-85-1-TCA3.

A COOPERATIVE FOR RESEARCH ON ADVERSE SOILS

Plant Breeding Department

A cooperative was established to share resources and responsibilities in adverse soils research. IRRI will work to strengthen one national program for each adverse soil type, so they can assume regional responsibilities. National programs selected are India for salinity, Indonesia for peat soils, Pakistan for alkalinity, Sri Lanka for Fe toxicity, and Thailand for acid sulfate soils. See Cooperative Country Projects.

Genetic evaluation and utilization (GEU) program

Deepwater and flood tolerance

Plant Physiology, Plant Breeding, and Agronomy Departments and International Rice Testing Program

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SCREENING FOR ELONGATION ABILITY

Plant Physiology Department

A total of 48 entries from the International Rice Deepwater Observational Nursery (IRDWON), the International Floating Rice Observational Nursery (IFRON), and the International Tide-Prone Rice Observational Nursery were screened for elongation ability. BR516-341-1, from the cross BR51-49-6/Habiganj A 4, was the most outstanding entry from IFRON.

SCREENING FOR SUBMERGENCE TOLERANCE

Plant Physiology Department

Submergence tolerance tests were conducted in concrete tanks in the greenhouse on 20,634 entries, including 1,675 from the germplasm bank (GB) and 16,148 from the pedigree nursery for rainfed lowland and deepwater rice. The GB entries showed no outstanding cultivars. Outstanding entries from the pedigree nursery were selected and transplanted in the field for further evaluation. Descendants of FR13A, FR43B, and Kurkaruppan were disproportionally represented among the best entries for submergence tolerance. Chenab 64-117 produced offspring mostly in the intermediate class of submergence tolerance (Table 1).

OUTSTANDING DEEPWATER RICES FROM IRTP NURSERIES

International Rice Testing Program

Entries that performed well in deepwater situations at several locations were

Baisbish (IFRON)
BKNFR76043-7-2-1-1 (IFRON)
BKNFR78023-38-1K-1-1 (IRDWON)
HTA7403-110-1-1-3 (IRDWON)
IR21038-77-P2-5-2-3-1-1 (IRDWON)
Jalamagna (IFRON)
Leb Mue Nahng 111 (IFRON)
SPR7410-0-256 (IFRON)
SPR7411-7-2-1 (IFRON)

INHERITANCE OF SUBMERGENCE TOLERANCE

Plant Breeding and Plant Physiology Departments

Submergence tolerance was investigated in an 8 × 8 diallel cross, where LD_{50} (duration in days to 50% mortality) of the completely submerged F_1 and parental seedlings was used to characterize submergence tolerance.

Additive and nonadditive gene effects were highly significant. Correspondence between parental means and the means of their progenies was close (Table 2), with $r = 0.84^{**}$, reflecting strong prepotency of the parents in transmitting submergence tolerance to their offspring. Three lines – BKNFR76106-13-2, IR31406-333-1, and BKNFR76106-16-0-1 – were the best parents. The mean submergence duration of the F_1s (7.3 d) was longer than that of the parents (6.9 d), indicating dominance of submergence tolerance. Highly tolerant parents also had high general combining ability (GCA) effects (Table 2), and F_1s of crosses between two tolerant parents were found to be the most tolerant of the diallel populations. The high narrow-sense heritability value of 0.79 also showed

Table 1. Distribution of crosses by parental source of submergence tolerance among 5 average levels of submergence tolerance, based on lines retained by the deepwater and rainfed rice breeding programs. IRRI, 1986.

SES score	Crosses (no.)	Percentage with given parentage[a]				
		Very tolerant	Medium tolerant	Slightly tolerant	Floating rice	Tall traditional rice
1	18	66.7	16.7	5.6	5.6	5.6
3	27	55.6	18.6	7.4	7.4	11.1
5	63	28.6	25.4	9.5	6.3	14.3
7	100	13.0	20.0	8.0	36.0	23.0
9	205	9.3	14.1	5.4	47.8	23.4

[a]Very tolerant = FR13A, FR43B, and Kurkaruppan; medium tolerant = Chenab 64-117, Goda Heenati, and FRG2; slightly tolerant = IR8234-OT-9-2.

Table 2. Mean calculated LD_{50} for parents and offspring of an 8 × 8 diallel cross for submergence tolerance. IRRI, 1986.

Parent	LD_{50}[a] (d)	General combining ability
IR11288-B-B-69-1	4.9	−1.07
IR42	5.1	−0.85
IR29012-4-1-3	5.6	−0.58
IR21567-16-2-2	6.5	−0.63
BKNFR76106-13-2	7.9	+1.31
IR8234-OT-9-2	8.0	+0.03
BKNFR76106-16-0-1	8.1	+0.84
IR31406-333-1	9.4	+0.94

[a]Duration in days to 50% mortality.

Table 3. Crosses with the longest LD_{50} in an 8 × 8 diallel cross for submergence tolerance. IRRI, 1986.

Parents	LD_{50} (d)	Specific combining ability
BKNFR76106-16-0-1/IR31406-333-1	9.7	0.63
IR29012-4-1-3/BKNFR76106-13-2	8.7	0.72
BKNFR76106-13-2/IR42	9.0	1.32
IR21567-16-2-2/BKNFR76106-13-2	9.3	1.33

the importance of additive gene action in submergence tolerance.

Parents with high submergence tolerance values also had high GCA effects. Therefore, crosses between tolerant parents are recommended for faster improvement of tolerant varieties.

The high heritability suggests the different varieties can be used for extensive crossing and selection in a conventional breeding program to improve submergence tolerance of varieties.

The tolerant lines IR31406-333-1 and BKNFR76106-16-0-1 showed high specific combining ability as well as GCA effects (Table 3), suggesting them as a cross to achieve higher submergence tolerance.

INTERNODE NUMBER AND LENGTH IN DEEPWATER RICE

Plant Breeding Department

Deepwater and nondeepwater rices grown under normal irrigated conditions varied in internode length and number. Twenty-five varieties including floating, deepwater, traditional tall, modern variety (MV) elongating, and MV nonelongating were selected. For each variety, 30 primary tillers selected randomly from 6 uniform plants at panicle emergence were studied. Internode length of tillers was measured from the top, and those less than 1 cm were not counted. Floating rices had, on the average, 8 internodes, with 6 elongated to more than 6 cm; deepwater rices had 6-7 internodes, 5 elongated; tall traditional varieties had 5-6 internodes, 4 elongated. The MV elongating types, like the tall traditional rices, had four elongated internodes but invariably had a higher total number of internodes. The MV nonelongating types had only two to three elongated internodes (Fig. 1). By this measurement, elongating rices can be distinguished from nonelongating ones even when they are grown in shallow water.

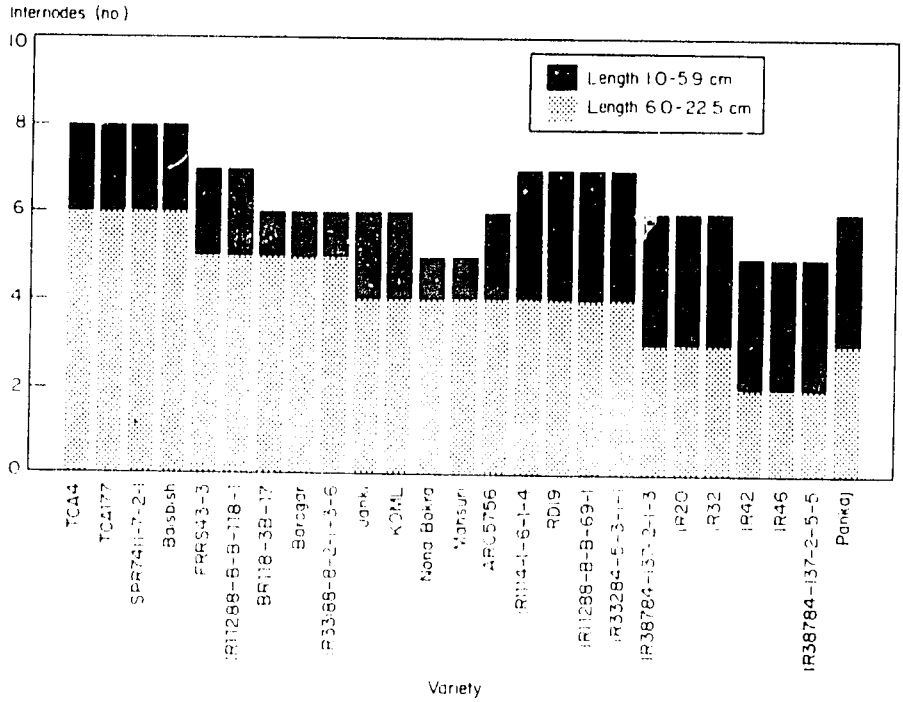
INHERITANCE OF PLANT ELONGATION ABILITY

Plant Breeding and Plant Physiology Departments

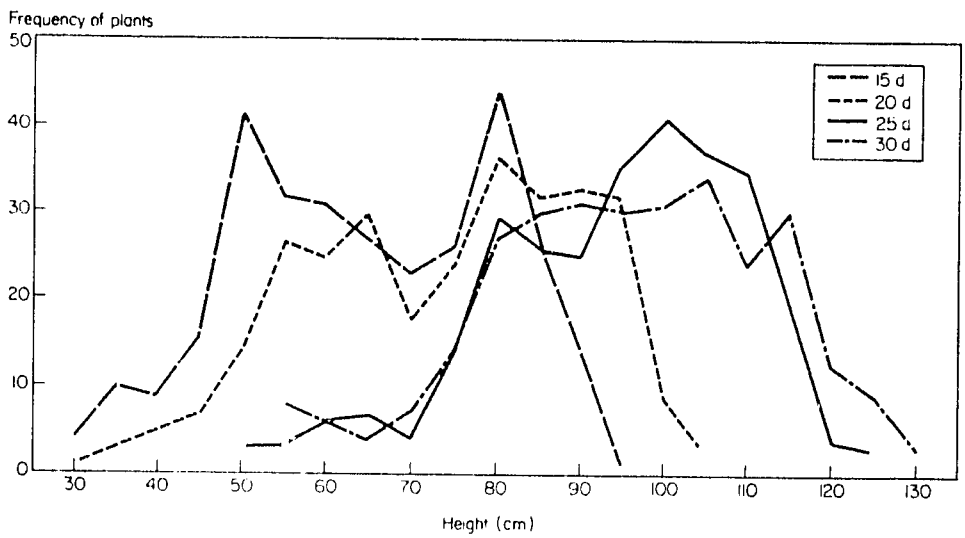
Segregation in plant elongation as a function of seedling age. In an effort to find an appropriate seedling age to distinguish elongating from nonelongating rices at a water depth of almost 70 cm, we studied 15-, 20-, 25-, and 30-d-old F_2 populations of a cross between Baisbish (floating) and IR42 (MV nonelongating). Seedlings were planted in rows in a tank along with the parents, keeping 5-d intervals between each set.

At 15-30 d after seeding, seedling height was recorded and water depth was increased to 30 cm. The next day, the depth was increased to 65 cm, where it was maintained for 7 d. The height of the plants was then measured. Three hundred plants of each set were analyzed for height.

In 15-, 20-, and 25-d-old populations, clear bimodal distributions were observed (Fig. 2). The segregation ratio was 9 elongating:7 nonelongating. Elongation therefore behaved as a dominant trait controlled by two complementary genes. Segregation was unclear in the population of 30-d-old seedlings, presumably because the low water depth was no longer a limiting factor at this age.



1. Internode number and length in 25 rice varieties and lines. IRRI, 1986.



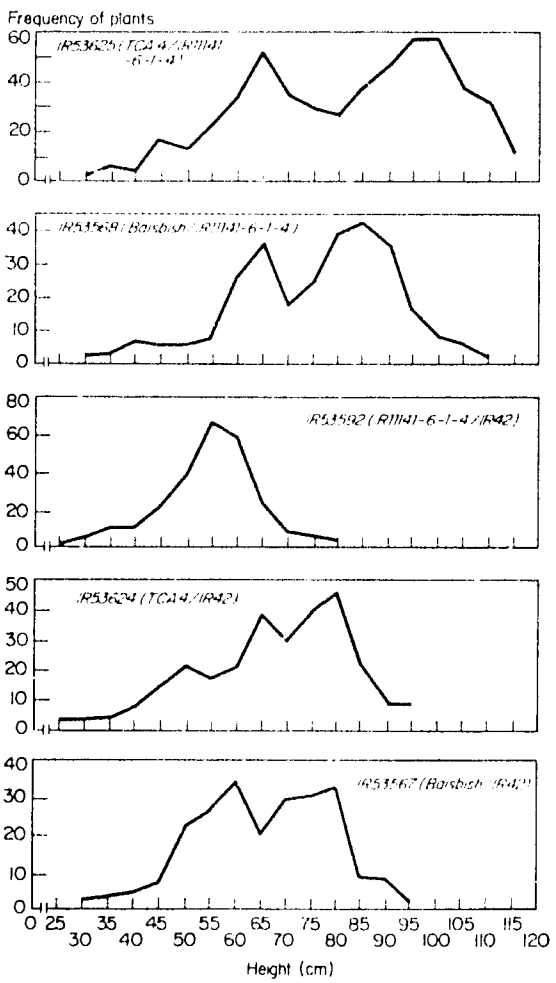
2. Distribution of F_2 plants by elongation ability in 15-, 20-, 25-, and 30-d-old populations of IR42/Baisbish after submergence. IRRI, 1986.

Thus even 15-d-old populations are suitable for segregation studies. However, since these plants are relatively delicate, 20-d-old plants are preferable.

Segregation for plant elongation ability after abrupt flooding. We studied the F_2 populations of the following crosses in a controlled-water tank with 65 cm maximum water depth:

Baisbish/IR42 (IR53567)
TCA4/IR42 (IR53624)
Baisbish/IR11141-6-1-4 (IR53568)
TCA4/IR11141-6-1-4 (IR53625)
IR11141-6-1-4/IR42 (IR53592)

Twenty-day-old plant populations were submerged for 7 d. After drainage, individual measurements were made of height, elongated leaf, and sheath. Frequency distributions of height indicate clear bimodal patterns in all crosses except IR53592, which had only one peak (Fig. 3). In all bimodal distributions, segregation for elongated and nonelongated plants was near the ratio of 9:7, indicating that parents differ in 2 pairs of genes. In IR53592, where both the elongating and the nonelongating parents are semidwarfs, the abrupt flooding possibly did not differentiate the population into two categories.



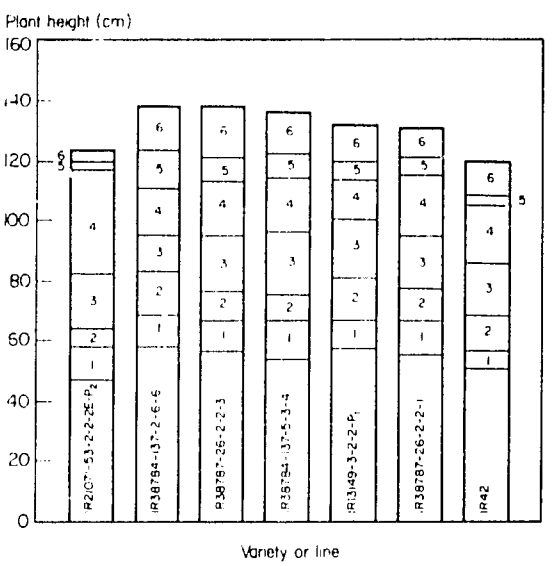
3. Distribution of plants by elongation ability in F_2 populations of 5 crosses after submergence. IRRI, 1986.

YIELD POTENTIAL OF PROMISING DEEPWATER RICES

Agronomy Department

Seeds of 21 promising rices were multiplied in the 1986 dry season. Some agronomic characteristics of these rices are shown in Table 4. IR13149-3-2-2-P1, IR21037-2-1-2E-P3-6, IR28932-9-3-3-2, and IR28932-9-3-3 were outstanding.

In the wet season (WS), seven rices were tested for N response in a medium deepwater rice pond at IRRI. The water depth was increased by 5 cm/d, starting at 30 d after transplanting (DT), and was maintained at 50 cm. Because of the monsoonal rain and typhoons, the water depth rose to 65 cm, but it was gradually reduced to 50 cm. Weekly height measurement starting at 20 DT showed that the rices had varying abilities to elongate with increasing water depth (Fig. 4). IR38784-137-2-6-6 was the tallest, and check variety IR42 was the shortest. IR13149-3-2-2-P1 yielded highest at 3.4 t/ha with N fertilizer application and 2.9 t/ha



4. Weekly plant height measurements from 20 days after transplanting (1) to flowering (6) of some promising medium deepwater rices. IRRI, 1986 WS.

Table 4. Some agronomic characteristics of promising lines from the deepwater breeding program. IRRI, 1986 DS.

Line	Agronomic characteristics			
	Plant height (cm)	Tillers (no./m²)	Panicles (no./m²)	Days to harvest (25-d-old seedlings)
IR13149-3-2-2-P1	118	469	425	119
IR13260-100-1E-P3	130	356	288	105
IR21037-2-1-2E-P3-6	112	369	250	119
IR21038-77-P2-5-2-3-1-1	137	238	238	101
IR21071-53-2-2-1E-P1	130	243	243	91
IR21071-53-2-2-2E-P2	93	381	313	95
IR26662-196-2-1-1-3-3-2	127	375	288	105
IR28333-10-1-1	150	238	231	125
IR28932-9-3-3-2	115	231	218	119
IR28932-9-3-3	115	238	225	119
IR38685-7-2-3-3	112	356	263	115
IR38784-137-5-3-4	105	362	331	101
IR38787-26-2-2-3	106	363	363	91
IR21038-77-P2-5-2-3-1-1	147	225	181	101
IR11141-6-4	130	238	193	125
IR38784-137-2-6-6	100	338	306	125
IR38784-137-2-3-5	120	563	381	107
IR38784-137-2-3-1-2	118	738	463	107
IR38784-137-2-3-1-3	116	356	244	107
IR38784-137-2-3-1-1	121	556	431	107
IR21071-53-2-3-1E-P4-12	115	362	310	95

Table 5. Grain yield of some promising medium deepwater rices (50 cm maximum water depth) as influenced by N fertilizer application. IRRI, 1986 WS.

Entry	Grain yield (t/ha)	
	No fertilizer N	58 kg N/ha
IR21071-53-2-2-2E-P2	0.7 d	0.5 e
IR38784-137-2-6-6	2.2 b	2.7 bc
IR38787-26-2-2-3	1.6 c	2.5 bcd
IR38784-137-5-314	1.9 bc	2.3 cd
IR13149-3-2-2-P1	2.9 a	3.4 a
IR38787-26-2-2-1	1.6 c	2.1 d
IR42	1.7 bc	2.9 ab

without N. The poor elongation ability of IR21071-53-2-2-2E-P2 drastically reduced its yield with increasing water depth (Table 5).

NITROGEN FERTILIZER EFFICIENCY IN DEEPWATER RICE

Agronomy Department

In 1986 WS, photoperiod-sensitive IR11288-B-B-69-1 was tested in the second deepwater rice trial in

Table 6. Effects of sources, rates, and methods of N fertilizer application on the yield of IR11288-B-B-69-1 at 100-cm water depth. IRRI, 1986 WS.

Treatment[a]	Yield (t/ha)
No fertilizer N	2.9 d
29 kg N/ha	
PU B&I	3.5 a
2/3 PU B&I fb 1/3 foliar spray of urea solution at 5-7 DBPI	3.1 bcd
SCU B&I	3.4 ab
USG deep placed at 10-12 cm	3.5 a
58 kg N/ha	
PU B&I	3.3 abc
2/3 PU B&I fb 1/3 foliar spray of urea solution at 5-7 DBPI	3.3 abc
SCU B&I	3.5 a
USG deep placed at 10-12 cm	3.3 abc
116 kg N/ha	
PU B&I	3.4 ab
2/3 PU B&I fb 1/3 foliar spray of urea solution at 5-7 DBPI	3.3 abc
SCU B&I	3.0 cd
USG deep placed at 10-12 cm	3.5 a

[a]PU = prilled urea, B&I = broadcast and incorporated, fb = followed by, DBPI = d before panicle initiation, SCU = sulfur-coated urea, USG = urea supergranules.

deepwater ponds at IRRI. Prilled urea (PU), sulfur-coated urea (SCU), and urea supergranules (USG) at 3 N rates (29, 58, and 116 kg N/ha) were applied using 3 methods: broadcast and incorporated (B&I), B&I followed by foliar spray of urea solution at 5-7 d before panicle initiation (DBPI), and deep placement of USG. Water depth was increased by 5 cm/d, starting at 30 DT, and was maintained at 100 cm until harvest.

IR11288-B-B-69-1 yielded 2.9 t/ha without N fertilizer. Without flash flooding at 2 wk after transplanting, PU B&I and USG deep-placed at 29 kg N/ha both yielded 3.5 t/ha, similar to the yield of SCU B&I at 58 kg N/ha and USG deep-placed at 116 kg N/ha (Table 6). Foliar spraying of urea solution at 5-7 DBPI following B&I at transplanting gave no yield advantage to the B&I and USG deep-placement methods.

Genetic evaluation and utilization (GEU) program

Adverse temperature tolerance

Plant Physiology and Plant Breeding Departments and International Rice Testing Program

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KOREA-IRRI COLLABORATIVE PROJECT ON RICE COLD TOLERANCE **142**
Rice Cold Tolerance Screening Nursery **142**
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SCREENING RICE CULTIVARS FROM MADAGASCAR FOR LOW TEMPERATURE TOLERANCE AT THE SEEDLING AND ANTHESIS STAGES **142**
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HIGH ALTITUDE RICES **144**

IRTP COLD TOLERANCE TRIALS

International Rice Testing Program

The entries that performed well across locations were

Barkat	K39-96-1-1-1-2
Cheolweon 29	Lien-Chan-Ze-Thou
Cheolweon 31	Quella-Inia
Cheolweon 32	Reinei
China 1039	Stejaree 45
Diamante-Inia	Ta-Mao-Tao
K333	Wasetoramochi
K335	

Barkat, China 1039, K333, and Stejaree 45 have consistently given good scores for cold tolerance.

Some entries performed very well at specific sites; these are reported in detail in the International Rice Testing Program section.

KOREA-IRRI COLLABORATIVE PROJECT ON RICE COLD TOLERANCE

Plant Physiology and Plant Breeding Departments

Rice Cold Tolerance Screening Nursery. In the cold water gradient screening nursery, 1,100 entries were tested. The entries with more than 80% fertility at 17 °C are shown in Table 1. Several varieties from China had also been found tolerant in tests at IRRI, e.g., China 988, Bir-Ze-Goo, Ta-San-Bir-Goo, Woo-Gao Tsan, Se Lin R, Chun-Nen-Tsan, and Naga Kuek Look Saap Yat Choo. Those with high fertility had a wide range of culm length, days to heading, spikelets per hill, panicles per hill, and leaf color.

Pedigree Nursery. F_2 populations of 33 crosses were grown in the nursery, which was irrigated with water at 20 °C from 20 d after transplanting until maturity. Plants with yellow leaves were discarded, and those with good fertility at maturity were selected. Thirty-nine crosses of F_3 and subsequent generations from IRRI and Thailand were also planted. From the 15 crosses from Thailand (Table 2), 240 promising plants were selected. Selected plants were characterized by good fertility and long grains. After seed increase at IRRI, the promising plants will be evaluated in Thailand

Screening for cold tolerance at anthesis. Entries from the 1986 International Rice Cold Tolerance Nursery and selected materials were grown in pots under field conditions. At panicle emergence, the plants were transferred to the greenhouse with an air temperature of 19 ± 1 °C for 10 d. After treatment the plants were returned to normal conditions. Of the 120 entries, 8 were not screened because they flowered late in the season.

Only 5 entries had a sterility percentage less than 50%: China 1039, Qing Gang Huang, Cha Cheng, Ching-Hsi 15, and Fuzi 102.

Observational yield trial. Thirty-five entries were grown at 100 and 200 kg N/ha. Average yields at both N levels were similar. The number of panicles per hill was higher at 200 kg N/ha, but fertility and the 1,000-grain weight were lower. At 100 kg N/ha, IR8866-30-3-1-4 gave the highest yield of 6.7 t/ha (Table 3). This line is a cross between [illegible]8-13 and IR2053-362-1-4 and consistently yie[illegible] high in previous trials. Except for IR27877-81452-3-1-3 and B2938b-Sr-13-4-1, the entries that yielded high at 100 kg N/ha were also the highest yielders at 200 kg N/ha.

SCREENING RICE CULTIVARS FROM MADAGASCAR FOR LOW TEMPERATURE TOLERANCE AT THE SEEDLING AND ANTHESIS STAGES

Plant Physiology Department

To identify donor and outstanding cold-tolerant varieties from Madagascar, 178 accessions from the International Rice Germplasm Center (IRGC) and 3 from FOFIFA (Centre National de la Recherche Appliquée au Developpement Rural) were screened at the seedling and anthesis stages in the greenhouse and phytotron using the standard procedure used at IRRI.

Nineteen accessions remained green after 10 d in the cold water tank at 12 °C (score 1-3); 39 other cultivars showed good recovery (score 5-7). Only Latsibavy scored 1. This cultivar belongs to the series of Latsika varieties commonly cultivated in the Ankaratra mountain region (1,700-2,000 m) within the High Plateau.

Fourteen cultivars showed cold tolerance at anthesis (less than 30% spikelet sterility). Lava 1418, IRAT129, and 617A had the highest fertility. Maintimolotsy 1226, 617A, IRAT118, IRAT119, and Latsibavy showed tolerance at both stages.

Table 1. Characteristics of entries in the screening nursery with more than 80% fertility at 17 °C water temperature. Chuncheon, Korea, 1986.

Variety or line	Fertility (%)	Days to heading (no.)	Culm length (cm)	Spikelets/hill (no.)	Panicles/hill (no.)	Leaf color[a]	Vigor[a]	Phenotypic acceptability[a]	Panicle exsertion[a]
Chiagbyeo (Cheolweon 29)	81	119	46	92	12.7	3	3	2	3
NR10073-167-2-1-1	81	127	99	152	11.0	6	5	1	1
Naga Kuck Look Saap Yat Choo	86	132	75	69	21.0	4	1	4	3
RGA701-R-R-R-3	80	115	83	88	16.3	6	3	4	3
YR3825-B-B-23	88	136	51	107	14.0	4	4	1	3
YR4194-31-3-2-3	80	137	53	87	16.7	3	3	1	3
Sangpungbyeo	87	137	51	77	19.0	2	3	3	3
HR4916-B-42-B-2	82	132	49	98	13.7	3	3	1	3
China 988	88	126	63	91	14.3	6	2	1	3
Bir-Ze-Goo	91	125	56	109	11.7	5	3	1	3
K143-1-2	87	116	67	98	15.7	5	3	1	3
Ta-San-Bir-Goo	87	128	77	89	12.7	6	2	3	1
Woo-Gao-Tsan	93	124	86	141	10.3	3	3	4	3
IR20897-B-6	87	128	91	111	10.3	4	3	2	3
RP1848-54-2-31	82	135	66	95	11.7	6	2	3	3
Se Lin R	81	135	70	98	14.3	5	1	3	1
Chun-Nen-Tsan	88	138	52	139	13.7	4	2	5	3
IR20913-B-60	92	134	70	147	11.0	6	3	3	3
SR11134-3-4	88	129	57	123	14.7	1	3	1	1
SR11269-8-1	83	136	31	124	11.0	4	4	4	5
SR12188-HB168-7-1	88	144	25	84	17.0	1	3	5	5

[a] 1 = best, 9 = poorest.

Table 2. Materials selected from the Chuncheon Pedigree Nursery for seed increase at IRRI and subsequent evaluation in Thailand, 1986.

Cross no.	Cross	Plants selected (no.)
SPTLR80135	SRT (unknown)/RD2//IR4427	10
SPTLR82114	RD10/Jao Muey	10
SPTLR82116	RD10/Khao Niaw Naew	10
SPTLR82118	RD10/Khao Pong Krai	15
SPTLR82126	RD4427-70-6/Jao Muey	20
SPTLR82130	RD4427-70-6/Khao Pong Krai	20
SPTLR82138	B733C-167-3-2/Khao Jao 4	15
SPTLR82139	B733C-167-3-2/Ble Char	10
SPTLR82172	SPTLR76083-25-1-4/ Khao Pong Krai	20
SPTLR82174	SPTLR76083-25-1-4/Jao Muey	10
SPTLR82176	SPTLR76083-25-1-4/ Khao Jao 4	10
SPTLR82183	BKNLR75005-PSL-3-1/ Khao Niaw Naew	15
SPTLR82186	BKNLR75005-PSL-3-1/ Khao Jao 4	30
SPTLR82196	IR445-63-1-2-1/ Khao Niaw Naew	15
SPTLR82198	IR445-63-1-2-1/ Khao Pong Krai	30

SCREENING CULTIVARS FROM HUNGARY FOR COLD TOLERANCE AT THE SEEDLING STAGE

Plant Physiology Department

Forty-nine entries from Hungary in the IRGC were screened for cold tolerance at the seedling stage using water at 12 °C. Most of them were relatively tolerant of low water temperature at the seedling stage. The most tolerant were Agostano, Kaka Gyongye, Nucleoryza, Pegonil 15, and Szaniszlo 15. Agostano is relatively tall and belongs to the javanica group, while the rest are short japonicas. They have good spikelet fertility but are generally susceptible to blast.

Table 3. Entries with grain yield greater than 6 t/ha in the observational yield trial at Chuncheon, Korea, 1986.

Line	Grain yield (t/ha)
100 kg N/ha	
IR8866-30-3-1-4	6.7
IR2061-522-6-9	6.5
YR2404-15-4-9-3-2	6.5
HR3790-9-1-4-2	6.5
HR3990-1-1-5	6.2
HR4627-60-7-2	6.2
IR5716-18-1	6.2
SR11010-B-403	6.1
IR29819-R-B-34-1-3	6.1
200 kg N/ha	
HR3790-9-1-4-2	6.7
IR29819-R-B-34-1-3	6.7
YR2404-15-4-9-3-2	6.6
IR2061-522-6-9	6.6
IR8866-30-3-1-4	6.3
IR5716-18-1	6.1
IR27877-81452-3-1-3	6.1
B2938b-Sr-13-4-1	6.1
SR11010-B-403	6.1

HIGH ALTITUDE RICES

Plant Breeding Department

Collaboration with the Philippine Government in developing rices for high altitude areas is reported in the section on Cooperative Country Projects. Field evaluation in Banaue included screening of breeding materials and field trials of advanced lines.

Genetic evaluation and utilization (GEU) program

Innovative breeding methods

Plant Breeding, Plant Physiology, Agronomy, Plant Pathology, and Entomology Departments, International Rice Germplasm Center, and Tissue Culture Facility

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HYBRID RICE

Plant Breeding, Plant Physiology, Agronomy, Entomology, and Plant Pathology Departments

Identification of promising F_1 rice hybrids (*Plant Breeding and Agronomy*). We evaluated F_1 hybrids derived from new cytoplasmic male sterile (CMS) and restorer lines developed at IRRI. Some hybrid combinations showed significantly higher yields (1-2.3 t/ha in the dry season [DS] and 0.6-1.0 t/ha in the wet season [WS]) than the best check (Table 1). Yields during WS were low because of exceptionally high rainfall and frequent typhoons. IR54752A/IR29723-143-3-1, IR46830A/IR13524-21-2-3-3-2-2, IR46830A/IR13524-21-2-3-3-2-2, and IR46830A/IR29723-143-3-2-1 showed numerical superiority, but the difference was slightly less than the least significant difference (LSD) value at the 5% level. Twelve F_1 combinations were evaluated along with 276 elite breeding lines in replicated yield trials with irrigation during DS and WS. IR46830A/IR9761-19-1 ranked first in DS but was statistically the same as the next highest yielding entry, which was the breeding line developed through the conventional breeding program. During WS, IR46828A/IR13524-21-2-3-3-2-2 was the highest yielding hybrid and ranked sixth in the trial, and IR46830A/IR9761-19-1R ranked eighth; however, both were statistically the same as the highest yielding breeding line developed through the conventional breeding program. We will evaluate all combinations listed in Table 1 more critically in multilocation trials during 1987.

Some heterotic hybrid rice combinations were also identified in Korea and Malaysia (see section on Cooperative Country Projects).

Physiological characteristics of F_1 rice hybrids (*Plant Physiology and Plant Breeding*). Studies to identify the physiological characteristics responsible for heterosis in F_1 rice hybrids were continued (Annual report for 1985). Three F_1s with different growth durations, their parents, and 2 check varieties (IR58 and IR64) were tested in the field during DS for growth and yield performance at 2 N rates (40 and 150 kg/ha) and in standard nutrient solution for initial growth.

Growth characteristics. At both N levels, the total biomass production of late-maturing cultivars was higher than that of early-maturing ones. The late-maturing F_1 hybrid IR54752A/IR29512 had the highest biomass: 19.1 t/ha at 40 kg N/ha and 22.7 t/ha at 150 kg N/ha (Table 2). Early crop growth rate (CGR) at 150 kg N/ha hardly differed among cultivars except in IR64 and the early-

Table 1. Promising F_1 rice hybrids identified at IRRI during 1986.

Trial[a]	Hybrid	Yield (t/ha)	Difference from the best check[b] (t/ha)	% of check	Growth duration (d)
		Dry season trials			
RYT Irr	IR46830A/IR9761-19-1	7.7	0.44^{ns}	106	114
RYT HR I	IR54754A/IR46R	7.4	1.2*	119	126
RYT HR II	IR54754A/ARC11353R	7.9	2.3*	142	133
	IR54752A/IR46R	7.0	1.4*	126	126
	IR54753A/IR46R	7.0	1.4*	126	126
	IR54752A/ARC11353R	6.8	1.2*	122	131
RYT Malagaya	IR54752A/IR29723-143-3-2-1	7.4	0.9^{ns}	114	130
		Wet season trials			
RYT HR I	IR54752A/IR64	3.9	1.0*	134	126
	IR54752A/IR46R	3.4	0.5^{ns}	117	135
RYT HR II	IR19728/IR25167-9-2-2-2-1-2-1	3.6	0.6*	120	122
RYT HR III	IR46830A/IR50R	4.1	0.7*	120	110
	IR46830A/IR13524-21-2-3-3-2-2	4.0	0.6^{ns}	118	120
	IR46830A/IR29723-143-3-2-1	4.0	0.6^{ns}	118	115
	IR46828A/IR13524-21-2-3-3-2-2	4.0	0.6^{ns}	118	125

[a]RYT Irr = replicated yield trial of the irrigated rice breeding program, RYT HR = replicated yield trial of hybrid rice breeding programs I, II, and III (groups I, II, and III). [b]* = significantly higher than the check by DMRT or LSD test, ns = nonsignificant.

Table 2. Grain yield and total plant dry weight at harvest of early- and late-maturing F_1 hybrids, their parents, and checks at 2 N levels, IRRI, 1986 DS.

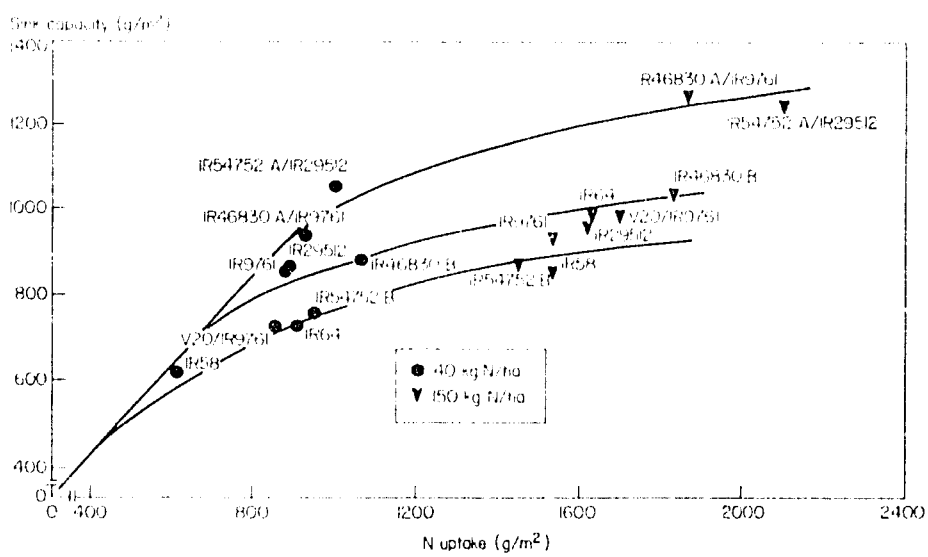
Cultivar[a]	Growth duration (d)	Plant dry weight at maturity (t/ha)		Grain yield (t/ha)	
		40 kg N/ha	150 kg N/ha	40 kg N/ha	150 kg N/ha
V20B	94	4.1 e	6.4 e	4.9 e	7.1 e
IR9761-19-1	111	12.3 cd	15.6 cd	8.0 bc	8.7 bcd
V20A/IR9761 (Wei You 64)	100	11.9 cd	14.2 d	7.2 cd	8.6 cd
IR46830B	103	13.7 bc	16.0 cd	8.2 bc	8.6 cd
IR46830A/IR9761	110	14.7 bc	16.8 bcd	9.0 ab	11.3 a
IR54752B	130	16.6 ab	17.8 bc	7.5 cd	8.0 de
IR29512	130	16.6 ab	19.4 b	8.1 bc	8.9 bcd
IR54752A/IR29512	127	19.1 a	22.7 a	10.0 a	10.0 b
IR58 (check)	103	10.8 d	15.7 cd	6.2 d	8.5 cd
IR64 (check)	110	12.4 cd	17.9 bc	7.1 cd	9.5 bc

[a]V20B and Wei You 64 were badly affected by tungro and sheath blight; IR46830B and IR54752A/IR29512 suffered severe lodging at high N.

maturing F_1 hybrids Wei You 64 and IR46830A/IR9761. CGR after heading varied, depending on the maturity of the cultivar and its varietal characteristics. Late-maturing cultivars usually showed a remarkable decrease in CGR after heading, while in early-maturing cultivars CGR remained relatively high. The highest CGR, 0.3 t/ha per day, was observed at about 45 d after transplanting in IR64 and IR46830A/IR9761.

A higher ability to partition photosynthates to the sink was observed in the medium-maturing IR46830A/IR9761 and the late-maturing IR54752A/IR29512 (Fig. 1). Early-maturing F_1 hybrids tested in this experiment and in 1985 did not show better partitioning of photosynthates to sink.

Yield performance. IR46830A/IR9761 gave a significantly higher grain yield of about 11.2 t/ha at



1. Relationship between N uptake before heading and sink capacity of F_1 rice hybrids, their parents, and checks at 2 N levels, IRRI, 1986 DS.

150 kg N/ha (Table 2), which was comparable to those reported for IR8 in the 1960s.

The addition of N did not significantly increase the yield of late-maturing cultivars; other cultivars showed a significant yield increase, except those that lodged.

Embryo size and initial growth. The positive midparent heterosis in embryo weight of the 3 F_1 hybrids ranged from 12 to 28%, but heterosis in the F_2s was only 4-8% (Table 3). The variation between heterosis in embryo and endosperm weight in F_2 hybrids was small. Seedling weight at 21 d after germination was significantly higher in F_1 hybrids than in the better parents. However, heterosis in seedling weight in F_2 hybrids was lower than in F_1 hybrids. In previous studies using different F_1 hybrid combinations, heterosis in embryo weight was closely related to heterosis in seedling growth; the same was observed in this experiment. The close relationship between embryo and seedling heterosis may indicate the possibility of using heterosis in embryo weight as the index of heterosis in overall growth in F_1 hybrids.

Performance of F_1 rice hybrids under stress conditions (*Plant Breeding, Plant Pathology, and Entomology*). Results (Table 4) from an observation trial under upland conditions indicated that, in several instances, F_1 hybrids performed better than

Table 3. Heterosis[a] in embryo weight, endosperm weight, and seedling growth of F_1 and F_2 hybrids. IRRI, 1986.

Cultivar	Seedling weight[b] (mg/plant)	Embryo (mg)	Endosperm (mg)
	1st combination		
V20B	161 b	0.48	21.83
IR9761-19-1	154 b	0.33	16.78
V20A/IR9761 (F_1)	211 a (134)	0.52 (128)	23.36 (121)
V20A/IR9761 (F_2)	200 a (127)	0.44 (108)	20.05 (104)
	2d combination		
IR46830B	181 b	0.42	15.74
IR9761-19-1	177 b	0.33	16.78
IR46830A/IR9761 (F_1)	214 a (119)	0.42 (112)	15.33 (94)
IR46830A/IR9761 (F_2)	193 ab (108)	0.40 (108)	18.02 (107)
	3d combination		
IR54752B	184 c	0.35	18.90
IR29512-81-2-1	173 c	0.34	19.20
IR54752A/IR29512 (F_1)	248 a (139)	0.40 (116)	17.98 (94)
IR54752A/IR29512 (F_2)	215 b (120)	0.38 (104)	19.90 (106)

[a]Values inside parentheses. [b]Seedlings were grown in standard full-strength nutrient solution for 21 d from germination. In a column for each combination, means followed by a common letter are not significantly different at the 5% level by DMRT.

Table 4. Performance of F_1 rice hybrids, their parents, and check varieties at 2 N levels under upland conditions. IRRI, 1986 WS.[a]

Hybrid or line	Yield (t/ha)		Percentage of check	
	30 kg N/ha	90 kg N/ha	30 kg N/ha	90 kg N/ha
IR54752A/IR20933-68-21-1-2	4.9	5.8	170	123
IR20933-68-21-1-2	2.6	2.[illegible]	89	57
IR54752B	3.2	2.8	111	60
IR54752A/IR14753-120-3	3.5	3.4	120	71
IR14753-120-3	2.1	1.8	73	38
IR54752A/IR54R	5.3	3.6	182	79
IR54R	3.0	3.4	105	74
IR54752A/IR15847-215-2-1	2.6	1.6	92	34
IR15847-215-2-1	2.4	7.1	83	150
UPLRi-5 (check)	2.9	4.7	100	100

[a]Data from Unfavorable Upland Rice Breeding Program.

their parents; the F_1 combination IR54752A/IR20933-68-21-1-2 also appeared superior to the recommended variety (UPLRi-5) in the trial.

In saline soil (7 dS/m), 6 of 12 hybrids evaluated showed strikingly increased survival compared with their parents (Table 5). In three cases, hybrids and parents were comparable, and in two, hybrids were inferior to their better parent. The hybrid Zhen Shan 97A/Milyang 54 showed superiority to the parents at early stages, but subsequently became comparable. F_1 hybrids were thus superior to their parents in adaptability to salinity. Since the parents of the hybrids tested are not known for their tolerance for salinity, the improved performance of the hybrids may be attributed to their increased root and shoot vigor. F_1 hybrids also showed better adaptation to high altitude irrigated conditions in Banaue, Philippines (see section on Cooperative Country Projects).

Therefore, it appears that F_1 hybrids may adapt better to several stress situations and may help to achieve higher and stable yields. We need to explore their potentials not only under tropical irrigated conditions, but also under certain unfavorable environments, e.g., rainfed lowland drought-prone, favorable upland, salinity-affected irrigated, and high altitude irrigated.

Screening tests of F_1 hybrids and their parents for green leafhopper, blast, and sheath blight indicated that the disease or insect reaction of a hybrid depends on the reaction of the parents. If both parents were susceptible, the hybrid was also susceptible; if one or both of the parents were resistant, the hybrid was also resistant, provided resistance was controlled by a major dominant gene. Thus, to develop suitable hybrids for the tropics where disease and insect incidences are high, parents must possess the required resistance.

Cytoplasmic male sterility and fertility restoration (*Plant Breeding*). *Development of new CMS lines.* We developed nine additional CMS lines (Table 6) by transferring the nuclear genotype of nine elite maintainer lines into the wild aborted (WA) cytoplasm derived from CMS lines Zhen Shan 97A and V20A (from China), and IR46828A, IR46829A, and IR48483A (developed at IRRI from Zhen Shan 97A and V20A). Six of these maintainer lines originated at IRRI, two in India, and one in Korea. The Korean line is a japonica and would therefore be useful to develop japonica rice hybrids in countries where japonica rice is preferred. Seeds of these CMS lines are being multiplied for distribution to national hybrid rice breeding programs.

Table 5. Survival percentage of some parents and respective hybrids (F_1) at 6, 12, and 15 wk after transplanting (WT) in a saline field (7 dS/m). IRRI, 1986.

Hybrid, variety, or line	Survival (%)								
	6 WT			12 WT			15 WT		
	Female	Male	F_1	Female	Male	F_1	Female	Male	F_1
Zhen Shan 97A/Milyang 54	26	32	50	16	12	16	16	10	16
IR46830A/IR50	28	58	60	8	46	54	8	40	46
IR46830A/IR9761-19-1	28	26	64	8	14	34	8	8	18
V20A/IR9761-19-1	16	26	28	26	14	18	14	8	12
IR21845/IR29512	28	74	38	18	66	22	14	62	16
IR21845/IR19392	28	48	60	18	44	54	14	44	50
IR21845/IR20933	28	22	44	18	8	40	14	8	34
IR21845/IR14753	28	28	46	18	24	40	14	24	30
IR21845/IR15847	28	22	24	18	16	18	14	12	12
IR21845/IR4422	28	36	32	18	28	24	14	20	12
IR21845/IR13146	28	38	36	18	24	28	14	24	22
IR21845/IR54R	28	28	46	18	28	46	14	26	40
Mean	27	36	42	17	27	32	13	24	27
IR9884-54-3 (resistant check)		93			90			83	
IR8 (susceptible check)		42			40			33	

Table 6. New WA-type cytoplasmic male sterile line developed at IRRI, 1986.

Line	Parentage		Origin of maintainers	Days to 50% flowering (no.)
	Female	Male		
IR58019A	97A/12*IR19809-12-3-2-1	IR19809-12-3-2-1	IRRI	73
IR58020A	97A/12*IR17525-278-1-1-2	IR17525-278-1-1-2	IRRI	101
IR48021A	97A/11*IR19805-12-1-3-1-2	IR19805-12-1-3-1-2	IRRI	76
IR58022A	IR46828A/10*IR19774-23-2-2-1-3	IR19774-23-2-2-1-3	IRRI	66
IR58023A	V20A/10*PY2	PY2	India	86
IR58024A	IR46828A/8*Suweon 161	Suweon 161	Korea	76
IR58025A	IR48433A/8*Pusa 167-120-3-2	Pusa 167-120-3-2	India	89
IR58026A	IR46829A/7*IR31787-24-3-2-2	IR31787-24-3-2-2	IRRI	75
IR58027A	IR46829A/6*IR15795-151-2-3-2-2	IR15795-151-2-3-2-2	IRRI	89

Evaluation of CMS lines. Either some or all of the seven CMS lines designated during 1985 were evaluated at IRRI and in Indonesia, Korea, India, and Malaysia. IR54755A and IR54758A possessed white shriveled anthers with pollen grains that were all unstained and withered when treated with 1% I-KI solution. Other CMS lines had light yellow anthers with pollen grains that were either unstained spherical or partially stained round. All the CMS lines were completely male sterile because there was no seed set on their bagged panicles. CMS lines IR54752A, IR54753A, and IR54754A were adaptable to tropical conditions. IR54756A and IR54757A — the CMS lines developed by converting the Korean rice varieties — were adaptable to Korean conditions and were already being used to develop hybrids for Korea. IR54755A was derived from a different cytoplasmic source (ARC13829-16, see Annual report for 1985) but has the same genetic background as IR46828A (WA CMS source). IR54755A does not have an adequate level of disease and insect resistance for use in developing hybrids for the tropics. We are therefore transferring this CMS system into different maintainer lines that are better adapted to the tropics. IR54758A possesses Basmati type of grain and should be useful in developing F_1 hybrids for northwest India and Pakistan. However, we have not yet received any feedback from India with regard to the adaptability of this CMS line.

Among the three CMS lines found suitable for the tropics, IR54752A showed better combining ability and appeared to possess a fairly good outcrossing rate (10-25%). IR54753A and IR54754A, although good for combining ability, showed very low outcrossing rates (less than 2%); their utility in hybrid development may thus be limited.

Identification of purified restorers. We evaluated 192 elite lines in testcrosses with CMS lines IR46830A, IR54752A, IR54753A, and IR54754A to identify restorers. The testcrosses used three to five single plants of the elite lines. The testcross F_1 progenies were evaluated for spikelet fertility along with the corresponding single plant progenies of the male parent used for the testcross. The testcross F_1s with all plants showing spikelet fertility comparable to that of the male parent were selected. The 64 lines identified as prospective restorers were retestcrossed, using 5-10 single plants, with CMS lines used in the original testcross. The retestcross F_1 progenies were evaluated for spikelet fertility along with their corresponding male parents. The retestcross F_1s showing normal spikelet fertility in all the plants were marked, and their corresponding male parent progenies were designated as R lines. Other male-parent progenies giving partially fertile or partially sterile plants along with fertile plants in the retestcross F_1s were rejected.

On the basis of the retestcrosses evaluated during 1986 DS and WS, 70 elite lines were designated as purified restorers. These as well as other purified restorers identified earlier are available to our collaborators in national programs. The observations recorded in the testcross and retestcross nurseries indicated that most of the prospective restorer lines are mixtures of restorer, partial restorer, and nonrestorer genotypes. These lines must be purified before their use as male parents of experimental F_1 rice hybrids. Otherwise,

the experimental F_1 hybrids will show varying degrees of incompletely fertile plants, which will reduce yield in F_1 hybrids; therefore their yield potential could not be evaluated precisely.

Causes of incomplete fertility restoration of some established R lines of the WA cytosterility system. Some well-established restorer lines IR26, IR36, IR54, IR9761-19-1 (hereafter referred to as IR9761), and IR2797-105-2-2-3 (hereafter referred to as IR2797) possessing the WA CMS system for V20A and Zhen Shan 97A showed incomplete fertility restoration in crosses with another CMS line IR17492-18-10-2-2-2A (hereafter referred to as IR17492A) possessing the same CMS system. Two hypotheses were advanced to explain such a differential behavior. The first hypothesis considered the role of fertility restoration inhibition genes present in the CMS line. The second hypothesis implied the role of intervarietal hybrid sterility, known in rice, independent of cytoplasmic male sterility. The five restorers were crossed to IR17492A to produce F_1s. The backcross (BC) and F_2 generations were produced from each cross. Thus, each of the five sets of materials included the parents, F_1 of male sterile and restorer parents, F_1 maintainer (BC), and F_2. To test for the presence of fertility inhibitor genes, 15 fertile segregants in the F_2 population of the cross IR17492A/IR54 were randomly selected and advanced to the F_3. Simultaneously, 10 randomly selected completely pollen-sterile segregants of the same F_2 were testcrossed to IR54. Progenies of F_3 families and the testcross F_1 were grown and observed for fertility behavior. Nonsegregation of progenies in any of the F_3 families and appearance of fertile plants in the testcross F_1 progenies were considered evidence of the presence of genes that inhibit fertility restoration. To test the operation of the intervarietal F_1 sterility phenomenon, IR17492B was crossed to all the five restorers included in the study. Maintainer/restorer F_1 plants along with male sterile/restorer F_1s were grown and scored for fertility.

Two of the 15 F_3 progenies bred true; others segregated for spikelet fertility, which indicated that genes for fertility inhibition segregated in the F_2. The absence of fertility genes in some of the F_2 genotypes resulted in normal spikelet fertility of the corresponding F_3 progenies possessing WA cytoplasm. We also observed a high proportion of fully fertile plants in all the testcross F_1 progenies (Table 7). This could again be due to the segregation of fertility restoration inhibition genes present in the CMS line IR17492A. The male sterile F_2 plants giving normal fertility in the testcross F_1 obviously did not possess inhibitory genes for restoration ability.

The crosses IR17492B/IR54 and IR17492B/IR26 showed more or less normal spikelet fertility in the F_1, although combinations involving IR36, IR9761, and IR2797 exhibited partial sterility to partial fertility. Thus, in crosses with IR54 and IR26, intervarietal hybrid sterility probably did not play a role. Inhibitor genes present in the CMS line IR17492A were perhaps responsible for the partial fertility in the F_1, while in the combinations

Table 7. Fertility reaction of testcross progenies of completely sterile F_2 plants (derived from the cross IR17492/IR54) and IR54. IRRI, 1986.

Completely sterile F_2 plants testcrossed to IR54 (plant no.)	Plants (no.) with pollen and spikelet fertility reaction[a]		
	F	PF	PS
1	P: 16	7	0
	S: 11	11	1
2	P: 23	11	1
	S: 21	14	0
3	P: 7	12	1
	S: 8	11	1
4	P: 17	6	0
	S: 15	6	2
5	P: 14	8	2
	S: 11	13	0
6	P: 6	0	0
	S: 6	1	0
7	P: 4	6	0
	S: 2	8	0
8	P: 37	7	0
	S: 38	6	0
9	P: 3	2	0
	S: 2	3	0
10	P: 10	2	0
	S: 11	1	0

[a]P = pollen fertility, S = spikelet fertility. For P, F (fertile) = 60-100% fertility, PF (partially fertile) = 30-60%, PS (partially sterile) = 1-30%. For S, F = 80-100% fertility, PF = 30-80%, PS = 1-30%. No pollen or spikelets were completely sterile.

involving IR36, IR9761, and IR2797 intervarietal F_1 hybrid sterility genes in addition to fertility restoration inhibitory genes contributed to the decreased spikelet fertility in the F_1. The CMS line IR17492A therefore appeared to possess genetic factors for fertility inhibition. Genes that condition intervarietal F_1 hybrid sterility also contributed to the decreased spikelet fertility in the F_1.

Outcrossing of CMS lines and methods of hybrid seed production (*Plant Breeding*). *Outcrossing rate of CMS lines used in hybrid seed production.* We used 10 CMS lines for male sterile line multiplication and hybrid seed production plots. Hybrid seed yields in the seed production plots continued to be low during 1986 (Table 8). In DS, the major cause of low seed yield was hopperburn in seed production plots involving the CMS lines V20A, Zhen Shan 97A, and IR54756A, and tungro virus in plots involving IR46828A and IR46830A. CMS line IR46830A showed an outcrossing rate of 6-19% compared with V20A (21-38%), Zhen Shan 97A (24-30%), and IR54756A (7-22%). In WS, the major cause of low yield was low outcrossing rate (0.05-14%) because of unusually heavy rains and numerous typhoons. IR54753A and IR54754A showed very low outcrossing rates (0.05-0.9%) compared with IR54752A (4-14%), but the reason is unclear.

Table 8. Outcrossing rate and seed yield on CMS lines used in hybrid seed production, IRRI, 1986.

Season	Seed production plots (no.)		Outcrossing rate (%)		Seed yield (kg/ha)	
	A/B	A/R	A/B	A/R	A/B	A/R
Dry	7	11	8-19	6-36	12-105	5-255
Wet	10	10	0.3-10	0.05-14	9-83	9-276

We conducted several experiments to determine the optimum female-to-male ratios, optimum stage of application and concentration of gibberellic acid (GA_3), optimum stage and extent of clipping of flag leaves, and optimum planting pattern of female and male rows during 1986 WS. Results have not yet been analyzed.

Another collaborative experiment on the effect of female-to-male row ratio on outcrossing rate and hybrid seed yield, conducted in Korea, showed the highest outcrossing rate (38.6%) with a 3:1 row ratio and the highest seed yield (90.8 g/m^2) with a 4:1 row ratio (see section on Cooperative Country Projects).

Effect of growth stage and extent of flag leaf clipping on outcrossing rate and seed yield. The hybrid rice seed production technology developed in China involves flag leaf clipping of female and male parents after booting to improve outcrossing. We studied the effect of growth stage and extent of flag leaf clipping on outcrossing rate and seed yield of CMS line IR54752A in an A/B multiplication plot at the IRRI farm during 1986 WS. We clipped the flag leaves at 3 stages (booting, initial heading, and 20% heading) and at 3 lengths (10, 20, and 30 cm) compared to the control (no clipping). The experiment was conducted in a randomized complete block with four replications. Percent of outcrossing rate was estimated from 5 hills, and seed yield from 10-m^2 net plots, and converted into kg/m^2. Results (Table 9) showed that for IR54752A flag leaf clipping to 10-20 cm length at 20% heading gave the best results. The outcrossing rate and seed yield were low in the experiment,

Table 9. Effect of growth stage and extent of flag leaf clipping (10, 20, 30 cm) on outcrossing rate and seed yield of IR54752A line in CMS line multiplication plot, IRRI, 1986 WS.

Growth stage	Outcrossing rate (%)				Yield (kg/ha)			
	10 cm	20 cm	30 cm	Mean	10 cm	20 cm	30 cm	Mean
Full booting	7.3	5.8	7.6	6.9	195	204	250	216
Initial heading	7.4	7.8	7.1	7.4	231	304	258	264
20% heading	8.8	6.9	7.5	7.7	262	313	287	287
Mean	7.8	6.8	7.4	7.3	229	273	265	256
Control				5.3				179
LSD (0.05)				2.7				69

perhaps because of unusually high rainfall and numerous typhoons.

Effect on outcrossing rate of growth regulators influencing plant and floral traits. Hybrid rice seed production techniques developed in China involve the use of GA_3 to improve outcrossing rate on CMS lines used in seed production plots. We studied the effect of some growth regulators, viz., gibberellic acid (GA_{4+7} 10^{-4} M), and a mixture of GA_{4+7} and ethephon (10^{-4}M), and with benzyladenine (BA) (5×10^{-5} M), on some plant and floral characteristics of the CMS line IR46830A. The growth regulators were sprayed at initial heading at 40 ml solution per potted plant in a pot experiment conducted during 1986 WS. GA_{4+7} alone and in combination with ethephon or BA increased plant height (control 51 cm, treated 79-81 cm), improved panicle exsertion (control 58%, treated 76-88%), and increased the duration of the opening of florets (control 99 min, treated 163-198 min), suggesting that we should critically study the effect of growth regulators to improve the outcrossing rate on CMS lines used in hybrid rice seed production.

Development of breeding lines with large stigma and anthers. Since 1981, we have been attempting to transfer large exserted stigma and large anther size from a genetic stock (6209-3, developed from the cross Guan Kang A/*Oryza rufipogon*//*O. longistaminata* and introduced from the Sichuan Academy of Agricultural Sciences, Chengdu, Sichuan, China) into lines with improved plant type. We crossed this stock with some elite maintainer and restorer lines and observed a strong linkage between large stigma or large anther, or both, with poor plant type of wild rices in the F_2. To break these undesirable genetic linkages, we intermated the selected F_2 plants and continued intermating for several generations. In each generation after intermating, we selected promising single plants to evaluate for floral and agronomic traits in pedigree rows. We evaluated 50 pedigree lines compared with check varieties in a replicated trial and identified 4 promising lines (Table 10) that showed longer stigma, anthers, and filament or higher stigma exsertion rate than IR54 (check). These lines were considerably superior agronomically to the genetic stock 6209-3, but still did not match the size of its stigma and anther. The yield of the stock 6209-3 could not be estimated precisely because of its high grain shattering, but it was very low.

We are also employing the BC breeding method, using large-stigma or large-anther plants with poor plant type from the previously mentioned segregating generations and some elite maintainers and restorer lines as recurrent parents.

WIDE HYBRIDIZATION

Plant Breeding Department

During the past years we reported successful production of F_1 hybrids between 3 elite breeding lines of *O. sativa* and 18 accessions of *O. officinalis*. The F_1 hybrids were completely sterile and were

Table 10. Floral and agronomic traits of promising breeding lines developed for large exserted stigma and large anthers. IRRI, 1986.

Line	Generation[a]	Cycle of intermating	Stigma length (mm)	Stigma exsertion (%)	Anther length (mm)	Filament length (mm)	Plant height (cm)	Days to 50% flowering (no.)	Panicles/ plant (no.)	Yield (t/ha)
1400-9	F_6	2	1.8	20.4	3.5	4.8	95	92	19	3.2
1451-5	F_4	2	2.0	22.0	3.2	4.7	99	91	17	4.2
1797-3	F_4	3	2.7	57.9	3.3	5.1	96	78	16	3.6
1852-3	F_2	5	2.1	34.4	2.6	5.8	104	86	13	4.0
IR54 (check)	–	–	2.2	7.8	2.2	4.7	91	93	16	4.2
6209-3 (check)	–	–	4.1	89.7	4.9	4.6	104	113	7	–[b]
LSD (0.05)			.4	15.9	0.5	1.2	9	5	4	1.3
CV (%)			11.4	26.3	9.0	15.7	5.8	3.7	17.8	37.5

[a]Refers to the number of intermatings done in the F_2 and subsequent generations before evaluating in pedigree rows.
[b]Very low, could not be measured due to high grain shattering.

backcrossed to *O. sativa* parents. A total of 367 BC_1 plants were obtained, of which 10 were hypertriploids and the rest triploids. The triploids had two genomes of *O. sativa* (AA) and one genome of *O. officinalis* (C). These AAC triploids were backcrossed to their respective *O. sativa* parents, and 94 BC_2 plants were obtained. The chromosome number of these plants varied from 2n to 2n + 6. Twenty-five disomic plants were fully fertile and resembled the *O. sativa* parent closely. The plants with 25, 26, 27, 28, 29, and 30 chromosomes were partially or fully sterile; these plants had the full chromosome complement of *O. sativa* plus alien chromosomes of *O. officinalis*. Twelve monosomic alien addition lines were isolated from among the 2n + 1 progenies.

F_2 populations were grown from 2n and 2n + 1 plants. Plants with higher chromosome number were backcrossed to the *O. sativa* parent to obtain BC_3 progenies. Single plant selections from F_2 populations were made and grown in pedigree rows during 1986 DS and WS. A total of 1,457 F_3 progeny rows were grown in 1986 DS, and 836 F_4 progeny rows in 1986 WS. These progenies were concurrently evaluated for agronomic and grain quality characteristics as well as for disease and insect resistance. Although all the lines resembled the *O. sativa* parent in gross morphological characteristics, some variations were noted in plant height, grain size and shape, lodging resistance, and growth duration. Several lines inherited resistance to brown planthopper (BPH) and whitebacked planthopper (WBPH) from *O. officinalis* (Table 11). The *O. sativa* parents used in the crosses are susceptible to BPH and WBPH, but *O. officinalis* accessions are resistant. *O. sativa* lines, on the other hand, are resistant to bacterial blight (BB), but *O. officinalis* accessions are susceptible. One of the breeding lines derived from these crosses is susceptible to BB. Results clearly show that gene transfers from *O. officinalis* to *O. sativa* have occurred, although on the basis of cytological observations it was concluded that such gene transfers would be impossible.

Table 11. Some promising insect-resistant lines derived from backcrosses of *O. sativa/O. officinalis*. IRRI, 1986.

Line	Growth duration (d)	Grain size and appearance	Reaction[a] to			
			BB	BPH	WBPH	GLH
IR54742-1-18-12	139	Medium long, slender	R	R	R	R
IR54742-1-18-22	130	Medium long, slender	R	R	R	R
IR54742-1-20-10	125	Medium long, slender	R	R	S	R
IR54742-5-36-4	122	Long, slender	R	R	R	R
IR54742-6-20-3	135	Long, bold	R	R	R	R
IR54742-11-1-9	116	Long, slender	R	R	S	R
IR54742-11-22-2	116	Long, slender	R	R	R	R
IR54742-13-10-19	130	Long, slender	R	R	R	R
IR54742-22-22-12	110	Long, slender	R	S	S	R
IR54742-24-14-11	132	Long, slender	R	R	R	R
IR54742-26-11-17	111	Long, slender	R	S	S	R
IR54742-31-16-25	128	Long, slender	R	R	R	R
IR54742-33-18-20	128	Long, bold	S	R	S	R
IR54742-38-26-10	132	Medium, bold	R	R	S	R
IR54742-41-15-30	145	Long, slender	R	R	R	R
IR54745-2-10-17	137	Medium long, slender	R	R	S	R
IR54745-2-47-24	140	Medium long, slender	R	R	S	R
IR54746-4-23-3	133	Long, slender	R	R	R	R
IR54751-2-44-15	113	Medium long, slender	R	S	R	R
IR54751-3-25-8	140	Long, slender	R	S	R	R
O. officinalis (check)	120	Short, bold	S	R	R	R
IR31917-45-3-2 (check)	135	Long, slender	R	S	S	R

[a]R = resistant, S = susceptible, BB = bacterial blight, BPH = brown planthopper, WBPH = whitebacked planthopper, GLH = green leafhopper.

BIOCHEMICAL MARKERS

Plant Breeding Department and International Rice Germplasm Center

Identification of polymorphic genes coding for isozymes. Starch gel electrophoresis of young shoot extracts was used to survey isozyme polymorphism. The variations observed and their genetic interpretation are summarized in Table 12. New variants have been found for GOT (*Got-1*[3] and *Got-3*[2] alleles), for ENP (allele *Enp-1*[0]), and for ACP (allele *Acp-5*[2]). Recent segregation data have confirmed loci *Amp-4* and *Pox-5*. *Got-3*, *Pgd-2*, *Enp-1*, and *Acp-5* still must be tested. With these latter 4 loci, young shoots permit the survey of 25 polymorphic genes with at least 78 alleles.

Mapping of genes coding for isozymes. The location of *Got-1*, *Icd-1*, *Amp-1*, *Amp-2*, *Amp-4*, *Est-5*, *Cat-1*, and *Pox-5* loci was investigated by trisomic analysis. Homozygous primary trisomics with IR36 background were crossed with four varieties (Bamoia 341, Ma Hae, Miriti, and Bikyat) that carry variant alleles. F_1s of each trisomic were analyzed for gene dosage effects. Variations among their zymograms, explainable by gene dosage effects (Fig. 2), were found in triplo-1/Miriti for *Got-1*, triplo-1/Bikyat for *Icd-1*, triplo-1/Bamoia 341 for *Est-5*, triplo-2/Ma Hae for *Amp-1*, triplo-3/Ma Hae for *Cat-1*, triplo-3/Bamoia 341 for *Pox-5*, and triplo-8/Ma Hae for *Amp-2* and *Amp-4* (Table 13). Trisomic heterozygotes showing gene dosage effects for *Got-1*, *Amp-1*, *Amp-2*, *Amp-4*,

Table 12. Enzyme variation observed in plumules and coleoptiles of *O. sativa* rices. IRRI, 1986.

Enzyme	Locus	Allele	Frequency[a]	Marker accession[b]
Phosphoglucose isomerase (PGI)	*Pgi-1*	1	F	6274, 27748, 43400
		2	F	12880, 43675, 33888
		3	VR	CNPAF 800157
		4	VR	19906
	Pgi-2	1	F	6274, 27595
		2	F	29726, 41048
		3	R	6245, 6538
		4	R	12880, 9158
Glutamate oxaloacetate transaminase (GOT)	*Got-1*	1	VF	6274, 6538, 27748
		2	VR	6245
		3	VR	42469
	Got-3	1	VF	8896, 9145, 27748
		2	VR	6304
Shikimate dehydrogenase (SDH)	*Sdh-1*	1	F	6245, 12880, 6538
		2	F	23754, 27748, 43675
		3	VR	53950
		4	VR	53642, 6274
Alcohol dehydrogenase (ADH)	*Adh-1*	0	VR	NIG 624
		1	VF	6274, 27748, 32301
		2	R	23754, 43675
		3	R	6245
Isocitrate dehydrogenase (ICD)	*Icd-1*	1	VF	6274, 53642, 37901
		2	R	27642
		3	VR	9158
Phosphogluconate dehydrogenase (PGD)	*Pgd-1*	1	F	6538, 12880
		2	R	7755
		3	F	6274, 6245
	Pgd-2	1	VF	6274, 6245, 6538
		2	VR	43675

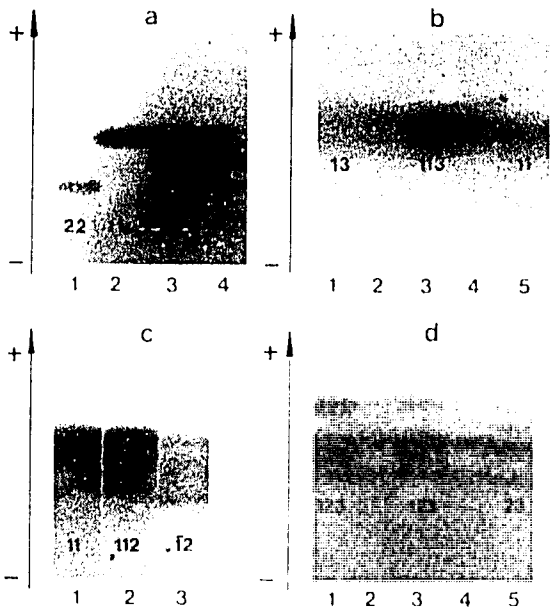
continued on next page

Table 12 continued.

Enzyme	Locus	Allele	Frequency[a]	Marker accession[b]
Malic enzyme (MAL)	*Mal-1*	1	F	12880
		2	F	27748, 6274
Aminopeptidase (AMP)[c] Leu-NA Arg-NA Ala-NA substrates	*Amp-1*	0	VR	29040
		1	F	27595, 62474, 43675
		2	F	12880, 6245, 6538
		3	R	23754
		4	R	33888
		5	VR	27748
		6	VR	9011
Aminopeptidase (AMP) Ala-NA substrate	*Amp-2*	1	F	12880, 33888
		2	F	6274, 6245
		3	VR	6434
		4	VR	32301
Aminopeptidase (AMP) Leu-NA substrate	*Amp-3*	0	R	12880, 19906
		1	F	6274, 43675
		2	F	6245, 27748, 6434
		3	VR	43400, 32575
		4	R	33888, 9158
		5	VR	33153
		6	R	6538, 27595
Aminopeptidase (AMP) Arg-NA substrate	*Amp-4*	1	VF	6274, 12880, 6245
		2	R	33191, 23754
		3	VR	33888
Endopeptidase (ENP)	*Enp-1*[d]	0	?	9145
		1	VF	8896, 27748,27762
Esterase (EST)[e]	*Est-1*	0	F	43675, 23754
		1	F	6274, 33888, 27748
	Est-2	0	F	43675, 12880, 27748
		1	F	37901, 23754, 6434
		2	F	6274, 33153, 53642
	Est-5	0	VR	37801
		1	VF	6274, 32301, 6434
		2	R	6538, 27595
	Est-9	1	F	12880, 6245
		2	F	6274, 6538
Acid phosphatase (ACP)	*Acp-1*	1	F	6245, 6538
		2	F	12880, 43675
		3	VR	27595
	Acp-4	1	F	23754, 6274
		2	F	6245, 6538
	Acp-5	1	VF	8896, 27748, 27762
		2	VR	8244
Catalase (CAT)	*Cat-1*	1	F	6274, 6245, 6538
		2	F	23754, 32301
		3	VR	43675
Peroxidase (POX)	*Pox-2*	0[f]	F	9145, 27748, 27762
		1	F	8896, 9245, 8259
	Pox-5	1	F	6274, 6245, 27748
		2	F	6538, 12280

[a] 0% < VR < 1% < R < 10% < F < 90% < VF < 100%. [b] These are accessions from the International Rice Germplasm Center, except one from the Centro Nacional de Pesquisa-Arroz, Feijao (CNPAF), Goiania, Brazil, and one from the National Institute of Genetics (NIG), Misima, Japan. [c] Leu-NA = leucyl-β-naphthylamide, Arg-NA = arginyl-β-naphthylamide, Ala-NA = alanyl-β-naphthylamide. [d] Fewer than 50 accessions have been analyzed. [e] *Est-4* was renamed *Est-5*, and *Est-8* was renamed *Est-9*. [f] There are different interpretations; some other *Pox* bands might be allelic to *Pox-2*[1].

Cat-1, and *Pox-5* were backcrossed to the paternal parents. The segregation ratios for all these loci significantly deviated from the 1-to-1 ratio and fitted the trisomic ratio (Table 14). In addition, the trisomic heterozygotes at *Amp-1* and *Amp-2* were pollinated by lines carrying a third allele (JC 1 and Cut 389, respectively), and triallelic heterozygotes were recovered in the testcross progenies (see *Amp-2* in Fig. 2).



2. Zymograms of trisomic F_1s. a. Got-1 zymograms. 1, $Got\text{-}1^{22}$ (Mirati); 2, $Got\text{-}1^{13}$ (IR36); 3, disomic heterozygote $Got\text{-}1^{22/13}$; 4, trisomic heterozygote $Got\text{-}1^{22/13/13}$. b. Icd-1 zymograms. 5, $Icd\text{-}1^{11}$ (IR36); 1, 2, and 4, disomic heterozygotes $Icd\text{-}1^{11/13}$; 3, trisomic heterozygote $Icd\text{-}1^{11/13/13}$. c. Est-5 zymograms. 1, $Est\text{-}5^{11}$ (IR36); 3, disomic heterozygote $Est\text{-}5^{11/12}$; 2, trisomic heterozygote $Est\text{-}5^{11/12/12}$. d. Amp-2 zymograms. 2, 4, and 5, disomic heterozygotes $Amp\text{-}2^{23/3}$; 1 and 3, triallelic trisomic heterozygotes $Amp\text{-}2^{23/3/3}$.

Thus, trisomic analysis indicates the following locations: *Got-1*, *Icd-1*, and *Est-5* on chromosome 1; *Amp-1* on chromosome 2; *Cat-1* and *Pox-5* on chromosome 3; and *Amp-2* and *Amp-4* on chromosome 8. Linkage tests indicated that *Cat-1* and *Pox-5* are linked on chromosome 3, and that *Amp-2* and *Amp-4* are independent but located on chromosome 8.

Varietal classification based on isozymes. Previous analyses of isozyme variation at 15-21 loci among rices from several continents have led to the identification of 6 varietal groups: indica (group I), japonica (group VI) with its temperate and tropical forms, and four marginal groups (II-V) restricted to the north of the Indian subcontinent. This scheme provides a rationale to help optimize hybridization programs for genetic improvement. More than 600 varieties and lines were classified in 1986.

To facilitate use of the classification based on isozymes, we have established a simplified procedure by identifying five diagnostic genes that permit us to classify most varieties. These are *Pgi-1* and *Pgi-2*, which encode phosphoglucose isomerases; and *Amp-3*, *Amp-2*, and *Amp-1*, which

Table 13. Gene dosage effects at 8 loci in F_1 progenies of the primary trisomics. IRRI, 1986.

Triplo	Plants[a] (no.)															
	Got-1		*Icd-1*		*Amp-1*		*Amp-2*		*Amp-4*		*Est-5*		*Cat-1*		*Pox-5*	
	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T
1	8	3	30	5	5	–	5	–	5	–	22	4	5	–	10	–
2	24	–	16	–	39	15	26	–	26	–	35	–	25	–	25	–
3	24	–	30	–	23	–	25	–	23	–	32	–	35	11	20	9
4	14	–	26	–	26	–	24	–	26	–	21	–	35	–	21	–
5	10	–	18	–	19	–	10	–	10	–	28	–	22	–	21	–
6	8	–	26	–	19	–	11	–	11	–	23	–	26	–	8	–
7	19	–	12	–	14	–	14	–	15	–	24	–	14	–	11	–
8	9	–	19	–	51	–	34	12	34	12	35	–	57	–	15	–
9	14	–	37	–	23	–	11	–	23	–	24	–	48	–	13	–
10	10	–	23	–	34	–	11	–	24	–	24	–	34	–	17	–
11	22	–	24	–	13	–	17	–	13	–	57	–	12	–	28	–
12	24	–	23	–	12	–	12	–	12	–	46	–	33	–	19	–

[a]Plants displaying usual diploid zymograms (D) or unbalanced zymograms resulting from trisomy (T).

Table 14. Segregation ratio (heterozygotes:homozygotes) for 6 isozyme loci in BC_1 generation of primary trisomics in rice. IRRI, 1986.

Trisomic	Segregation ratio					
	Got-1	*Amp-1*	*Amp-2*	*Amp-4*	*Cat-1*	*Pox-5*
Triplo-1	53:14[a]					
Triplo-2	19:15	57:13[a]	30:23	23:30	25:28	11:8
Triplo-3		57:61	66:53	38:51	98:21[a]	53:11[a]
Triplo-8		59:43	85:16[a]	76:25[a]	38:31	

[a]Significantly different from 1:1 at the 0.001 level and fitting the trisomic ratio.

encode aminopeptidases efficient with leucyl-β-naphthylamide, alanyl-β-naphthylamide, and both these substrates, respectively. The enzymes are extracted by manual grinding of a single plumule in a few drops of water and are separated by 4 h of electrophoresis at 15 V/cm in a 14% starch gel with a Tris (0.009 M)-histidine (0.005 M) gel buffer at pH 8.0 and a Tris (0.400 M)-citrate (0.105 M) electrode buffer at pH 8.0. The enzymes are then stained using standard procedures. The resulting zymograms are translated in terms of loci and alleles. The simplified classification method uses these data to assign a given variety to one of the groups. It consists of an algorithm with five steps, corresponding to the five loci, where the criteria taken into consideration are the alleles of the variety at these loci. The global procedure is summarized in Figure 3.

The original and the simplified methods were compared in a sample of more than 3,000 traditional varieties. They coincide in 99% of the cases. The other 1% corresponds to rices that fall in a given group in one case and are classified as intermediaries in the other case.

The simplified method is thus highly reliable. It is fast and inexpensive, and requires no sophisticated equipment.

TISSUE CULTURE

Tissue Culture Facility

Anther culture. The two major constraints in anther culture studies are low efficiencies of callus induction and green plant regeneration, especially in indicas. In 1986, we continued to identify factors such as *in vitro* conditions, source of explants, and media and media components that could increase callus induction and plant regeneration efficiencies.

Influence of anther position at plating on anther callusing. Taipei 309 anthers were plated on agar medium in different positions — either flat or on edge — to determine whether anther orientation significantly affects anther callusing in rice as has been observed in barley. It was clear that rice anthers are not as strictly position-specific as barley anthers, although plating on edge is superior for anther callusing to plating the anthers flat. Observations made on IR5, Basmati 370, and Pankaj showed the same trend of anther callusing response in relation to anther orientation.

Abscisic acid stress increases callus induction efficiency. Abscisic acid (ABA), up to 30 mg/liter, added to the callus induction medium was used to stress the anthers for 1, 2, 3, and 4 d in either liquid or semisolid medium. Taipei 309 was the test variety. The highest percentage of callus induction in semisolid medium was at 2.5 mg ABA/liter for 2 d. The same concentration was best, using liquid medium, but the duration was 3 d. In both semisolid and liquid media, stressing the anthers from 4 d onward in the presence of ABA was detrimental.

Effect of callus-induction medium sterilization method and pH on callusing and plant regeneration efficiency. The effect of autoclaving and filter-sterilization at different callus induction medium pH on callus production and plant regeneration was tested using Taipei 309 anthers. Autoclaving the medium decreased the final pH, while filter-sterilization did not affect it. Average callus production per anther was highest at pH 4.2 for the filter-sterilized medium, while pH 5.0-6.6 was optimum in the autoclaved medium (Table 15). On the average, callus induction was better in filter-sterilized than in autoclaved medium. Filter-sterilization may be better, because it will eliminate

Material

A set of 36 varieties that carry all known alleles at loci *Pgi-1*, *Pgi-2*, *Amp-1*, *Amp-2*, and *Amp-3*.

Technique

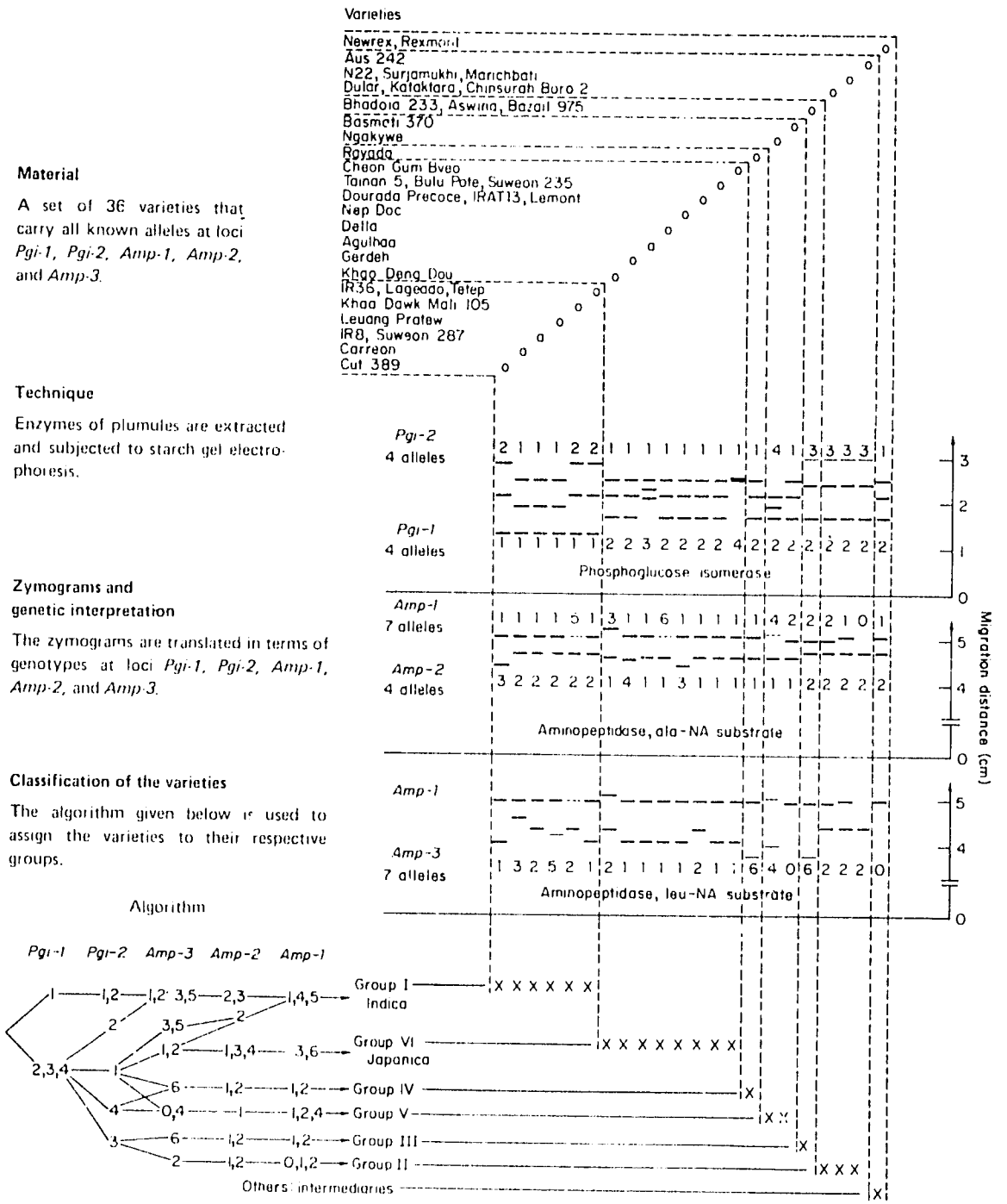
Enzymes of plumules are extracted and subjected to starch gel electrophoresis.

Zymograms and genetic interpretation

The zymograms are translated in terms of genotypes at loci *Pgi-1*, *Pgi-2*, *Amp-1*, *Amp-2*, and *Amp-3*.

Classification of the varieties

The algorithm given below is used to assign the varieties to their respective groups.



3. A simple method for classifying rice varieties based on isozymes using genotypes at the 5 loci *Pgi-1*, *Pgi-2*, *Amp-3*, *Amp-2*, and *Amp-1*. IRRI, 1986.

the breakdown of sugars and other substances, which not only reduces the nutrients present but also impairs callus growth because of the presence of breakdown products. The highest efficiencies of callus induction and green plant regeneration were obtained in filter-sterilized medium at pH 5.8.

Effect of osmoticum on callus induction and plant regeneration. The effects of mannitol and

Table 15. Callus induction and plant regeneration in Taipei 309 using different methods of sterilization[a] and callus-induction medium pH. IRRI, 1986.

pH	Av callus production (no.)		Calli with green plants (%)		Av green plant production[b] (no.)	
	A	F	A	F	A	F
4.2	2.36	2.89	48.3	23.3	6.1	8.8
5.0	2.40	2.28	51.7	40.0	3.4	6.6
5.8	2.27	2.37	41.4	63.3	6.8	5.8
6.6	2.42	2.36	56.7	53.3	4.6	5.2
7.4	2.29	1.88	53.3	33.3	6.2	4.6
8.2	2.25	2.25	58.6	33.3	7.9	5.6
Av	2.33	2.38	51.7	42.7	5.8	6.0

[a] A = autoclaved, F = filter-sterilized.

[b] Computed as $\frac{\text{no. of green plants produced}}{\text{no. of calli producing green plants}}$

sorbitol as osmotica in callus induction media on callusing and regeneration efficiencies were tested using Taipei 309, IR36, and IR43. Concentrations of 0, 4, 8, and 12% (wt/vol) were used. In Taipei 309, callus induction as well as regeneration efficiency was increased by 4% sorbitol; the addition of mannitol at the same concentration was inhibitory. Concentrations higher than 4% sorbitol or mannitol did not produce calli.

Effect of seed specific gravity on anther culturability. The specific gravity of rice seeds has been shown to affect grain yield. To establish whether the specific gravity of seeds from which panicles for anther culture have been collected affects anther culture efficiency, 4 varieties were tested at specific gravities of 1.0-1.1, 1.1-1.2, and >1.2. In Taipei 309, anthers from mid-density grains (1.1-1.2) gave the highest callus induction efficiency; efficiency was lowest in anthers from seeds having specific gravity >1.2. The same trend was observed in three other varieties. Plant regeneration was likewise higher in calli induced from anthers coming from low-density grains.

Plant regeneration in IR varieties. Many IR varieties are moderately or highly recalcitrant to anther culture techniques. After several attempts, plant regeneration was achieved in IR36. Pollen calli were induced at a low frequency (3.7%) in He medium. Of 52 calli plated for regeneration, one differentiated to green plantlets. Plant regeneration of low frequency was observed in IR5. IR54 and IR62 gave only albino plants.

RAC3 — another model variety in anther culture. In basic studies, it is necessary to identify highly responsive varieties that could be used as test materials. In previous years, Taipei 309 was considered the model plant for callus induction and regeneration. In studies on anther culturability, RAC3, a japonica variety from China that was derived from anther culture, showed high capacity for callus induction and regeneration. In E-10 medium, it produced an average of 2.35 calli/anther plated; in 2 replications, an average of 90% of calli plated in the best regeneration medium produced green plants.

Salt screening of anther culture-derived lines. Anther culture-derived lines of the F_1 hybrids IR36/Nona Bokra, IR5657-33-2/IR4630-22-2-5-1-3, and IR4630-22-2-5-1-3/Pokkali were screened for salt tolerance at the seedling stage in the phytotron. Among 22 anther culture-derived lines from IR36/Nona Bokra, 15 entries performed better than IR36, but no line was better than Nona Bokra. In IR5657-33-2/IR4630-22-2-5-1-3, 7 (20.6%) out of 34 anther culture lines were as good as or better than the check, Nona Bokra, and 32 (94.5%) were better than the more susceptible parent, IR5657-33-2. On the other hand, all eight anther culture lines from IR4630-22-2-5-1-3/Pokkali had a higher survival rate than either parent.

The results of the screening experiments show the potential of the anther culture technique in the production of lines tolerant of salt.

Production of lines for upland conditions. Through 1986, 92 F_1 crosses with one or both parents adapted to upland conditions, plus 8 parents, were subjected to anther culture. From 57,590 anthers plated, total callus production was 35,214. From the 100 cultivars tested, 37 regenerated green plants. Out of 7,313 calli plated for regeneration, only 197 produced a total of 1,618 green plants. So far, 341 lines have produced seeds; the other lines are still being grown in the screenhouse.

Production of salt-tolerant lines. Seventy-six F_1 crosses for salt tolerance have been passed through anther culture. Calli have been produced from

most of these crosses, and transfer of the calli for plant regeneration is in progress.

Somatic cell culture. *Somatic embryogenesis.* Somatic embryogenesis is a pathway in plant regeneration from *in vitro* cultures to produce true-to-type plants. This phenomenon is also important in studies of protoplast culture and fusion and in DNA-transfer techniques.

In 1985, we reported somatic embryogenesis in IR28, IR40, IR43, Tetep, and *Oryza perennis*. This year, the ontogeny of embryoids from the scutellar tissues of mature rice seeds was studied more carefully, using histological and scanning electron microscope techniques. Histological techniques established that scutellar tissues, especially the subepidermal portion, are the site of active cell division, which eventually gives rise to callus. Scanning electron microscope study showed the development of globular and organized structures into cup-shaped and bottle-shaped embryoids with a scutellum, coleorhiza, and developing coleoptile structures similar to those in zygotic embryos.

Callus induction in wild rices. Wild rices are excellent sources of resistance to pests and diseases. The establishment of protocol for the *in vitro* culture of wild rices is necessary for successful somatic hybridization. From four wild rice species represented by nine accessions, three entries *Oryza nivara* (Acc. 101508 and Acc. 10095) and *O. rufipogon/O. sativa* (Acc. 10191) — produced calli.

In vitro germination of Sclerophyllum coarctatum seeds. S. coarctatum is an important source of genes for salinity and submergence tolerance. This wild species is vegetatively propagated using cuttings and runners. It is thus necessary to establish a procedure to propagate it through seeds or embryos. Mature seeds or those whose seed coat has turned brownish black failed to germinate in any of the media tested. On the other hand, immature ones — those whose seed coat is green and whose endosperm is soft — had an average of 90% germination. This is apparently the first report of seed germination in *S. coarctatum*.

Field experiments. *IRRI.* Eight anther culture-derived lines that had been identified as promising in earlier observational yield trials were tested in replicated yield trials for three seasons (1985 WS-1986 WS). AC800 and its sister line AC800-1, which were regenerated from the cross IR48/Suweon 290, outyielded both parents and check varieties for two seasons (Table 16). This increase in yield stems partly from high tiller number.

The harvest indices of three anther culture lines from IR48/Suweon 290 were also determined during 1986 DS and 1986 WS (Table 17). AC800

Table 16. Mean yield and tiller number of anther culture-derived lines and their parents in a replicated yield trial. IRRI, 1985 WS and 1986 DS.

Variety or line	Grain yield (t/ha)		Tillers (no.)	
	1985 WS	1986 DS	1985 WS	1986 DS
IR36 (check)	4.79 b-d	5.76 ab	15 ab	19.4 a
IR42 (check)	4.15 d	5.06 b-e	11 c-f	14.1 bc
IR48	4.97 bc	5.03 b-e	10 d-f	9.7 f
Suweon 290	2.92 e	5.60 a-d	9 f	10.1 ef
AC800	5.43 ab	5.64 a-c	16 a	17.8 a
AC800-1	5.87 a	6.25 a	16 a	18.8 a
AC1182	4.60 cd	5.41 b-e	11 c-f	13.1 b-d
IR48	4.97 bc	5.03 b-e	10 d-f	9.7 f
BG90-2	2.86 e	4.87 d-g	12 b-e	11.0 d-f
AC655	4.43 cd	4.84 e-g	10 ef	10.5 ef
AC721-1	4.35 cd	4.65 fg	10 ef	10.5 ef
IR58	4.69 cd	5.73 ab	13 bc	18.6 a
IR19792-15-2-3-3-3	4.82 b-d	4.22 g	15 ab	15.1 b
AC833	5.05 bc	4.71 e-g	16 a	19.0 a
AC833-2	4.77 b-d	5.09 b-e	14 ab	18.1 a
IR30	4.10 d	4.75 e-g	13 b-d	12.4 c-e
AC32B18	4.73 b-d	4.93 c-f	15 ab	17.8 a

Table 17. Harvest index of anther culture-derived lines and their parents in a replicated yield trial, IRRI, 1986 DS and WS.

Variety	Harvest index	
	1986 DS	1985 WS
IR36 (check)	0.49	0.46
IR42 (check)	0.39	0.25
IR48	0.38	0.32
Suweon 290	0.44	0.37
AC800	0.53	0.50
AC800-1	0.53	0.51
AC1182	0.44	0.45

and AC800-1 gave harvest indices higher than those of both parents and the check varieties.

A total of 325 anther culture-derived and 359 somatic culture-derived lines regenerated from various crosses for irrigated, upland, and cold-tolerant varieties — as well as from crosses involving tolerant parents — were screened for agronomic characteristics for 3 seasons (1985 WS-1986 WS) in the observational nursery (3-row plots). Promising test lines were selected each season and planted in the observational yield trial (OYT) in 10-row plots. They were screened for plant type, yield, tillering ability, lodging resistance, threshability, spikelet fertility, exsertion, and resistance to BPH biotypes 1, 2, and 3, rice tungro virus, BB, rice blast, and salt tolerance. From among the lines screened in the observational nursery, 15 highly promising lines were selected and screened in 10-row plots in the OYT in 1986 DS, and 20 in 1986 WS.

Twelve anther culture-derived lines from crosses IR42/IR4630-22-2-5-1-3, IR4630-22-2-5-1-3/IR5657-33-2, IR5657-33-2/IR4630-22-2-5-1-3, and IR4630-22-2-5-1-3/Pokkali showed marked increases in tiller number compared with their parents. Anther culture-derived lines from IR4630-22-2-5-1-3/IR5657-33-2 were shorter than the taller parent, IR4630-22-2-5-1-3.

AC700 and AC700-1 regenerated from Suweon 290/BG90-2, AC599A regenerated from BG90-2/Taipei 309, and five somatic culture-derived lines from IR43 and IR54 produced higher yields and had more tillers than their respective parents and the check varieties IR36 and IR42.

Collaborative research. Anther culture was employed in the immediate production of homozygous lines for upland conditions and for salt tolerance. Some lines showed better tolerance to these environmental stresses than one or both parents.

Collaborative anther culture research with the Rural Development Administration (Korea) on the production of cold-tolerant lines and with the Peruvian National Rice Program and the National University Pedro Ruiz Gallo (Peru) on lines suited to Latin American conditions was continued. Some lines that were tested under the appropriate conditions showed increased tolerance.

See Cooperative Country Projects for details.

DIRECT SELECTION FOR YIELD IN EARLY GENERATIONS

Plant Breeding Department

We continued practicing the breeding approach of direct selection for yield in early generations, described in the Annual report for 1985. Sixty-four F_2 populations derived from single cross F_1s appearing heterotic were evaluated in replicated yield trials. Eighteen populations were grown in the F_3 and 20 in the F_4. The 3,173 lines from F_4 plants selected as superior to the check varieties were evaluated in the F_5. In OYT, we evaluated 126 lines under 2 fertility levels in comparison with check varieties of different growth durations. Twenty-seven promising lines were selected for evaluation in a replicated yield trial during 1987 DS to estimate the genetic improvement made for yield, in comparison with the best yielding check varieties developed at IRRI through the pedigree method.

RAPID GENERATION ADVANCE

Plant Breeding Department

In 1985, we grew 522,035 plants of 254 populations from 211 crosses. In 1986 we grew 528,106 plants from 275 crosses. Table 18 classifies the populations into cultural types.

To make more efficient use of rapid generation advance (RGA), a limited degree of bulk selection for resistance to BPH biotype 2 was carried out on 15 crosses from Thailand destined for Thailand's

Table 18. Populations grown in and sent out from rapid generation advance. IRRI, 1985 and 1986.

Cultural type	Populations grown		Populations sent out	
	no.	Generation	no.	Generation
Rainfed lowland				
1985	6	F_4	23	F_4-F_6
1986	24	F_2		
Deepwater				
1985	145	F_2-F_5	31	F_3-F_6
1986	130	F_2-F_3		
Low temperature				
1985	95	F_2-F_3	101	F_4-F_5
1986	115	F_2-F_3		
High temperature				
1985	8	F_3-F_4		
Tidal wetlands				
1986	6	F_2-F_3		

Central Plains, where BPH resistance is essential. A modified seedbox screening test was used. Ten-day-old seedlings grown in RGA trays were infested with 2d instar BPH nymphs at a rate of about 3 nymphs/seedling. Damage ratings were taken at 30 d after infestation, when the susceptible check variety was completely destroyed.

Table 19. Survival after brown planthopper infestation as a function of parent. IRRI, 1986.

Parent	Populations (no.)	Plants (no.)		Survival (%)
		Before	After	
	Comparison A			
SPR7212-13-1-1	6	7776	2730	35
SPR7212-13-2-1	6	9216	1441	16
	Comparison B			
IR13429-196-1	4	5328	2271	43
IR9743-25-2-2	4	5616	989	18
	Comparison C			
Basmati 370	6	9784	2475	25
Hawm Naipol	6	8046	1722	21
	Best cross[a]			
	1	1296	806	62

[a]SPR7212-13-1-1/IR13429-196-1//Basmati 370.

The crosses represented various balanced combinations of six parents. Table 19 gives the average selection pressures due to BPH infestation on the various populations as a function of the parent. The best population, predictably, was SPR7212-13-1-1/IR13429-196-1//Basmati 370 — the one combining the best three parents from the three combinations.

Genetic evaluation and utilization (GEU) program

Seed science and technology

International Rice Testing Program

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SEED DORMANCY

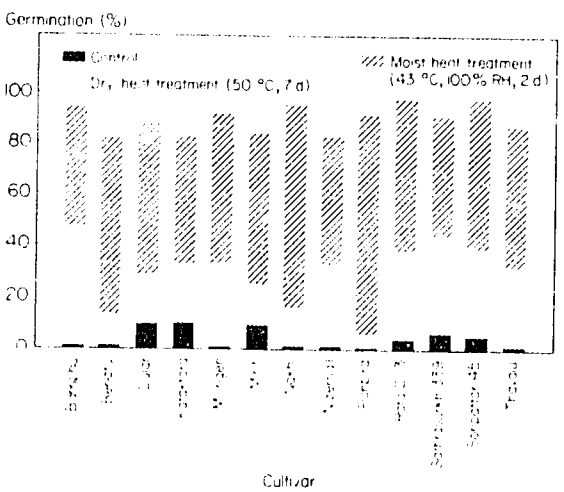
Seed dormancy studies on 121 cultivars of cultivated rice *Oryza sativa* L. indicated that the japonica and javanica subspecies generally have shorter periods of dormancy than the tropical indica subspecies. Cultivars observed to have strong seed dormancy included both early- and late-maturing types and both photoperiod-sensitive and insensitive strains, suggesting a lack of association between these factors and degree of dormancy.

Environmental effects during seed maturation affected the expression of dormancy. The average germination over a common set of 51 cultivars was 82% for seeds harvested in the dry season (DS) and 40% for those from the wet season.

Dry heat treatment at 50 °C for 3-7 d successfully broke dormancy in most cultivars. Some of the strongly dormant cultivars did not respond satisfactorily to dry heat treatment but responded to moist heat treatment (43 °C, 100% relative humidity [RH]) for 2 d (Fig. 1).

TOLERANCE FOR AGING

Accelerated aging of seeds at 43 °C and 100% RH for 6 d indicated varietal differences in tolerance for aging stress (Table 1).



1. Effects of moist heat treatment in breaking dormancy in 13 strongly dormant rice cultivars. IRRI, 1986. RH = relative humidity.

Higher initial levels of dormancy provided greater tolerance for accelerated aging (Table 2).

Table 1. Germination percentage upon accelerated aging averaged over cultivars that were grouped into 5 classes based on their germination percentage in the control. IRRI, 1986.

Control		Mean germination (%) after aging[a]	
Germination percentage class	Cultivar (no.)	2 d	6 d
0-20	38	89.03	16.13
21-40	27	89.26	15.37
41-60	22	89.82	11.64
61-80	19	89.53	7.63
81-100	15	91.60	3.80

[a] *r* value between control and 6-d aging = −0.98**.

Table 2. The 6 varieties most tolerant of aging in DS and WS (43 °C, 100% RH, 6 d). IRRI, 1986.

Variety	Germination (%) after aging	
	Dry season (64 entries)	Wet season (121 entries)
Dharial	10	53
ARC6000	3	55
Habiganj Boro IV	13	41
Taal 2	2	45
ARC11554	6	25
Suweon 287	6	22
Grand mean for all entries studied	0.88	12.58

Table 3. Varieties with germination rate exceeding the mean by more than one standard deviation.[a] IRRI, 198[illegible]

Variety or line	Germination rate (%)	
	Field	Phytotron
Laxmi	90.0	76.7
B3981C-PN-165-2-1	93.0	83.3
TNAU (AD) 103	89.7	91.7
IR25924-92-1-3	90.0	80.0
IR50	88.3	85.0
PND160-2-1	98.3	93.3
RNR1429	98.7	95.0
IR31779-19-3-3-2-2	95.0	96.7
Mean over 68 entries	62.5	49.9
Range	3.5-98.7	1.7-96.7
SD (n = 68)	25.3	24.3

[a] Entries tested: 68.

GERMINATION RATE

Sixty-eight varieties were raised during DS in the field and in the phytotron, and the harvested seeds were evaluated for germination rate. Varieties showing consistently superior performance are indicated in Table 3. The germination rate showed a highly significant positive association with the rate of emergence in the soil ($r = 0.641^{**}$). Association with protein content of the seed was nonsignificant, but associations with P and K contents of the seed and dehydrogenase and α-amylase activity were positive and significant. Preliminary studies also indicated a possible positive association of germination rate with P and K contents of the seed, dehydrogenase activity, and α-amylase activity.

Genetic evaluation and utilization (GEU) program

Integrated GEU program

Plant Breeding, Agronomy, Multiple Cropping, Plant Physiology Departments and International Rice Germplasm Center—Upland Rice Breeding

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We made 3,154 crosses in 1986, grew F_2 populations from 1,616 crosses, evaluated 128,837 pedigree nursery rows, tested 905 breeding lines in replicated yield trials, and sent 83,471 seed packets of IRRI breeding lines abroad — 40,798 seed packets filled 385 seed requests, and 42,673 packets went through International Rice Testing Program (IRTP) nurseries.

IRRIGATED RICE

Plant Breeding Department

Of the 690 crosses made for irrigated rice in 1986, 368 were single crosses and 322 were multiple crosses. F_2 populations from 329 cross combinations were grown, and 67,614 pedigree nursery rows were evaluated in replicated yield trials (RYTs).

Thirty-five elite breeding lines were evaluated in the lowland rice performance trials conducted at 12 sites by the Rice Varietal Improvement Group of the Philippine Seed Board. More than 200 elite breeding lines were evaluated internationally in IRTP nurseries. Many other promising lines requested by collaborators were also evaluated by national rice improvement programs.

IRRI lines named varieties. In 1986, 8 IRRI breeding lines from the irrigated breeding program were named varieties in 5 countries, bringing to 155 the number of IRRI breeding lines named as varieties worldwide.

- IR841-67-1-2 was released as Empase 104 in Brazil. This line is drought tolerant and has long, slender, aromatic grains.
- IR4422-198-3-6-1 was released as IR4422 in Sierra Leone. This sturdy-stemmed selection has high yield potential and has also been released as a variety in Liberia.
- IR2058-78-1-2-3, released as IR46 in Nigeria, is the same selection that has been released as IR46 in the Philippines, Indonesia, Brazil, the Ivory Coast, and Cameroon.
- IR4744-295-2-3, a high yielding selection, was released as Tajum in Indonesia. It has excellent grain quality and gall midge resistance.
- IR4570-83-3-3, released as IR48 in Indonesia, was also released as IR48 in the Philippines and as NN5B in Vietnam. This is a late-maturing variety with intermediate amylose content (AC) and excellent cooking quality. It does well under medium deep conditions of up to 50 cm water depth.
- IR3941-45-Plp-28, a cold-tolerant breeding line, was released as Himalaya 741 for cultivation in the hill zone of Himachal Pradesh, India.
- IR19728-9-3-2 was released as Pant Dhan 6 for the broadcast-sown areas of the lower hill zone of Uttar Pradesh, India.
- IR28224-66-2 was released as a general purpose variety called PR109 in Punjab, India. It is resistant to local isolates of bacterial blight (BB) and has field tolerance for whitebacked planthopper, the two most serious problems in the Punjab.

Elite breeding lines. Pedigree nurseries are thoroughly evaluated for disease and insect resistance and for grain quality. Only entries with multiple resistance and good grain quality are selected. Evaluation for yield is done in replicated trials at IRRI during dry (DS) and wet (WS) seasons. Selected entries are evaluated for N response at IRRI and three other stations in the Philippines: the Maligaya Rice Research and Training Center in Muñoz, Nueva Ecija; the Bicol Rice and Corn Experiment Station, Pili, Camarines Sur; and the Visayas Rice Experiment Station, Iloilo. Elite breeding lines that perform well in these trials are nominated to the Lowland Rice Performance Trials of the Philippine Seed Board. Promising breeding lines being tested in these trials are listed in Table 1 along with their characteristics.

During recent years we have developed many lines with long, slender, translucent grains having intermediate AC and intermediate gelatinization temperature (GT). These lines have superior grain quality. Some of the promising ones are IR31802-48-2-2-2, IR31868-64-2-3-3-3, IR32429-47-3-2-2, IR32429-122-3-1-2, IR35366-40-3-3-2-2, IR24594-204-1-3-2-6-2, IR25604-99-1-3-2-2, and IR29723-171-1-2-2. We have also selected some aromatic lines, the two best being IR44699-21-1-3-4 and IR44699-26-3-1-1.

Several very early-maturing lines with multiple resistance to diseases and insects and high yield

Table 1. Elite breeding lines for irrigated conditions and their characteristics. IRRI, 1986.

Line	Growth duration (d)	Amylose content (%)	Gelatinization temperature	Reaction to[a]							
								BPH biotypes			GLH
				BI	BB	RTV[b]	GSV	1	2	3	
IR31802-48-2-2-2	105	22	I	3	1	5	3	3	3	5	3
IR31868-64-2-3-3-3	110	22	I	1	1	5	3	3	3	7	3
IR32307-107-3-2-2	112	26	I	6	1	5	3	3	3	3	3
IR32429-47-3-2-2	105	24	I	1	1	5	3	3	3	3	3
IR32429-122-3-1-2	110	24	I	4	1	5	3	3	3	3	3
IR35366-28-3-1-2-2	115	26	I	5	1	3	3	3	3	3	3
IR35366-90-3-2-1-2	115	26	I	7	1	3	3	3	3	3	3
IR39357-133-3-2-2-2	110	26	I	1	1	7	3	3	3	7	3
IR41985-77-3-3-3	110	26	I	1	1	3	3	3	3	3	5
IR41985-111-3-2-2	105	21	I	1	5	3	3	3	3	3	9
IR41996-50-2-1-3	100	24	I	4	1	3	1	3	3	3	7
IR41996-163-2-1-2	110	27	I	1	1	3	1	3	3	3	3
IR42000-211-1-2-2-3	105	22	I	1	1	3	3	3	3	7	5
IR42015-83-3-2-2	107	25	L	5	1	3	5	3	7	3	3
IR42068-22-3-3-1-3	112	27	I	1	1	3	5	3	3	3	3
IR25604-99-1-3-2-2	130	23	I	8	1	3	3	3	3	3	3
IR28222-9-2-2-2-2	130	25	L	4	1	3	3	3	3	3	3
IR28224-3-2-3-2	130	26	L	4	1	3	3	3	3	5	3
IR28228-12-3-1-1-2	130	24	I	4	7	3	3	3	3	3	5
IR32453-20-3-2-2	133	25	L	4	7	3	3	3	3	3	5
IR33043-46-1-3	130	25	L	4	5	3	3	3	3	3	3
IR34086-179-1-2-1	135	22	L	6	1	3	3	3	3	3	3
IR37721-9-2-1-3	140	25	L	4	1	3	3	3	3	3	3
IR40720-72-1-2	140	25	L	4	1	3	5	3	3	3	3

[a]BI = blast, BB = bacterial blight, RTV = tungro, GSV = grassy stunt, BPH = brown planthopper, GLH = green leafhopper.
[b]Data on RTV represent field reaction under epidemic conditions in Mindanao.

potential have been identified. The most promising are IR31802-48-2-2-3, IR31868-64-2-3-3-3, IR35366-90-3-2-1-2, IR32307-107-3-2, IR39357-133-3-2-2-2, IR41985-77-3-3-3, IR41985-111-3-2-2, IR41996-50-2-1-3, and IR42000-211-1-2-2-3.

Some of the promising lines with medium growth duration and multiple resistance to diseases and insects are IR24224-3-2-3-2, IR28222-9-2-2-2, IR28228-12-3-1-1-2, IR28228-28-1-3-3-2, IR32453-20-3-2-2, and IR33043-46-1-3.

RAINFED LOWLAND RICE

Plant Breeding, Agronomy, Multiple Cropping, and Plant Physiology Departments

As in previous years, the rainfed lowland rice breeding program concentrated on developing improved germplasm for areas where drought, submergence, and stagnant flooding are constraints to rice production. Rainfed rices require disease and insect resistance, acceptable grain quality, appropriate growth duration, and moderately high yielding plant type in addition to stress tolerance.

Breeding operations (*Plant Breeding*). The breeding nurseries at IRRI were divided into drought-prone and medium deepwater nurseries for convenience of handling. The drought-prone nurseries consisted of 91 F_2 populations and 25,459 pedigree rows. The medium deepwater nurseries consisted of 109 F_2 populations and 13,910 pedigree rows. Unreplicated observation trials with 2,157 entries and RYTs with 113 entries were grown at IRRI and in farmers' fields.

As part of our collaborative work, over 5,000 seed samples were sent to scientists in Bangladesh, Burma, India, Kampuchea, Malaysia, Nepal, Sri Lanka, Thailand, and the West Indies.

Drought and submergence tolerance (*Plant Breeding, Agronomy, and Plant Physiology*). Drought is the major environmental stress in rainfed lowland areas. Breeding lines are screened for drought tolerance in DS nurseries and are

evaluated under drought-prone conditions in rainfed areas of the Philippines. Under rainfed lowland conditions, good recovery from drought is essential. Several breeding lines showed good drought recovery and performed well in a drought-prone farmer's field (Table 2).

Considerable progress has been made in transferring tolerance for short-term flooding from traditional cultivars into improved lines. Some undesirable characteristics of the traditional parents (red pericarp, stunted growth, long awns, etc.) were present in many of the earlier improved lines. By using these prebred lines in further crosses, or by strong selection in multiple crosses with traditional parents, breeding lines with good phenotypic acceptability and a high level of submergence tolerance have been developed (Table 3). Most of these are derived ultimately from FR13A or FR43B, both of which have shown the most tolerance in screening at IRRI. IR43459-18-2-3-3 is also moderately photoperiod sensitive.

Medium deep conditions (*Plant Breeding and Multiple Cropping*). Sixty-four entries were evaluated in the medium deepwater yield trial in 1985. Water depth was maintained at 30-40 cm from 3 wk after transplanting until harvest. Yield

Table 2. Rainfed lowland breeding lines that performed well in the drought-prone observation trial and showed good recovery in the drought screening nursery. IRRI, 1986.

Line	Parentage	Growth duration (d)	Drought recovery[a]
IR33355-39-1-1-3	IR52/IR46//IR6115-1-1-1	120	3
IR38499-CO-350-1-2-2	Composite cross 103	130	3
IR42243-113-1-3-2	IR13259-153-5E-P2-2/IR8234-OT-9-2//IR64	125	3
IR42243-68-2-3-1	IR13259-153-5E-P2-2/IR8234-OT-9-2//IR64	125	1
IR42243-92-1-3-1	IR13259-153-5E-P2-2/IR8234-OT-9-2//IR64	125	3
IR42265-38-6-4-3	Mahsuri/IR46//IR9729-67-3	115	3
IR43040-25-1-2-3	Leaung Yai 148/IR9129-209-2-2-2-1	135	3
IR43522-91-3-3-2	KDML 105/IR19728-9-3-2-3-3//IR19660-73-4-2-2	130[b]	3

[a]From 1986 Agronomy Department screening. Drought recovery scores range from 1 (90-100% plants recovered) to 9 (0-19% recovery). Average scores for the checks were 4 for tolerant IR442, 3 for tolerant Salumpikit, 7 for susceptible IRAT9, and 5 for susceptible IR20. [b]Weakly photoperiod sensitive.

Table 3. Rainfed lowland breeding lines with submergence tolerance and good phenotypic acceptability. IRRI, 1986.

Variety or line	Parentage	Source of tolerance	Tolerance score[a]		Growth duration (d)	Plant height (cm)
			Mean	Observations (no.)		
IR40931-33-1-3-2	BKNFR76106-16-0-1-0/ IR19661-131-1-2	FR13A	1.8	5	130	110
IR42205-33-1-3-3-2	IR4215-301-2-2-6/IR19382-42-3-3-2//BKNFR76106-16-0-1-0	FR13A	2.2	5	135	100
IR43459-18-2-3-3	IR8234-OT-9-2/BKNFR76106-13-2//IR13540-56-3-2-1	FR13A, Nam Sagui 19	1.0	4	150	90
IR43494-15-1-2-3	NSPT/BKNFR76106-13-2// IR13540-56-3-2-1	FR13A	2.3	3	130	90
IR43559-39-2-1-2	IR13423-10-2-3/FR43B// MTU7029/IR19728-9-3-2-3-3	FR43B	1.7	6	135	100
IR43559-137-1-3-4	IR13423-10-2-3/FR43B// MTU7029/IR19728-9-3-2-3-3	FR43B	3.0	6	120	90
IR46292-24-2-2-1	Chenab 64-117/IR60// IR13540-56-3-2-1	Chenab 64-117	2.3	3	130	100
IR42 (check)			8.5	336	135	105
IR46 (check)			8.0	31	125	110

[a]Submergence score from Plant Physiology Department is based on survival where 1 = same % survival as the tolerant check FR13A, and 9 = all plants dead. Mean scores include values from earlier generations in the pedigree nursery.

levels were much higher than in previous years (Table 4). Many entries outyielded the check varieties. Several breeding lines have been among the highest yielders in 3 consecutive years (e.g., IR24705-11-3-2-3-3, IR13149-71-3-2-3, IR26760-27-1-3-2-1). The two highest yielding lines were derived from a cross made in Indonesia (B4259) and selected at IRRI. IR38699-49-3-1-2 is a photoperiod-sensitive line that flowers in late October.

In 1986, 271 lines were evaluated under medium deepwater conditions in an observation trial at IRRI and in a farmer's field in Bay, Laguna. Entries at both sites were subjected to several short-term flash floods and prolonged stagnant flooding of 50-70 cm. Several improved lines showed good survival and phenotypic acceptability at both sites (Table 5). Not all of them were submergence tolerant in screening at IRRI, but the lines with higher submergence tolerance scores tended to have better survival in the field. IR43559-25-5-3-2 was tolerant both in the screening tanks and in the field.

Photoperiod sensitivity (*Plant Breeding*). A major objective of the breeding program is to develop breeding lines with intermediate height,

Table 4. Highest yielding entries and checks in the medium deepwater yield trial. IRRI, 1985-86.

Variety or line	Parentage	Yield (t/ha)	Growth duration (d)	Plant height (cm)
B4259-48-1-1-3	IR46/IR4422-98-3-6-1	4.9	142	136
B4259-39-2-3	IR46/IR4422-98-3-6-1	4.6	134	133
IR24705-11-3-2-3-3	CSR1/IR52//IR5657-33-2	4.5	138	123
IR13149-71-3-2-3	BG90-2/IR46//IR4417-177-1-4	4.4	134	117
IR41389-20-1-5	RP975-109-2/IR19058-107-1	4.3	139	149
IR26760-76-2-1-2-3	Jaganath/IR2797-105-2-2-3//IR48	4.3	134	127
IR26760-27-1-3-2-1	Jaganath/IR2797-105-2-2-3//IR48	4.2	143	126
IR13149-3-2-2-P1	BG90-2/IR46//IR4417-177-1-4	4.1	136	121
IR38699-49-3-1-2	GEB24/IR13146-179	4.0	136	115
IR48 (check)		3.5	133	128
IR42 (check)		3.2	130	110
Pankaj (check)		2.9	130	130
IR54 (check)		2.7	122	108
Mahsuri (check)		1.3	138	15[illegible]
Mean		3.1	131	124
LSD (.05)		0.9	5	9

Table 5. Rainfed lowland breeding lines showing good survival and phenotypic acceptability under medium deep and shallow water conditions. IRRI, 1986.

Line	Parentage	Growth duration (d)	Plant height (cm)	Submergence tolerance[a]
IR21178-43-1-2-2-2	CR146-7055-225/IR2061-465-1-5//IR52	140	130	9
IR25077-KKN-38-PMI-2-1	B727G-KN-10-3-1/IR4570-74-2-2-3-3	125	105	9
IR31238-474-3-P1	IR54/KLG6986-161-7//IR48	135	130	7
IR41111-13-1-1-2	IR54/IR14632-22-3	140	120	9
IR41111-24-2-1-3	IR54/IR14632-22-3	140	115	9
IR43559-25-5-3-2	IR13423-10-2-3/FR43B//MTU7029/ IR19728-9-3-2-3-3	135	105	2
IR43559-39-2-6-3	IR13423-10-2-3/FR43B//MTU7029/ IR19728-9-3-2-3-3	135	90	7
IR43582-176-3-2-2	Patnai 23/IR9884-54-3//IR52/ IR6402-CT-7-0-0	Sensitive	115	8
IR46343-26-2-3	Nang Quot/IR17525-114-2-1-1// IR21837-81-3-3-1	140	105	9

[a]Average score, from Plant Physiology Department, IRRI.

moderately high yield, and strong photoperiod sensitivity. More emphasis has been placed on lines that flower in October, which should be suitable for many rainfed areas. Several improved lines combine photoperiod sensitivity with other desirable characteristics (Table 6). These lines flower in October, regardless of the seeding date, if seeded before mid-July. Progress on developing lines with later flowering dates has been slow, since only one generation in a year can be grown.

Table 6. Photoperiod-sensitive lines with improved plant type and good phenotypic acceptability. IRRI, 1986.

Line	Parentage	Flowering period	Reaction to[a]					Comments[b]
			BB	BPH			GLH	
				1	2	3		
IR38699-33-5-1-3-1	GEB24/IR13146-179	Late Oct	R	R	S	R	S	Medium deep
IR38699-49-3-1-2	GEB24/IR13146-179	Late Oct	R	R	S	R	R	Medium deep
IR41183-57-5-2-1	KDML 65 G1U-45/IR17494-32-3-1-1-3	Late Oct	R	R	R	R	S	*Bph 3* gene, aromatic
IR43511-150-2-2-5	Patnai 23/IR19735-5-2-3-2// IR18272-27-3-1	Early Oct	R	R	R	M	R	Medium deep, intermediate AC
IR43522-37-3-3-3	KDML 105/IR19728-9-3-2-3-3// IR19660-73-4-2-2	Mid-Oct	R	R	R	R	R	
IR43559-121-3-3-1	IR13423-10-2-3/FR438//MTU7029/ IR19728-9-3-2-3-3	Mid-Oct	R	R	R	R	R	Moderate submergence tolerance
IR43568-14-1-1-2	KDML 105/IR7812-4-5-5// KDML 105/IR19735-5-2-3-2-1	Mid-Oct	R	R	R	R	R	Aromatic

[a]Based on average scores for resistance from the Plant Pathology and Entomology Departments, IRRI. R = resistant, M = moderately resistant, S = susceptible. [b]AC = amylose content.

Table 7. Grain yield, days to flowering, and plant height of top yielding entries and local checks in the rainfed lowland rice yield nursery for drought-prone areas. Solana, Cagayan, Philippines, 1985 WS.

Variety or line	Stratum 1			Stratum 2			Mean yield (t/ha) across strata
	Days to flowering[a] (DAS)	Plant height (cm)	Yield (t/ha)	Days to flowering[a] (DAS)	Plant height (cm)	Yield (t/ha)	
IR19319-1-2-1-1-2	144	82	2.8	132	68	1.7	2.3
IR28526-44-1-1	121	107	2.8	132	92	2.0	2.4
IR33238-25-2-3-2	114	97	2.6	125	77	1.7	2.3
IR19431-72-2	107	87	2.8	128	74	1.4	2.1
IR19319-3-3-2-1	117	91	2.8	132	75	1.4	2.1
IR21188-87-3-3-2-2	107	81	2.7	143	69	1.2	2.0
IR21567-9-2-3-1-3	107	76	2.7	125	72	1.3	2.0
IR21567-9-2-2-2-1	104	74	2.6	114	73	1.6	2.1
IR33383-9-5-2-1	107	87	2.6	132	66	0.8	1.7
IR29341-85-3-1-3	114	90	2.4	128	72	1.5	2.0
IR13146-13-3-3	107	84	2.4	125	71	1.2	1.8
IR13146-45-2-3	117	94	2.3	128	79	1.5	1.9
IR19672-140-2-3-2-2	114	86	2.3	139	69	1.0	1.7
IR21567-18-3	107	77	2.3	121	70	1.1	1.7
IR37138-24-1-2-3	114	87	2.3	132	71	1.0	1.7
IR46 (check)	104	73	2.1	107	67	1.4	1.8
Wagwag Saigon (check)	143	132	1.7	144	101	1.9	1.8
Wagwag Fino (check)	143	116	1.4	157	97	1.2	1.3
LSD (.05)			0.64			0.60	
(.01)			0.86			0.80	
CV (yield)			16.57			27.88	

[a]Number of days after sowing.

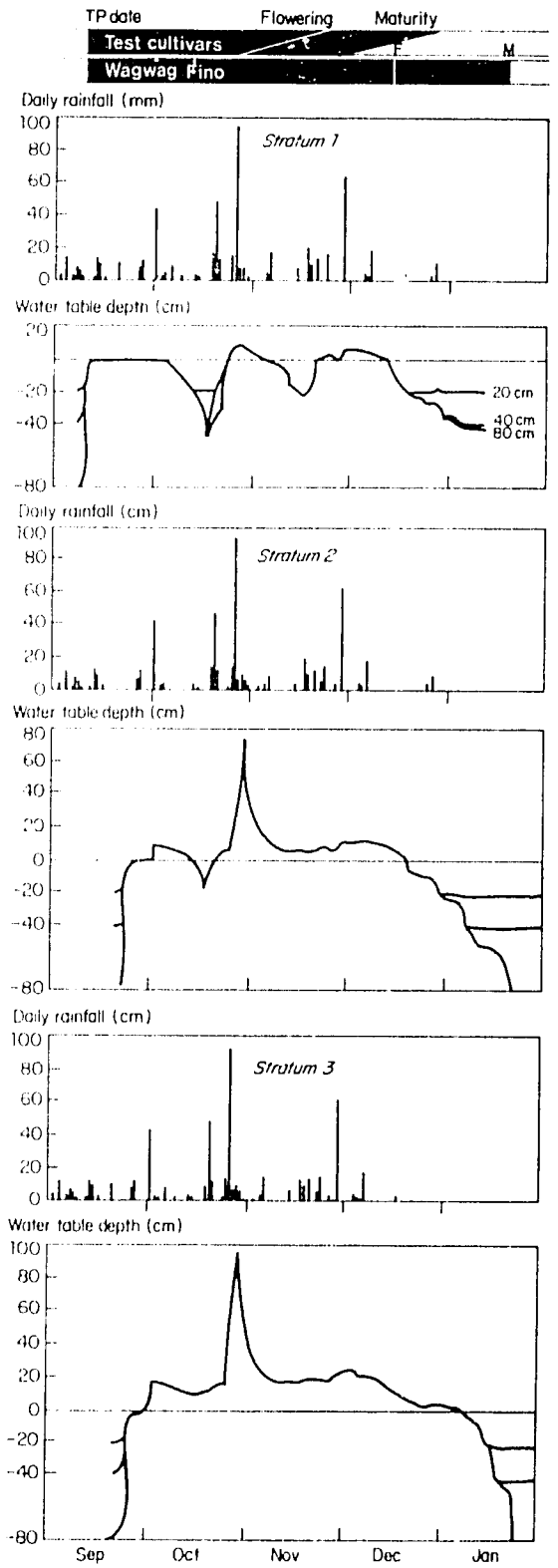
Thai-IRRI collaborative breeding project (*Plant Breeding*). Collaborative breeding nurseries were grown for the fourth consecutive year at six research stations in northeast Thailand. Plants selected from all stations totaled 1,073 from F_2 populations and 943 from the pedigree nurseries. An observation nursery of 106 advanced lines was grown at each station, and promising lines were identified for further testing.

Adaptation to drought- and submergence-prone rainfed lowland conditions (*Multiple Cropping*). Cultivar evaluation research was conducted in a difficult rainfed lowland area in Cagayan Valley to identify genetic materials adapted to environments with severe hydrological stresses. Testing sites were located in three strata of a toposequence of unfavorable rainfed lowland rice: drought-prone (stratum 1), drought- and submergence-prone (stratum 2), and submergence-prone (stratum 3). Yield nurseries of promising lines were composed specifically for these stress environments and tested during 1985 WS.

Hydrological monitoring revealed that the major physical stresses varied among the sites (Fig. 1). Stratum 1 had two short periods of water deficit. The free water level declined to 50 cm for several days. In strata 2 and 3, the level remained above the soil surface during the entire season, with consequent water stagnation. In the second week of December the level declined rapidly in stratum 1. In stratum 2, the decline was gradual from the second week of December to the first week of January. The decline did not begin until the second week of January in stratum 3, although rainfall ceased from the first week of December.

Yields of the best improved cultivars composing the drought-prone areas nursery exceeded those of the well-adapted local checks by as much as 100% in stratum 1 (Table 7) and yielded like the local checks in stratum 2. The best entries in the drought- and submergence-prone yield trial out-yielded the local check by 30-40% in strata 2 and 3 (Table 8).

Yields were positively correlated with days to flowering at all sites (Fig. 2), suggesting that strong selection pressure for late-maturing genotypes (greater than 130 d) exists in drought- and submergence-prone and submergence-prone environments; and for medium-maturing genotypes (120-130 d) in drought-prone environments.



1. Rainfall and water table hydrographs for 3 strata in a rainfed lowland rice-growing toposequence. Solana, Cagayan, Philippines, 1985 WS. TP = transplanting.

Table 8. Grain yield, days to flowering, and plant height of top entries and local checks in the rainfed lowland rice yield nursery for submergence-prone areas. Solana, Cagayan, Philippines, 1985 WS.

Variety or line	Stratum 2			Stratum 3			Mean yield (t/ha) across strata
	Days to flowering (DAS)	Plant height (cm)	Yield (t/ha)	Days to flowering (DAS)	Plant height (cm)	Yield (t/ha)	
IR28930-5T	150	88	1.6	147	89	1.3	1.5
IR29012-4-1-3	150	76	1.6	151	74	1.3	1.5
IR35649-7-3-2-3	150	68	1.2	151	73	1.4	1.3
IR26721-135-2-6-1-3	127	75	1.1	94	71	1.4	1.3
IR3234-OT-9-2	150	70	1.1	151	69	1.0	1.1
IR28905-4-1-1	150	65	1.1	143	73	0.8	1.0
IR37105-3-1-3	121	65	1.0	126	60	0.7	0.9
CN505-5-3-2	131	58	1.0	136	63	1.2	1.1
IR26707-256-2-2	135	62	1.0	130	55	0.4	0.7
IR35875-8-3-3-4	150	80	0.9	151	81	0.8	0.9
IR21313-36-2-2-3	142	71	0.9	136	68	0.9	0.9
IR26708-2-2-3-1-04	150	69	0.9	147	73	0.9	0.9
BKNFR76026-29-2-1-3	142	67	0.8	143	68	1.0	0.9
IR37119-4-3-2-3	127	65	0.8	136	59	0.7	0.8
IR33126-77-3-1	150	103	0.7	151	101	0.5	0.6
Wagwag Fino (check)	156	87	0.8	157	93	1.2	1.0
KDML105 (check)	121	69	0.3	122	67	0.2	0.3
LSD (.05)			0.59			0.57	
(.01)			0.80			0.43	
CV (yield)			34.67			27.56	

UPLAND RICE

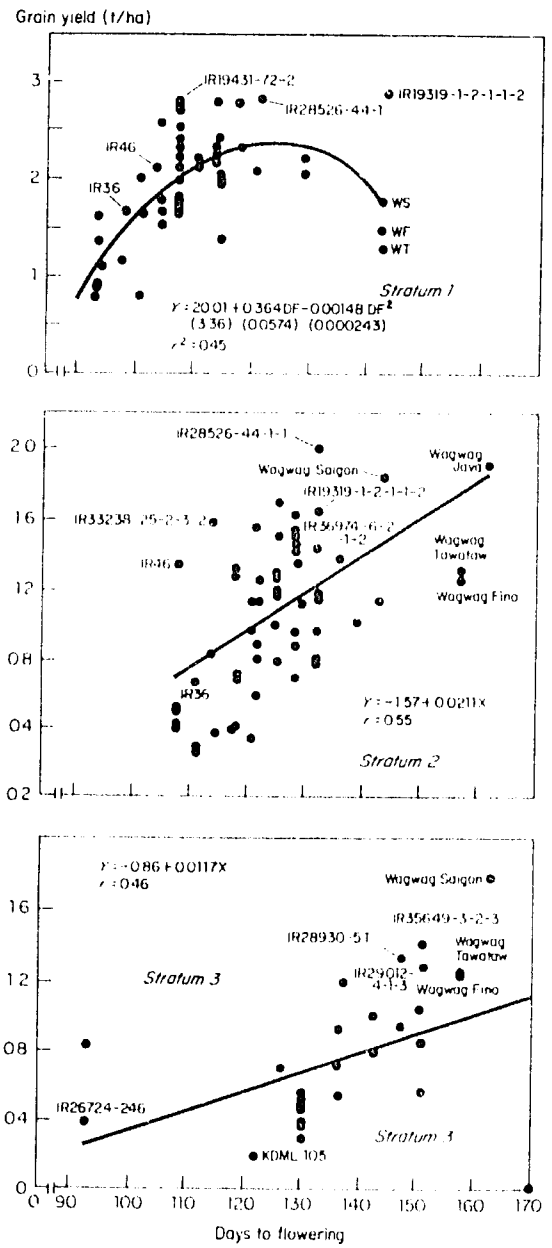
International Rice Germplasm Center and Plant Breeding, Plant Pathology, Agronomy, and Multiple Cropping Departments

Breeding operations (*International Rice Germplasm Center*). We continued our efforts to recombine the extensive root system and stable yield of the traditional upland varieties with the recovery ability and improved yield potential of irrigated ecotypes. The deep-and-thick root system has been recognized as the principal mechanism of drought avoidance. Other major breeding objectives were adaptations to a wide range of environments, especially acid soil, low P supply, blast (Bl) incidence, and high weed infestation.

We also continued to generate crosses with collaborating national centers in drought-prone areas in India, Senegal, Zanzibar, Mexico, and Thailand, and with the West Africa Rice Development Association (WARDA). In 1986, 226 single crosses, multiple crosses, and backcrosses were made. Of these, 148 were made for the national (India, 51; Senegal, 26; Zanzibar, 24; Mexico, 37; Thailand, 3) and regional (WARDA, 7) centers.

During the year, 280 F_2 bulk populations were grown to be carried up to the F_4. In DS, 158 F_4 and F_5 bulk populations were grown in a dry seedbed and selected for deep-and-thick roots prior to transplanting. At maturity, 1,424 plants were selected as having desirable traits — intermediate height, long and well-exserted panicles, heavy grains, nonshattering characteristic, moderate tillering, and freedom from diseases and grain discoloration — and were grown in a farmer's field during WS. Moderate infection of leaf Bl allowed us to select 2,707 plants that were resistant and also had outstanding agronomic traits.

Replicated yield trials (*International Rice Germplasm Center*). During WS, 95 upland breeding lines, 3 improved varieties, and 2 traditional upland varieties were grown at 3 sites: a farmer's field in Santo Tomas, Batangas; on the IRRI upland experimental farm; and in an acid upland soil in Cavinti, Laguna. Rains were frequent, and total precipitation was about 30% higher than in previous seasons at all sites.



2. Days to flowering and grain yield relationship of entries tested on three strata in the rainfed lowland rice toposequence. Solana, Cagayan, Philippines, 1985 WS.

However, a 3-wk dry spell just after seeding at the Batangas site caused poor emergence and missing hills.

Despite poor emergence in the farmer's field, the yields were average, 1.0-3.7 t/ha. About 40% of the breeding lines outperformed the check varieties. The top yielders were IR26957-86-2, IR12721-5-1-1-3, and IR13754-6-3 (Table 9). These lines generally mature 3-5 d later than the popular farmer's variety Kinandang Patong (maturity = 130 d after seeding), and have intermediate plant stature, higher panicle number, and a weed-competitive plant type (horizontal or droopy lower leaves and erect upper leaves). The grains have intermediate AC and low GT. The lines are generally resistant to Bl and BB races 1 and 2. The IR13754 lines are tolerant of Al toxicity.

The yields at IRRI ranged from 0.9 to 3.5 t/ha. The IR13754 lines were again superior (3.1-3.5 t/ha) to other lines and were slightly better than or equal to the best check variety, UPLRi-7 (3.2 t/ha) (Table 10). The semidwarf check, IR43, yielded only 2.9 t/ha. Kinandang Patong yielded 0.9 t/ha because of severe BB and lodging. All entries matured 10 d earlier on the IRRI farm than in Batangas. IR13754-6-3 and IR26957-86-2 were again among the top yielders.

In the acid upland soil in Cavinti, the yields of 40 entries ranged from 0.6 to 1.9 t/ha (Table 11). Some of the best performers at this site were the IR13754 and IR29429 lines and IR26957-86-2. Most of the entries matured early (115-125 d). Check variety IR43 matured in 130 d. At this site, 40 kg P/ha was added, which could account for the higher yields (1.2-1.6 t/ha) of the improved check varieties (IR43, UPLRi-5, and UPLRi-7) than the 0.2-0.6 t/ha in the 1985 crop season when only 20 kg/ha was used. Kinandang Patong, however, was seriously affected by both leaf Bl and brown spot. The additional P did not boost its average yield (0.6 t/ha) under acid upland conditions. On the other hand, the improved lines were generally more resistant to Bl and brown spot.

The three IR29429 lines from the cross Khao Nho/IR11248-13-2-3 also have the plant ideotype (horizontal lower leaves and erect upper leaves) that competes more effectively with weeds. They have intermediate AC and low GT. One line, IR29429-B-3-B-1-4, is tolerant of Al toxicity.

Considering the performance across the 3 sites, 11 lines showed high, stable yield. Among them, IR13754-6-3, IR26957-86-2, and IR26958-34-2 were the most stable. These lines performed well in the 1985 WS observational yield trial (OYT) when prolonged drought occurred in midseason.

Table 9. Yields and other agronomic traits of promising entries grown in a farmer's field in Santo Tomas, Batangas, Philippines, 1986 WS.

Variety or line	Yield (t/ha)	Maturity (DAS)	Plant height (cm)	Panicles (no./m²)	Bl reaction[a]	Al tolerance[b]	BB_1	BB_2	Amylose content (%)	Gelatinization temperature[c]
IR26957-86-2	3.7	137	129	217	1 (4)	9	3	3	22.4	HI/I
IR12721-5-1-1-3	3.5	134	123	261	1 (4)	5	5	3	26.2	L
IR13754-6-3	3.4	133	118	234	0	1	3	3	20.4	L
IR13754-5-10	3.4	138	124	213	1 (4)	1	7	3	27.0	L
IR13754-6-4	3.4	138	116	222	1 (4)	5	5	3	18.7	L
IR10120-7-2-1-4	3.3	138	125	175	1 (4)	5	7	5	22.2	I/L
IR27095-20-18	3.3	133	126	180	3-4	1	3	3	22.0	I/L
IR13754-5-2	3.2	135	123	239	1 (4)	5	5	3	22.3	L
IR27130-3-4	3.2	136	121	203	1 (4)	5	5	3	15.6	HI
IR27078-20-6	3.1	144	121	233	0	5	5	5	23.6	L
IR26958-34-2	3.1	132	138	223	1 (3-4)	9	5	3	20.6	HI/I
IR13754-5-7	3.1	138	130	239	4	1	3	3	27.0	L
IR10147-11[illegible]5-1-1-5	3.0	135	126	168	1 (4)	9	7	3	22.4	I
B2406B-SM247B-1-2-1-MR-5	3.0	135	121	153	0	5	5	3	21.0	I
IR43 (check)	2.3	138	81	280	4	5	3	3	17.1	L
UPLRi-5 (check)	2.7	140	119	160	1 (4)	9	5	3	22.2	I
UPLRi-7 (check)	2.6	124	108	174	4	5	5	3	24.0	L
Dinorado (check)	1.0	139	145	113	–	1	5	3	–	–
Kinandang Patong (check)	1.5	128	155	121	1 (4)	1	7	3	26.6	I

[a]First value is predominant Bl score. Numbers in parentheses refer to a few lesions of the most susceptible class observed in the plot. [b]Per relative root length (RRL) method of the Plant Physiology Department. [c]HI = high-intermediate, I = intermediate, L = low.

Table 10. Yields and other agronomic traits of promising entries at IRRI, 1986 WS.

Variety or line	Yield (t/ha)	Maturity (DAS)	Plant height (cm)	Panicles (no./m²)	Bl reaction[a]	Al tolerance[b]	BB race 1	BB race 2	Amylose content (%)	Gelatinization temperature
IR13754-6-3	3.5	125	115	252	0	1	3	3	20.4	L
IR13754-12-3	3.5	127	114	264	1 (4)	5	5	3	20.8	L
IR26957-86-2	3.4	128	126	273	1 (4)	9	3	3	22.4	HI/I
IR13754-6-4	3.3	127	118	275	1 (4)	5	5	3	18.7	L
IR27078-3-6	3.2	126	110	286	0	9	7	3	24.0	L
IR13754-7-3	3.2	125	118	280	1 (4)	1	3	3	26.0	L
IR13754-5-7	3.1	128	118	260	4	1	3	3	27.0	L
IR12979-24-1-8	3.1	122	118	247	–	5	3	3	25.0	I/L
IR26958-34-2	3.0	123	139	255	1 (3-4)	9	5	3	20.6	HI/I
IR27130-3-4	3.0	125	118	249	1 (4)	5	5	3	15.6	HI
IR43 (check)	2.9	129	84	319	4	5	3	3	17.1	L
UPLRi-5 (check)	2.2	126	116	222	1 (4)	9	5	3	22.2	I
UPLRi-7 (check)	3.2	112	109	212	4	5	5	3	24.0	L
Dinorado (check)	1.0	126	120	217	–	1	5	3	–	–
Kinandang Patong (check)	0.9	122	136	167	1 (4)	1	7	3	26.6	I

[a]First value is predominant Bl score. Numbers in parentheses refer to a few lesions of the most susceptible class observed in the plot. [b]Per RRL method.

Table 11. Yields of promising entries grown in an acid upland soil in Cavinti, Laguna, Philippines, 1986 WS.

Variety or line	Yield (t/ha)	Maturity (DAS)	Plant height (cm)	Panicles (no./m²)	Field leaf Bl reaction[a]	Brown spot	Al tolerance[b]	Amylose content (%)	Gelatinization temperature
IR13754-6-3	1.9	131	92	352	0 (4)	0.1	1	20.4	L
IR5420-1-1-2-3	1.8	125	91	313	0 (4)	0.1	5	17.0	L
IR26957-86-2	1.7	132	107	265	4	3	9	22.4	HI/I
IR29429-B-3-B-2-3	1.6	124	100	297	0 (4)	0.5	5	23.7	L
IR29429-B-3-B-1-4	1.6	124	90	272	0 (4)	0.1	1	22.4	L
IR29429-B-3-B-2-7	1.6	127	103	275	0 (3-4)	0.5	5	24.2	I
IR26958-34-2	1.6	124	104	268	0 (4)	5	9	20.6	HI/I
IR5931-113-1	1.6	124	95	225	0	0.1	9	26.8	I/L
IR7790-18-1-2-5	1.5	115	103	274	0 (4)	0.5	5	23.2	I/L
IR12979-24-1-8	1.5	123	99	299	0 (4)	0.1	5	25.0	I/L
IR13754-7-3	1.5	128	97	294	3 (4)	0.1	1	26.0	L
IR43 (check)	1.6	130	70	374	0 (4)	1.0	5	17.1	L
UPLRi-5 (check)	1.5	125	99	295	4	5	9	22.2	I
UPLRi-7 (check)	1.2	119	76	245	0 (4)	0.5	5	24.0	L
Dinorado (check)	1.4	125	130	220	3	3	1	–	–
Kinandang Patong (check)	0.6	118	110	184	5	20	1	26.6	I

[a]First value is predominant Bl score. Numbers in parentheses refer to a few lesions of the most susceptible class observed in the plot. [b]Per RRL method.

IR13754-6-3, coming from IR3880-10/IR2823-179-5-4, also performed well (2.8-4.2 t/ha) in the Agronomy Department OYTs in Batangas.

We are thus making good progress in fulfilling the recently added breeding objectives of adaptation to acid and P-deficient soils, and weed competitiveness. Although we had emphasized drought resistance under favorable soil fertility, the progenies have performed well under unfavorable environments because most of them have parents from African varieties such as OS4, LAC23, and F425 and from Asian traditional upland parents, which are adapted to acid soils. Resistance to Bl is undoubtedly carried over from the traditional varieties.

Evaluation of upland germplasm (*Plant Breeding*). Germplasm screening and evaluation during 1986 WS were at two sites: at IRRI under favorable conditions (good soil and low Bl pressure), where information was obtained on yield potential; and at Mahipon, Cavinti, Laguna, under very adverse conditions with very poor, acidic soil (pH = 4) and severe Bl pressure. The best materials are listed in Table 12.

Under very poor acidic soils with high Bl pressure:

- No group I (indica) entry showed good phenotypic acceptability. Furthermore, all entries from this group were very susceptible to Bl except Carreon, which showed some degree of tolerance.
- Four entries from group II (aus) were very promising, but need further evaluation to check their Bl resistance.
- Some group VI (japonica) entries — Azucena, Gogo Gundil, LAC23, IRAT104, IRAT288, and several very early CNA lines from Brazil — were far superior to the other entries.

Under good soils without Bl:

- The group I (indica) entries were outstanding for their daily productivity.
- The group II (aus) entries were acceptable, particularly Aus 196, which exhibited very high daily productivity.
- The group VI (japonica) entries merit strong attention, if improved, for their excellent plant type.

Compared with the check, these top entries have a much higher yield potential, and most are shorter in duration.

The Korean and Japanese entries (all group VI) showed some Bl, but their productivity under very severe environmental constraints was very high. As they are short-strawed and show very good response to low N inputs, they are of potential use for adverse upland conditions.

Upland japonicas, either traditional or improved, are clearly the best materials for adverse upland conditions, based on the evaluation of more than 5,000 accessions during the past 3 yr. Most have been discarded because of lack of promising traits — e.g., poor yield potential — under severe constraints — mostly acid soil, high Bl pressure, and sheath diseases. Of the 114 germplasm entries that were kept, more than 80% are japonicas (group VI). All these entries have a growth duration shorter than that of check variety UPLRi-5. The field germplasm will be maintained under adverse conditions to determine tolerance for diseases and pests.

The upland japonicas, both tropical and temperate, have plant structures suited to high yield potential (temperate) and adaptation to adverse environments (tropical). Their physiological mechanisms, frequently combined with excellent adaptive characters, are very efficient in terms of nutrient uptake. Their tillering ability is moderate, never high; this is an excellent trait because, most frequently, they do not develop nonproductive tillers. In-depth studies of the mechanisms of inheritance of all these useful traits are needed.

Evaluation of hybrid progenies (*Plant Breeding*). Seven hundred sixty-nine progenies were studied over 3 yr, 267 (35%) F_5 to F_8 of which were under study at the end of 1986. The frequency of progenies having at least one parent belonging to a given group is as follows: group I (indica), 129 (48%); group II (aus), 48 (18%); and group VI (japonica), 227 (84%).

Crosses with a group II entry were less promising than crosses with group I and group VI entries, since most of the F_2 progenies of a group II entry were too lodging-susceptible and possessed poor plant or panicle type.

Table 12. Top germplasm entries for adverse upland conditions. IRRI, 1986.

Seed-to-seed duration (d)	Variety or line	Mahipon[a]				Variety or line	IRRI[b]			
		EVV	LBI	NBI	PAcp		SD	LR	STB	YPD
Less than 95	CNA4102	1	1	[illegible]	1	CNA4102	3	5	3	38
	CNA4127	1	1	3	1	CNA4124	3	7	1	32
	CNA4128	1	5	1	1	CNA4127	3	7	3	51
	CNA4136	3	1	1	1	CNA4136	1	5	2	37
	IAC165	3	3	1	3	CNA4196	1	7	3	32
95-105	63-83 (A)	3	1	1	1	63-83 (A)	3	3	3	33
	ARC7046[c]	1	1	1	5	Aus 196[c]	1	7	2	58
	Aus 196[c]	1	1	3	1	Aus 454[c]	1	7	1	31
	Aus 454[c]	1	1	1	1	CNA4143	3	1	4	37
	CNA4146	3	3	1	1	CNA4146	3	1	4	31
	CNA4746	1	3	1	1	CNA5166	3	1	2	31
	IRAT115	3	1	1	1	IRAT144	3	1	4	31
	IRAT288	1	1	1	1	Surjamukhi[c]	1	1	1	31
	IRAT291	1	1	1	1					
	Jaeraeryukdo	3	3	5	1					
	Surjamukhi[c]	1	1	1	1					
	Yongdalichalbyeo	1	1	3	1					
106-119	Azucena (B)	3	1	1	1	Azucena (B)	3	1	1	38
	Azucena (C)	3	1	1	1	Azucena (C)	3	1	1	36
	CNA108-8-42-24-2B	3	1	1	1	B3622-TB-14-2[d]	3	1	7	52
	E425 (B)	3	1	5	3	B3622-TB-14-4[d]	3	1	4	38
	GS529	1	—	—	3	B3623G-TB-45[d]	3	1	4	39
	IRAT104 (A)	3	1	1	1	B3623G-TB-46[d]	3	1	3	41
	IRAT104 (C)	3	1	1	1	Bolibod natural	3	1	7	44
	IRAT104 (E)	3	1	1	1	B[illegible]319-1[d]	7	3	5	41
	IRAT110	3	1	5	1	Dinorado (A)	1	3	7	39
	ITA130	1	1	1	1	GH305[d]	5	3	3	59
	ITA173	1	1	3	1	IR12979-24-1[d]	3	3	3	61
	Lung Sheng No. 1	1	1	5	1	ITA235	3	3	3	39
	Milyang 26	1	1	1	1					
	Rikuto Norin 24	1	5	8	1					
	Saita[d]	4	1	1	1					
120-130	Gogo Gundil	3	1	1	1	C171-136[d]	4	1	5	44
	LAC23 (D)	1	1	1	1	Palawan (A)	1	1	1	36
	Moroberekan (A)	3	1		3	Palawan (C)	3	1	1	35
	Palawan (A)	1	1	1	3	P2030-F_4-235-1B-1B[d]	3	5	1	41
	Palawan (C)	3	3	3	1					
						UPLRi-5 (A)[d]	3	1	1	42
						UPLRi-5 (B)[d]	3	1	1	40
						UPLRi-7 (B)[d]	3	1	1	43
	Kinandang Patong (check)	3	3	5	7		3	6	[illegible]	20

[a]EVV = early vegetative vigor, LBI = leaf blast, NBI = neck blast, PAcp = phenotypic acceptability (overall agronomic characters). [b]SD = sheath disease susceptibility, LR = lodging resistance, STB = stem borer resistance, YPD = yield per day in kg. [c]Group II (aus) entry. [d]Group I (indica) entry.

Most of the crosses with group I entries exhibited F_1-F_2 sterility. However, submitting them to an approach different from intra-group crossing favored the selection of several very promising F_4-F_7 progenies.

Major emphasis will be given to intra-group VI crosses, while group VI/group I crosses for recombining the needed traits for the uplands from the two groups will merit special attention. From our most recent evaluation, few group II entries have been selected as very promising for future crosses.

The fertility of intra- and inter-group crosses was about the same, indicating that group VI/group I

(japonica/indica) crosses, when carefully selected, recover their fertility, even at the F_4 stage. There is therefore no reason to reject such crosses, which can show very promising recombinations from both parents for the major characters required for upland cultivation.

Evaluation of advanced-generation progenies (*Plant Breeding*). The total percentage of progenies with a group VI entry as one parent was 88%, showing wide use of this group for breeding for adverse environments. Progenies with group I and group II as female parents are becoming less numerous with the progress of progeny studies.

The 350 F_7-F_8 single plant selections and bulked progenies were evaluated at IRRI and Mahipon during 1986 WS.

IRRI. Screening at 30 and 90 kg N/ha at IRRI produced the results shown in Table 13. Eight crosses with 26 progenies were responsive to high N, and 10 with 76 progenies were responsive to low N. Of the total 102 progenies, 4 were longer in duration than the check; 2 were from the high N-responsive and 2 from the low N-responsive progenies. Nine entries yielded about twice as much as the check under both 30 or 90 kg N/ha, and 2 yielded higher than UPLRi-5, mostly under low N. Most were more drought- and Bl-tolerant than the check.

All these entries were very promising under intermediate upland environments.

Mahipon, Philippines. Of 310 F_7 progenies, 50 were found very promising for their adaptability under very acidic soils and heavy Bl at Mahipon. Most were from group VI/group VI crosses, especially IRAT104/Palawan, but several group VI/group I progenies, such as ITA235/UPLRi-7, were also promising. The same entry was not always promising at both IRRI and Mahipon, but a few, most frequently from the IRAT104/Palawan cross, were.

Mutation breeding (*Plant Breeding*). Ninety-two M_3 progenies were studied. They were from five traditional cultivars: Salumpikit (group I), 52 M_3 lines; Dinorado (group VI), 28; Azucena (group VI), 8; Speaker (group VI), 2; and Kinandang Patong (group VI), 2.

Table 13. Promising progenies[a] at the IRRI site, 1986 WS.

Cross	Parents[b]	Progenies (no.)	Yield (mean %) over the check		Mean seed-to-seed duration (d)
			30 N	90 N	
	Progenies responsive to high N rates				
IR47682	*IRAT13*/UPLRi-7	1	170	260	100
IR47686	*IRAT104/Palawan*	16	158	260	107
IR47691	*IRAT140/Palawan*	4	128	223	110
IR47701	*ITA235*/UPLRi-7	1	110	150	105
IR47699	*ITA235/Palawan*	1	110	220	113
IR47719	*IRAT117/IRAT177*	1	120	150	114
IR47722	*IRAT177*/Apura	1	120	150	114
IR47687	*IRAT104*/Salumpikit	1	150	210	111
Kinandang Patong (check)			100	100	113
	Progenies responsive to low N rates				
IR47682	*IRAT13*/UPLRi-7	1	220	240	99
IR47686	*IRAT104/Palawan*	37	192	194	108
IR47690	*IRAT140/Kinandang Patong*	2	155	150	110
IR47691	*IRAT140/Palawan*	13	137	166	108
IR47697	*ITA235*/IR9669 selection	1	120	210	113
IR47698	*ITA235/Kinandang Patong*	3	123	160	105
IR47699	*ITA235/Palawan*	9	126	152	108
IR47728	*IRAT112*/Papayo	1	150	140	114
IR47701	*ITA235*/UPLRi 7	8	139	120	103
IR47687	*IRAT104*/Salumpikit	1	180	200	125
Kinandang Patong (check)			100	100	113

[a]Group VI (japonica) entries are italicized. [b]UPLRi-5: Days to maturity: 124. Mean plot yield: 90 kg N/ha = 1.7 t/ha, 30 kg N/ha = 1.8 t/ha.

All the mutants were shorter than their parents. Some showed higher tillering ability and shorter panicles, but similar seed-to-seed duration.

Screening for adverse conditions (*Plant Pathology, Plant Breeding, Agronomy, and Multiple Cropping*). *Blast (Plant Pathology and Plant Breeding)*. One hundred sixteen entries were screened at Mahipon under severe Bl infestation in 1986 WS. The results are given in Table 14.

One entry, Carreon, from the 12 group I (indica) entries, showed no symptoms; 95% of the group VI (japonica) entries also showed no symptoms. Even if several of the group VI entries possessed vertical resistance, it is highly probable that most possess very good durable horizontal resistance (for example, IRAT104, IRAT13, and OS6).

Entries from group II (aus) showed no neck Bl. These were the only 4 out of about 150 group II entries that had been kept after 2 yr of evaluation and screening for Bl tolerance. They may show the same vertical or horizontal mechanisms as the other group VI entries.

Drought resistance (Agronomy and Plant Breeding). Two hundred seventy F_4 progenies were screened at IRRI for drought tolerance during 1986 DS. The top F_4 progenies are given in Table 15. Forty-eight (18%) showed a drought recovery score of 3 or less and at least 1 drought resistance scoring equal to or better than the check Salumpikit, a group I (indica) traditional entry from the Philippines.

Except for two entries, all were from intra-group VI crosses, including an improved and a traditional variety. IRAT104, Palawan, and Kinandang Patong are well known for showing very good drought tolerance.

Table 15. Top F_4 progenies in drought resistance screening. IRRI, 1986 DS.

Line	Cross[a]	Lines (no.)	Scored entries under the same designation (%)
IR47682	*IRAT13*/UPLRi-7	1	50
IR47683	*IRAT104/Dinorado*	1	100
IR47684	*IRAT104/Kinandang Patong*	2	100
IR47686	*IRAT104/Palawan*	25	24
IR47690	*IRAT140/Kinandang Patong*	1	17
IR47691	*IRAT140/Palawan*	16	19
IR47697	*ITA235*/IR9669 selection	2	33
Total		48	18

[a]Group VI (japonica) entries are italicized.

Poor environment (Multiple Cropping and Plant Breeding). The best entries in the germplasm and progeny screening in Claveria and Mahipon are given in Table 16. All were from group VI (japonica) except IR46782, which was a group VI/group I entry. Brazilian CNA entries had excellent yields in adverse environments. Most of the promising entries had IRAT104 (A) as one of their parents.

The situation was less clear in Claveria, Misamis Oriental, Philippines, where the environment is not as favorable for the japonicas. However, IRAT104 (A) again ranked very well. The top progenies were diverse in origin. However, even in a moderately adverse environment, japonica entries showed very good yield potential.

Table 14. Screening the F_6 for Bl. Mahipon, Laguna, Philippines, 1986 WS.

Group	Neck Bl: Susceptible no.	Susceptible %	No symptoms no.	No symptoms %	Approximate mean yield loss (%)
I = indica	11	92	1	8	49.1
II = aus	0	0	4	100	0
VI = japonica					
Upland traditional	1	4	27	96	0.1
Upland improved	3	5	63	95	0.9
Temperate	4	67	2	33	15.1

Table 16. Top 15 entries in observational trials in Claveria and Mahipon, Philippines.[a] 1986 WS.

Moderately adverse environment (Claveria)					Adverse environment (Mahipon)				
R	Variety or line	Yield (t/ha)	Seed-to-seed duration[b] (d)	Daily yield (kg)	R	Variety or line	Yield (t/ha)	Seed-to-seed duration (d)	Daily yield (kg)
1	IR47686-6-1-1	5.5	124	45	1	CNA4130	5.4	98	54
3	IR47690-18-B-1/7	4.8	128	38	2	CNA4097	4.5	98	46
4	IR47690-18-B-8/13	4.7	124	38	3	IR47686-13-1-1	3.9	119	32
9	IR47686-1-4-1	4.6	121	38	4	CNA4196	3.8	98	39
12	IR47686-30-4-2	4.5	128	35	5	IR47686-6-2-2-1	3.8	109	34
13	IR47682-9-1-B	4.4	121	36	6	IR47686-28-8-1	3.7	113	33
14	IRAT104 (A)	4.4	126	35	7	CNA4128	3.7	98	38
19	IR47686-30-4-1	4.2	128	33	9	IRAT13	3.4	109	31
21	IR47686-9-8-B	4.7	121	34	9	IRAT284	3.4	98	35
24	IR47686-10-1-B	4.1	131	31	11	IR47686-26-1-2	3.3	113	29
24	IR47691-19-3-B	4.1	124	34	12	IR47686-25-3-1	3.3	113	29
26	IR47691-45-5-1	4.1	121	34	13	IR47686-10-1-1-1	3.3	109	30
27	IR47691-19-2-B	4.1	124	33	14	IRAT104 (A)	3.2	109	29
28	IR47686-6-2-B	4.0	124	33	14	IR47686-6-4-1-1	3.2	119	27
32	IR47686-1-1-B	4.0	126	32	16	CNA108-8-42-24-2B	3.2	92	35

[a]R = ranking in the given trial. IR47682 = IRAT13/UPLRi 7, IR47686 = IRAT104/Palawan, IR47690 = IRAT140/Kinandang Patong, IR47691 = IRAT140/Palawan. [b]Maturity delayed by 4-wk drought.

Acid upland yield trial (*Multiple Cropping, Agronomy, Plant Breeding, and International Rice Germplasm Center*). The acid upland yield trial evaluated elite materials for acid infertile upland conditions. Trials were conducted at three sites: Cavinti, Laguna (54 entries); Claveria, Misamis Oriental (49 entries); and Santo Tomas, Batangas (41 entries). Excessive rain occurred throughout the growth period in Cavinti, along with strong wind velocities from four typhoons during October, when most of the entries were flowering. Lines from IR30716 (RP825-70-7/LAC23//LAC23) dominated the high ranks among the entries, with yields more than double those of the modern (UPLRi-5) and traditional (Kinandang Patong) checks (Table 17). Three of the IR30716 entries (IR30716-B-3-B-13-4, IR30716-B-8-B-5-6, and IR30716-B-1-B-1-2) had been top ranking entries in the acid upland observational trial at Cavinti and Claveria in the previous year.

In Claveria the trial had much lower yields than those in 1985. A short drought during the seedling stage and a severe drought during panicle development resulted in poor growth and high incidence of neck Bl. The top entry (IR30716-B-12-B-1-4) was the only one that also ranked among the top 15 entries in Cavinti (Table 18). Considering stability of performance across years at Claveria, only 2 entries (IRAT104 and UPLRi-7) were among the top 15 for 1985 and 1986.

In Santo Tomas, moisture conditions were favorable during the growing season. The local check Kinandang Patong, ranked last among the entries. Six of the top-ranking entries were also among the 15 best yielding in Claveria, but only 3 of the top entries in Santo Tomas (Aus 196, IR30716-B-1-B-7-5, and IR30716-B-12-B-1-4) were among the best in Cavinti (Table 19). One entry (B30716-B-12-B-1-4) ranked among the top 15 in all 3 trials.

Acid upland observational trial (*Multiple Cropping, Plant Breeding, and International Rice Germplasm Center*). The acid upland observational trial evaluates breeding material in acid infertile environments as early as possible in the selection process. The trial had 702 entries grown at 2 sites: Cavinti, Laguna, on soils of pH 4.0; and Claveria, Misamis Oriental, with pH 4.5.

In Cavinti, rainfall was evenly distributed throughout the growing season and there was no significant drought stress (Fig. 3). Yields of test

Table 17. Best 15 entries and check varieties and their associated characteristics. Acid upland yield trial, Mahipon, Laguna, Philippines, 1986 WS.

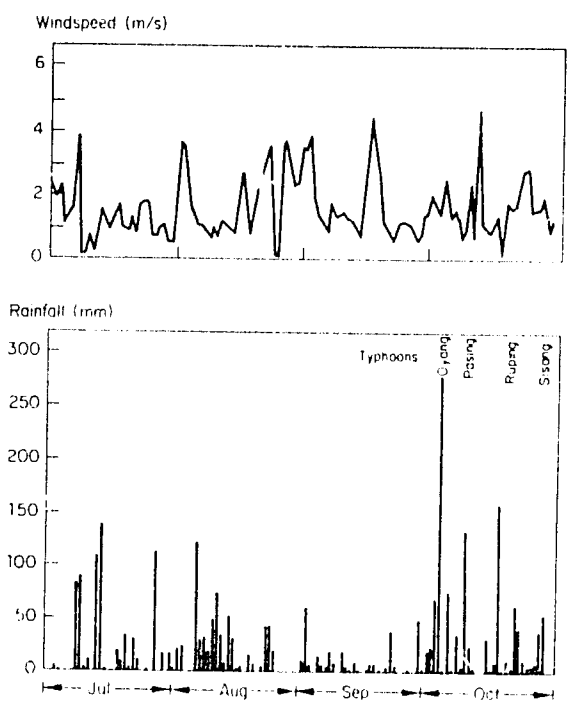
Rank	Variety or line	Yield (t/ha)	Early vigor (25 DAS)	Plant height (cm) at harvest	Neck Bl score at harvest	Rice bug score	Days to flowering	Phenotypic acceptability at harvest
1	AUS257	2.0	3	100	3.0	5.0	76	3.0
2	IRAT104	1.9	5	85	1.0	1.0	74	1.0
3	IR30716-B-3-B-13-4	1.4	2	90	2.3	4.3	91	3.0
4	IR30716-B-1-B-7-5	1.4	4	75	3.0	2.3	84	3.0
5	IR30716-B-8-B-5-6	1.3	4	95	2.3	3.7	87	3.6
6	IR30716-B-1-B-1-2	1.2	4	75	3.0	3.0	85	3.6
7	BPI 9-33	1.2	4	108	5.0	5.7	86	5.0
8	IR30716-B-2-B-8-2	1.2	5	80	1.7	3.0	88	3.6
9	IR30716-B-12-B-1-4	1.2	3	82	3.0	5.0	92	3.6
10	IR30716-B-2-B-9-1	1.1	3	75	2.3	5.0	89	3.0
11	IRAT140 (check)	1.1	3	80	5.0	2.3	85	5.6
12	Khao-Kinon	1.0	3	103	3.7	5.0	93	5.0
13	IR10068-18-2-6	1.0	5	78	1.3	3.7	91	3.6
14	IR7790-18-1-2-5	1.0	5	85	2.3	3.0	87	3.6
15	AUS196	1.0	4	92	3.7	5.0	78	5.0
34	Azucena	0.6	4	141	5.7	3.0	97	5.0
48	B2997C-TB-60-3-3	0.4	4	80	3.7	5.7	94	7.0
26	Kinandang Patong (check)	0.7	4	105	3.7	3.7	93	4.3
32	UPLRi-5 (check)	0.6	4	75	3.7	3.7	99	5.6
	LSD (0.05)	0.4	1	10	1.2	1.4	2	1.4
	CV (%)	22	20	7	23	22	2	21
	SE	0.2	1	5	0.6	0.7	1	0.7

Table 18. Best 15 entries and check varieties and their associated characteristics. Acid upland yield trial, Kalingagan, Claveria, Misamis Oriental, Philippines, 1986 WS.

Rank	Variety or line	Yield (t/ha)	Early vigor (25 DAS)	Plant height (cm) at harvest	Neck Bl score at harvest	Drought score	Days to flowering	Phenotypic acceptability at harvest
1	IR30716-B-12-B-1-4	2.8	3.6	78	0.7	2.3	102	5
2	IR13754-5-10	2.8	5.6	76	1.3	2.0	108	5
3	B2997c-TB-60-3-3	2.7	3.0	93	0.3	0.7	98	2
4	IR3880-2-3	2.7	5.0	85	0.7	2.3	101	2
5	UPLRi-5 (check)	2.6	2.3	85	1.7	1.3	106	1
6	BR319-1	2.6	4.3	75	1.7	2.3	99	6
7	IR10042-20-4-5	2.6	4.6	81	0.7	1.7	97	5
8	IR30716-B-2-B-12-5	2.6	3.7	77	1.0	1.3	107	5
9	IRAT104	2.5	3.0	96	0.7	2.3	110	4
10	UPLRi-7	2.5	2.6	72	1.0	1.6	100	2
11	ITA162	2.5	3.0	56	3.3	2.0	93	7
12	IR26957-86-2	2.5	5.6	85	1.7	2.3	105	5
13	33016B-TB-260-3-2-1-1-3	2.4	3.7	84	1.0	1.0	99	3
14	IR29429-B-3-13-2-7	2.4	4.3	87	1.3	2.3	106	3
15	BPI 9-33	2.4	4.3	93	1.7	1.6	95	5
36	IRAT140 (check)	1.9	5.6	84	2.3	1.0	96	5
44	Kinandang Patong (check)	1.8	3.7	109	2.0	0.7	99	4
	LSD (0.05)	0.6	3.4	8	1.9	1.8	4	2
	CV (%)	17	53	6	67	69	2	21
	SE	0.3	1.7	4	1.0	0.8	2	1

Table 19. Best 15 entries and check varieties and their associated characteristics. Acid upland yield trial in Santo Tomas, Batangas, Philippines, 1986 WS.

Rank	Variety or line	Grain yield (t/ha)	Yield per day (kg/ha)	Days to flowering	Plant height (cm)	Panicles (no./m²)
1	BR319-1	3.0	27.2	80	101	200
2	UPLRi-7	2.9	25.4	83	99	189
3	IR9560-2-6-3-1	2.9	22.4	95	80	232
4	IR3880-2-3	2.7	22.9	88	110	217
5	IR13754-5-10	2.7	21.7	94	111	230
6	IR13754-5-2	2.6	20.8	94	109	235
7	B3016B-TB-260-3-2-1-1-3	2.5	22.8	79	113	200
8	IR5420-1-1-2-3	2.5	20.9	88	98	241
9	AUS196	2.5	25.4	67	117	198
10	IR30716-B-1-B-7 5	2.5	23.9	72	105	175
11	IR10120-7-2-1-4	2.5	21.0	86	97	229
12	Dharial	2.4	25.7	64	114	191
13	IR9995-96-2	2.4	19.5	91	91	259
14	IR30715-B-12-B-1-4	2.4	20.8	83	93	228
15	B2997C-TB-60-3-3	2.4	20.7	83	110	210
23	IRAT140 (check)	2.2	19.7	80	108	142
27	UPLRi-5 (check)	2.0	16.8	91	99	187
41	Kinandang Patong (check)	1.5	13.4	79	138	155
	LSD (0.05)	0.5	4.8	4	8	48
	SE	0.2	2.2	2	4	24
	CV (%)	13	14	3	4	15



3. Daily distribution of rainfall and windspeed during the growing season. Acid upland yield trial Cavinti, Laguna, Philippines, Jul-Oct 1986.

entries ranged up to 535 g/m² (Table 20). The top ranking entries at this site were predominantly from japonica crosses. Major stresses were leaf and neck Bl, BB, and brown planthopper (BPH). Wind stress resulted from several typhoons, and lodging was severe. Most of the top 20 entries were very early- and early-maturing cultivars.

A severe drought occurred during the reproductive phase in Claveria. Entries that escaped tended to flower early (Table 21). Among the top 20 entries for the 2 sites, only IRAT104(A) showed rank stability across locations. Other top entries in Claveria, such as IR40472-B-B-B-1, IR47686-30-4-2, IR39262-B-B-B-4, and IR47686-30-4-1, were also in the top 8% of all entries in Cavinti.

Collaborative studies (*Plant Breeding*). *West Bengal, India.* Thirty-five F_4 progenies screened in Malda during 1986 WS suffered from very serious drought at heading. The outstanding entries are listed in Table 22, along with three local checks.

The entries had shorter growth duration than that at IRRI. The 3-wk difference was caused by the influence of latitude under the same temperature regime. All were from group VI/group VI

Table 20. Top 20 entries[a] and check varieties based on overall ranking in acid upland observational trial in Mahipon, Laguna, Philippines, 1986 WS.

Rank	Variety or line	Grain yield[b] (g/m²)	Early vigor score	Plant height (cm)	Neck Bl score	Rice bug score	Days to harvest (DAS)
1	CNA4130	535	1	107	1	1	99
2	CNA4097	452	1	110	1	0	99
3	IR47686-13-1-1	386	1	107	1	0	120
4	CNA4196	383	1	110	1	0	99
5	IR47686-6-2-2-1	376	3	119	3	1	110
6	IR47686-28-8-1	370	3	110	1	1	114
7	CNA4128	368	3	87	1	0	99
8	IR41718-B-B-B-8	361	3	86	0	3	115
9	IRAT13	343	3	90	1	3	110
10	IRAT284	343	1	107	3	3	99
11	IR47686-26-1-2	330	3	109	1	1	114
12	IR47686-25-3-1	329	3	113	3	1	114
13	IR47686-10-1-1-1	328	1	111	3	1	110
14	IRAT104 (A)	323	1	103	3	1	110
15	IR47686-64-1-1	323	3	100	3	1	120
16	CNA108-8-42-24-2B	320	1	96	3	0	94
17	Dam Boung	319	1	108	1	0	114
18	Chinei	316	1	88	1	0	94
19	IRAT115	311	1	73	3	3	99
20	IR36243-B-B-B-6	304	3	99	3	5	126
422	Burao	90	4	112	3	5	113
579	Kinawayan	58	3	112	0	3	127
154	B2997c-Tb-4-2-1	183	5	110	3	1	113
536	B3619c-Tb-6-1-4	66	6	87	0	3	113
446	IR6023-10-1-1	86	3	79	0	3	127

[a]Total no. of entries = 702. [b]Estimated from nonreplicated 2-row plots.

Table 21. Top 20 entries and check varieties, based on overall ranking in acid upland observational trial in Claveria, Misamis Oriental, Philippines, 1986 WS.

Rank	Variety or line	Yield[a] (g/m²)	Maturity (d)	Plant height (cm)
1	IR47686-6-1-1	554	94	89
2	IR41716-B-B-B-15	491	94	94
3	IR38552-B-B-B-1	483	98	95
4	IR47690-18-B-1/7	481	94	95
5	IR47690-18-B-8/13	466	91	95
6	IR29416-B-3-B-8-1-13	466	96	95
7	IR38547-B-B-B-12	465	98	90
8	IR29416-B-3-B-6-5-18	463	96	101
9	IR47686-1-4-1	463	91	100
10	IR40472-B-B-B-1	457	103	93
11	IR52812-CP128-C3-104-2	453	101	89
12	IR47686-30-4-2	447	98	104
13	IR47682-9-1-B	440	91	85
14	IRAT104 (A)	439	96	98
15	IR41712-B-B-B-11	431	94	81
16	IR39262-B-B-B-4	425	98	84
17	IR29416-B-3-B-6-5-17	424	96	93
18	IR30689-B-6-B-5-1-1	422	91	76
19	IR47686-30-4-1	421	98	116
20	IR30689-B-1-B-8-2-2	420	96	91

[a]Based on single plots of 3 m².

Table 22. Top F_4 progenies in Malda, West Bengal, India, screenings, 1986 WS.

Variety or line	Parentage	Maturity (d)	Yield/plot (g)	Spikelet fertility (%)
IR46787-10	IRAT104/Salumpikit	93	135	72
IR47699-22	ITA235/Palawan	87	140	67
IR47699-28	ITA235/Palawan	89	115	55
IR47705-6	Moroberekan/Palawan	89	100	71
IR47724-14	Moroberekan/IRAT177	90	140	47
Dular (check)		85	81	32
Panke (check)		100	123	9
Soni (check)		82	65	43

crosses except the cross with Salumpikit, an indica (group I) drought-tolerant variety. The group VI/group I cross had excellent drought tolerance at heading, with mean spikelet fertility of 62%; the best local check had 43% fertility. The entries' yield potential under drought was comparable to or better than that of the two top local checks, Dular and Panke.

CIAT, Colombia. Thirty-eight F_4 progenies from group VI/group VI crosses screened in Villavicencio during 1986 WS suffered from serious Bl infestation. The outstanding entries are listed in Table 23. Their level of Bl tolerance was as promising as that of the best CIAT lines, making these japonica/japonica crosses suitable for Bl tolerance, provided the parents are also promising in that trait. This is the case for Palawan (traditional cultivar from the Philippines) and IRAT104. Other japonicas such as ITA235 and Kinandang Patong can show good levels of Bl tolerance when crossed.

Table 23. Top F_4 progenies in Villavicencio, Colombia, screenings, 1986 WS.

Line	Parentage	Progenies selected (no.)
IR47686	IRAT104/Palawan	9
IR47691	IRAT140/Palawan	2
IR47698	ITA235/Kinandang Patong	2

DEEPWATER RICE

Plant Breeding Department

Facilities. We continued expanding our facilities for field testing of deepwater rices with the addition of about 1 ha of deepwater tanks and a water reservoir for existing tanks. All deepwater crosses in the F_2 are planted in screening tanks. For elongation we planted 3.5 million seedlings of 534 crosses and retained some 15% of these for transplanting or direct harvest from the tanks. For submergence tolerance, we planted 1.8 million seedlings of 287 crosses; about 5% survived the flash flood and could be transplanted into regular fields.

Hybridization. We grew 205 single and 534 multiple crosses aimed at deepwater conditions, including flash flood situations and stagnant deepwater. The most frequently utilized parents and their attributes are in the list:

- C20-1 (61 crosses) — pureline selection from Barogar, a tall photoperiod-sensitive Bihar deepwater rice for water depths of 1-3 m.
- Chenab 64-117 (53 crosses) — photoperiod-sensitive, submergence- and drought-tolerant deepwater rice released as Janki in Bihar, for water depths of 1-2 m.
- FRRS43-3 (145 crosses) — photoperiod-sensitive floating rice with very good elongation ability and drought tolerance.
- IR11141-6-1-4 (71 crosses) — deepwater rice combining modern variety (MV) type with excellent elongation ability, resistance to BPH biotypes 1 and 3, and drought tolerance.
- IR11288-B-B-69-1 (185 crosses) — photoperiod-sensitive deepwater rice with MV type, good elongation, and resistance to green

leafhopper (GLH), BB race 1, and BPH biotypes 1, 2, and 3.

- IR21071-53-2-3-2E-P2 (60 crosses) — MV type, early-maturing deepwater rice with high yield and elongation ability, for 1-m-deep water, with resistance to BPH.

Exchange of F_2 bulk deepwater rice crosses. We have been successful in using IRTP entries as a starting point in the exchange of early-generation materials. We sent International Rice Deep Water Observational Nursery (IRDWON) participants a listing of IRDWON entries used in crosses at IRRI. Participants returned the list with their favorite entries marked. IRRI then returned a detailed list of the available crosses (and their parentage) in which the favored IRDWON entries had been used. Finally, each IRDWON participant indicated which of these crosses he or she wanted to receive.

In 1986 we sent some 300 F_2 hybrid populations to rice breeding programs that requested them.

Release of deepwater rices in South Kalimantan, Indonesia. For additional rice-growing opportunities, several deepwater rices had been introduced by the Banjarmasin Research Institute for Food Crops in the past few years through IRTP. They were grown in farmers' field tests in river backswamps north of Banjarmasin in the October-April season, when water gradually rises and then stagnates. Three lines were obtained from IRTP nurseries, all originating from collaboration between the Rice Research Institute (RRI), Thailand, and IRRI's Plant Breeding Department. They were released in 1986 by Indonesia's Department of Agriculture as Tapus, Nagara, and Alabio for use in the deepwater rice areas of South Kalimantan. Descriptions of two of the varieties follow:

- Tapus — IR11288-B-B-118-1 (IR36/Leb Mue Nahng 111), developed via an initial rapid generation advance procedure. A tall leafy floating rice, with good ability to elongate in 2 m water. Photoperiod sensitive, October flowering at IRRI, 154 cm tall in shallow water. Resistant to BB race 1, moderately resistant to Bl, resistant to BPH biotypes 1, 2, and 3. Moderately susceptible to GLH. Long, slender, slightly chalky grains. Amylose content 26.3%, hard (33.5) gel consistency.
- Nagara — IR11141-6-1-4 (IR2061-465-1-5-5/Leb Mue Nahng 111), a MV elongating type developed in Thailand. Excellent elongating ability considering its short stature (117 cm tall in shallow water). Flowering in 102 d, with little photoperiod sensitivity. Drought resistant. Moderately resistant to BB race 1, resistant to BPH biotypes 1 and 3, moderately resistant to GLH. Slender but chalky grains, 25% amylose content, hard (32.5) gel consistency.

Pedigree nurseries at IRRI. We selected several hundred deepwater rices with various combinations of elongation ability, submergence tolerance, disease and insect resistance, and grain quality. Some of the outstanding lines are listed in Tables 24 (submergence tolerance) and 25 (elongation ability).

Testing under natural conditions. Through IRRI's farmers' field testing in Iloilo, Philippines, and through the exchange of seeds with colleagues in Asia, we have received feedback on the field performance of lines previously selected at IRRI. Lines with outstanding survival at more than one site (T = Tanisac, Iloilo, Philippines, 1986; C = Chinsurah, West Bengal, India, 1986; P = Pusa, Samastipur, Bihar, India, 1986) or with outstanding yield in an OYT in 1985 in Leganes, Iloilo, Philippines (L), are listed below. Yield data in the parentheses are based on 1.25-m^2 plots.

Cross and line	*Site*
C4-63/Gon Gaew	
IR6370-K23-1	L, T
ARC6650/IR42//IR4432-52-6-4	
IR20992-7-2-2-2-2-3	L (4.2 t)
Bhusuri Sali Paddy/CN540//IR54	
IR33225-45-3-1-1	C, P
Bhusuri Sali Paddy/CN540//IR9764-45-2-2	
IR33226-15-1-3-3-2	C, L, P
IR33226-16-1-1-3-3-3-3	C, P
FRG2/IR48//IR9764-45-2-2	
IR33279-1-501-1-1-1-1-2	L, T
FRG2/IR13426-19-2//IR9764-45-2-2	
IR33284-4-502-1-2-1-2-1	L, T
IR33284-4-503-1-1-2-3-2	T, C

IR11288-B-B-294-1/IR17494-32-3-1-1-3//IR42
IR35710-5-1-1-3-1-3 L (5.1 t)
KDML 105/Chenab 64-117//NSPT/BKNFR78022
IR38446-4-1-3-1 L (4.2 t)
IR38446-4-1-3-2 L (5.4 t)
IR38446-4-3-1-2 L, T
IR38446-4-8-3-2 L (4.0 t)
IR38446-5-4-3-1 L (4.5 t)
IR38446-5-5-3-1 L (6.0 t)
Chenab 64-117/IR19661-131-1-3-1-3
IR38692-33-3-3-6 C, P
RD19/IR7732-RGA-A96-1
IR38787-50-3-3-1 L (5.0 t)
RD19/IR19661-131-1-2
IR38793-248-6-6-2 L (4.0 t)
BKN6986-108-2/Jagannath//CR1009/IR54
IR39509-46-3-2-2 L, T

Bulk selection under natural flooding. IR crosses sent earlier to the Prachinburi Rice Research Center in Thailand underwent their second cycle of selection in abrupt natural flooding there. The best surviving F_3 populations are in the following list:

Cross	*Parentage*
IR40905	Badal 613/IR11288-B-B-118-1
IR40936	BR222-B-249/IR11288-B-B-118-1
IR40942	BR223-B-55-H2-B/IR11288-B-B-118-1
IR40957	BR308-B-2-9/IR11288-B-B-118-1
IR40960	BR314-B-4-6/IR11288-B-B-118-1
IR40964	BR516-48-3/RD19
IR40973	BR525-2-1/RD19
IR40980	BR311-B-5-4/IR11288-B-B-118-1
IR41136	IR13423-10-2-3/IR11288-B-B-118-1
IR41372	RD19/Sail Kotha

Most of these crosses are part of the effort to recombine outstanding elongation characteristics unique to floating rices from Bangladesh and India with grain appearance acceptable in Southeast Asia.

Table 24. Promising deepwater rices with submergence tolerance, selected from pedigree nurseries, IRRI, 1986.

Line	Plant height (cm)	Flowering duration[a]		SES score								
				BI	BB	BPH biotype		GLH	Sub[b]	Grl[c]	Grs[d]	Clk[e]
		Min	Max			1	2					
IR4568-86-1-3-2/FR43B												
IR37105-R-15-3-3	85	99	118	8	1	3	5	8	1	5	5	1
IR37105-50-21-3-2	115	100	118	4	1	5	7	5	3	4	5	9
IR37105-50-21-6-2	125	98	117	4	1	5	7	5	3	4	5	9
Chenab 64-117/IR17525-114-2-1-1												
IR41009-R-R-R-11-2-2	125	104	120	8		5		6	3	3	1	9
IR8234-OT-9-2/Nam Sagui 19												
IR41425-56-24-2-1	94	99	115	3	1	2	3	3	5	3	1	1
IR41425-58-22-2-3	94	100	116	3	1	2	5	3	5	3	1	2
IR41425-58-25-3-3	97	101	115	1	1	4	7	3	5	3	2	1
IR41425-58-26-3-1	100	100	114	1	1	2	3	3	5	3	4	1
IR41425-65-23-1-2	95	101	115		1	2	3	3	4	3	3	2
IR42425-65-23-3-2	95	99	115	1	1	3	3	3	4	3	2	2
IR41425-66-22-3-1	102	102	116	1	1	3	3	3	4	3	2	1
IR41425-67-21-3-3	97	102	116	3	1	3	3	3	4	3	2	1
IR41425-67-23-1-2	95	103	116	1	1	3	7	3	4	3	1	0
IR41425-67-23-2-2	103	103	116	1	1	3	5	3	5	3	1	0
IR8234-OT-9-2/IR4630-22-2-17												
IR41427-58-5-1-3-3-1	123	103	139	4	3	3	5	3	5	3	1	1
IR13149-19-1/BKNFR76106-16-0-1												
IR41464-9-1-2-2-2-3	120	105	131	8	3	3	5	3	5	4	3	5
IR41464-9-3-1-22-3	125	113	147	9		5		3	1	3	1	1

[a]Min = flowering duration in the off season, max = flowering duration in the wet season. [b]Submergence tolerance (greenhouse). [c]Grain length. [d]Grain shape. [e]Grain chalkiness.

Table 25. Promising deepwater rices with elongation ability, selected from pedigree nurseries. IRRI, 1986.

Line	Plant height (cm)	Flowering duration[a]		Trait									
				BI	BB	BPH biotype		GLH	Sub[b]	El[c]	Grl[d]	Grs[e]	Clk[f]
		Min	Max			1	2						
RD19/IR46													
IR37025-R-34-2-1	115	91	146	6	1	4	6	7	9	6	3	1	1
BKN6721-5-7-4/IR9264-321-3//IR11185-R-R-R-88-2													
IR39496-18-1-3-2-2-1	125	83	106	4	3	4	2	[illegible]	5	6	3	1	0
IR8234-OT-9-2/B1050C-MR-18-2//Baisbish/BKNFR77004-5-3-4///Madhukar/B1050C-MR18-2//Chenab 64-117/Baisbish													
IR39596-502-1-3	125	95	104	6		9	9	3	9	1	5	5	1
BKN7022-6-4/IR25861-31-1-3													
IR40554-5-1-1-2-1-3	113	96	126	5	5	4	4	3	3	8	3	3	7
Badal 613/IR11288-B-B-118-1													
IR40905-11-3-1-5-3-3	158	101	146	6	3	1	3	3	9	6	3	1	3
Chamara/IR11288-B-B-69-1													
IR40992-1-3-2-1-1-2	138	89	120	6	2	4	4	3	9	4	3	1	1
IR40992-1-3-2-1-3-3	130	89	120	6	2	2	2	3	9	4	3	1	1
HBJ Aman 1/IR11288-B-B-118-1													
IR41086-24-3-1-1-3-2	140	97	139	2	2	5	5	4	5	5	3	1	1
IR11288-B-B-118-1/DWCB-B-111-H1													
IR41125-7-3-2-2-3-3	131	95	120	5	5	4	5	7	9	4	3	1	2
IR11288-B-B-118-1/SPR7292-151-2-1													
IR41132-R-27-1-1	130	101	131	4	7	3	3	7	9	1	3	1	1
SPR7292-151-2-1/BR232-2B-3-4A													
IR41410-6-3-3-3-1	157	94	120	3	1	5	9	6	9	6	3	2	4
SPR7292-151-2-1/BR308-B 2-9A													
IR41414-10-3-3-2-3	135	101	105	6	1	7	6	4	9	4	4	4	6
BIET927/DWCT156-1//RP975-109-2/IR52													
IR42497-85-1-1-2-2	130	88	136	7	6	4	4	4	9	6	3	1	1
IR42497-85-2-1-3-3	140	97	136	8	7	7	4	3	9	5	3	1	1
IR42497-88-1-1-3-3	135	103	146	8	7	5	5	3	9	5	3	1	0
BR118-3B-17/BKN7022-6-4//IR13259-153-5E-P2-2/IR8234-OT-9-2													
IR42511-87-3-1-2-2	120	99	147	3	2	5	4	3	9	6	3	1	1
RD19-IR42//RD19/IR17494-32													
IR42569-329-5-2-1	93	106	119	8	7	5	5	5		6	5	5	4
RD19/IR19661-131-1-2//RD19/Khao Lo													
IR42580-23-2-1-1-3	140	96	136	7	3	8	8	4	5	6	1	1	1
RD19/Murungakayan 101B//RD19/IR19661-131-1-2													
IR42583-13-1-2-1-2	158	99	121	6	7	5	5	3	5	6	3	1	2
IR42583-13-4-2-1-3	168	99	136	6	6	4	7	3	4	6	3	1	0
Sarsari//IR13423-10-2-3/DWCT156-1													
IR435641-1-2-3-2-1	113	98	143	9	4	4	7	3		4	5	5	6
HTA7406-111-0-0-2/SPR7292-151-2-1//KDML 105/IR11288-B-B-69-1													
IR43947-50-3-2-1	168	103	136	6	1	3	3	3	9	4	3	1	2

[a]Min = flowering duration in the off season, max = flowering duration in the wet season. [b]Submergence tolerance (greenhouse). [c]Elongation ability (field). [d]Grain length. [e]Grain shape. [f]Grain chalkiness.

TIDAL WETLAND RICE

Plant Breeding Department

Shuttle breeding is used to improve tidal wetland rices. Hybridization is done at IRRI, and early-generation, segregating populations are evaluated at six Philippine sites that represent different tidal wetland conditions. The evaluations are carried out in WS in collaboration with Ministry of Agriculture and Food personnel. Tidal wetlands are usually left fallow during DS because of high salinity or lack of irrigation water. To advance generations, therefore, we plant segregating populations at the IRRI farm during DS with selection restricted to a few traits such as plant type and resistance to major pests and diseases. In shuttle breeding, mass selection is done for 4-6 generations to ensure that every population is exposed to the

natural conditions of the target environment for at least 2-3 cropping seasons.

In 1986, we made 108 single crosses and 42 multiple crosses. Among the traditional cultivars, Pokkali, Nona Bokra, Cheriviruppu, Patnai 23, and KDML 105 were the most frequently used parents. They were crossed with semidwarfs, such as IR4630-22-2-5-1-3, IR9764-45-2-2, IR9884-54-3, and IR8192-200-3-3-1-1, which possess some tolerance for soil stresses. For multiple crosses we used varieties that have submergence tolerance and pest and disease resistance, since these traits are also important under tidal wetland conditions.

Anther culture was possible for about 100 of the F_1 crosses. Plant regeneration was low, but there was significant improvement in regeneration efficiency compared with 1985.

In DS, we evaluated 81 F_2, 105 F_3, and 30 F_4 bulk populations at the IRRI farm. Even with relaxed selection, 50% of the F_2 populations had to be discarded because of high susceptibility to BB and tungro. The F_3 and F_4 populations discarded were considerably fewer (31 and 27%), indicating progressive selection efficiency.

In WS, we established 196 bulk populations (84 F_2, 42 F_3, 48 F_4, and 22 F_5) at 4 tidal wetland locations in the Philippines. All locations experienced high salinity as well as submergence during the vegetative phase. About 60% of the F_2 and F_3 populations were discarded because of very poor survival. In other advanced populations that had been evaluated earlier under similar conditions, survival was as high as 50-60%.

R_3 generational somaclonal variants of Pokkali and IR36 selected in 1985 were tested in a saline field with electrical conductivity of around 8 dS/m. All IR36 selections were killed by salt injury. All Pokkali selections survived but showed extreme susceptibility to BB. They were also dwarf and photoperiod insensitive. Twenty-three lines that showed relatively less susceptibility to BB were selected for further testing.

A nursery consisting of 210 elite IR lines from the Deepwater Rice Breeding Program with tolerance for adverse soil conditions was tested at 2 salt-affected tidal wetland sites in the Philippines. One site had acid sulfate soil. The check varieties were Pokkali and Nona Bokra (tolerant) and IR28 (sensitive). Three lines — IR31375-5-2-1-1, IR35665-60-2-1-3-3, and IR39537-27-5-1-3 — were comparable to the tolerant checks, which performed well.

Some traditional varieties commonly cultivated in the tidal wetlands of Indonesia and West Africa were collected and their seed increased for investigation of their adaptability traits.

Our collaborative breeding program with RRI, Thailand, for improving tidal wetland rices with acid sulfate soils continued, with more emphasis on evaluating segregating populations in farmers' fields. We established 12 F_2 populations, 82 F_3 progenies (previous years' selections), and 55 varieties and IRRI elite lines in a strongly acid field in Ongkarak. Flash floods and deep water were additional stresses that occurred during evaluation. Single plant selections were made from populations that showed good survival. Fifty percent of F_3 progenies performed better than the tolerant check KDML 105 and were selected for further evaluation. Among varieties and elite lines tested, only two varieties, Garcha and Obies, performed better than KDML 105 in terms of adaptability.

Control and management of rice pests

Diseases

Plant Pathology, Agronomy, and Entomology Departments

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BIOLOGICAL CONTROL

Plant Pathology Department

Antagonistic bacteria. Earlier studies showed the presence in ricefields of a number of bacteria that suppress sheath blight (ShB) and other rice fungal diseases (Annual reports for 1984 and 1985). Through a collaborative research project between IRRI and the State University of Gent, Belgium, the taxonomic status of 23 selected isolates was determined. Based on the gram reaction, 5 were positive and 18 negative. Among the gram-negative, 12 belonged to the genus *Pseudomonas* and 6 were Enterobacteriaceae. The gram-positive strains were *Bacillus subtilis*, *B. pumilus*, and *B. laterosporus*.

All strains of *Pseudomonas* produced fluorescence on King's Medium B. Seven were identified to be similar to *P. aeruginosa*, three to *P. fluorescens*, and two to *P. rubrisubalbicans*. Of the Enterobacteriaceae, one was comparable to *Erwinia* or *Enterobacter*, four were identical to *Serratia*, and one to *S. marcescens*.

Earlier studies also showed that antagonistic bacteria applied as a seed treatment reduced bakanae (Bak) incidence (IRRI highlights for 1985). During the 1986 dry season (DS), an experiment was conducted in a farmer's field where Bak had been endemic since 1978. Bacterization of IR42 seed harvested from this farmer's field suppressed Bak incidence as well as a benomyl application did (Table 1).

Application of antagonistic bacteria was studied at IRRI using seed bacterization, root-dipping in a bacterial suspension prior to transplanting, and direct spraying of the bacteria on rice plants at maximum tillering for ShB control. All isolates suppressed ShB on IR58 (Table 2). The same experiment repeated in the wet season (WS), however, showed no significant suppression of ShB, perhaps because of low disease pressure.

One hundred sixty-seven bacterial cultures were isolated from ricefield water, rice soil, and both infected and healthy plants collected from diverse geographical locations in Korea through collaborative research. The number of nonfluorescent bacteria associated with the rice system was higher than that of the fluorescent type. The majority of the nonfluorescent bacteria were isolated from soil; 58.3% of them inhibited mycelial growth in fungal pathogens. Most of the isolates that produced a blue fluorescent pigment on King's Medium B agar inhibited three pathogens — *Rhizoctonia solani*, *Pyricularia oryzae*, and *Fusarium moniliforme* — in vitro. Twelve isolates from both groups inhibited the mycelial growth of the three pathogens and suppressed ShB development on detached leaves (Table 3).

Table 1. Effect of seed bacterization on bakanae incidence (based on natural infection) in IR42 planted in a farmer's field. 1986 DS.

Treatment	Bakanae (%)
Benomyl	17.0 a
In-b-24	18.0 a
In-b-17	19.0 a
In-b-590	20.0 a
In-b-150	21.0 a
Untreated	49.5 b
Farmer's field	71.0 c

Table 2. Reduction of sheath blight (ShB) in IR58 by antagonistic bacteria that were applied as a seed treatment, a suspension for root dipping prior to transplanting, and direct spray on plants at maximum tillering.[a] IRRI, 1986.

Isolate	Sheath blight severity (% relative lesion height)					
	Seed treatment		Root dip		Spray	
	DS	WS	DS	WS	DS	WS
In-b-17	27 a	25 a	26 a	31 a	24 a	32 a
In-b-715	29 ab	33 a	26 a	37 a	29 ab	37 a
In-b-24	31 bc	34 a	28 ab	23 a	28 ab	35 a
In-b-108	31 bc	24 a	26 a	34 a	28 ab	27 a
In-b-157	32 bc	32 a	26 a	28 a	25 a	31 a
Check	37 c	37 a	37 c	37 a	37 c	37 a

[a]DS = dry season, WS = wet season.

***Trichoderma* spp.** *Trichoderma* are common soil fungi known to be antagonistic to many soilborne fungal pathogens. Recent studies at IRRI (Annual reports for 1983, 1984, and 1985) indicated that they are potential agents in suppressing ShB and other diseases of crops grown in rainfed and upland cropping systems. They are highly competitive for plant residue and thus exhaust the nutrient supply for pathogens. We

Table 3. Inhibition of mycelial growth of *Rhizoctonia solani*, *Pyricularia oryzae*, and *Fusarium moniliforme* by antagonistic bacteria isolated in different localities in Korea and suppression of ShB lesion development by the detached leaf method. IRRI, 1986.

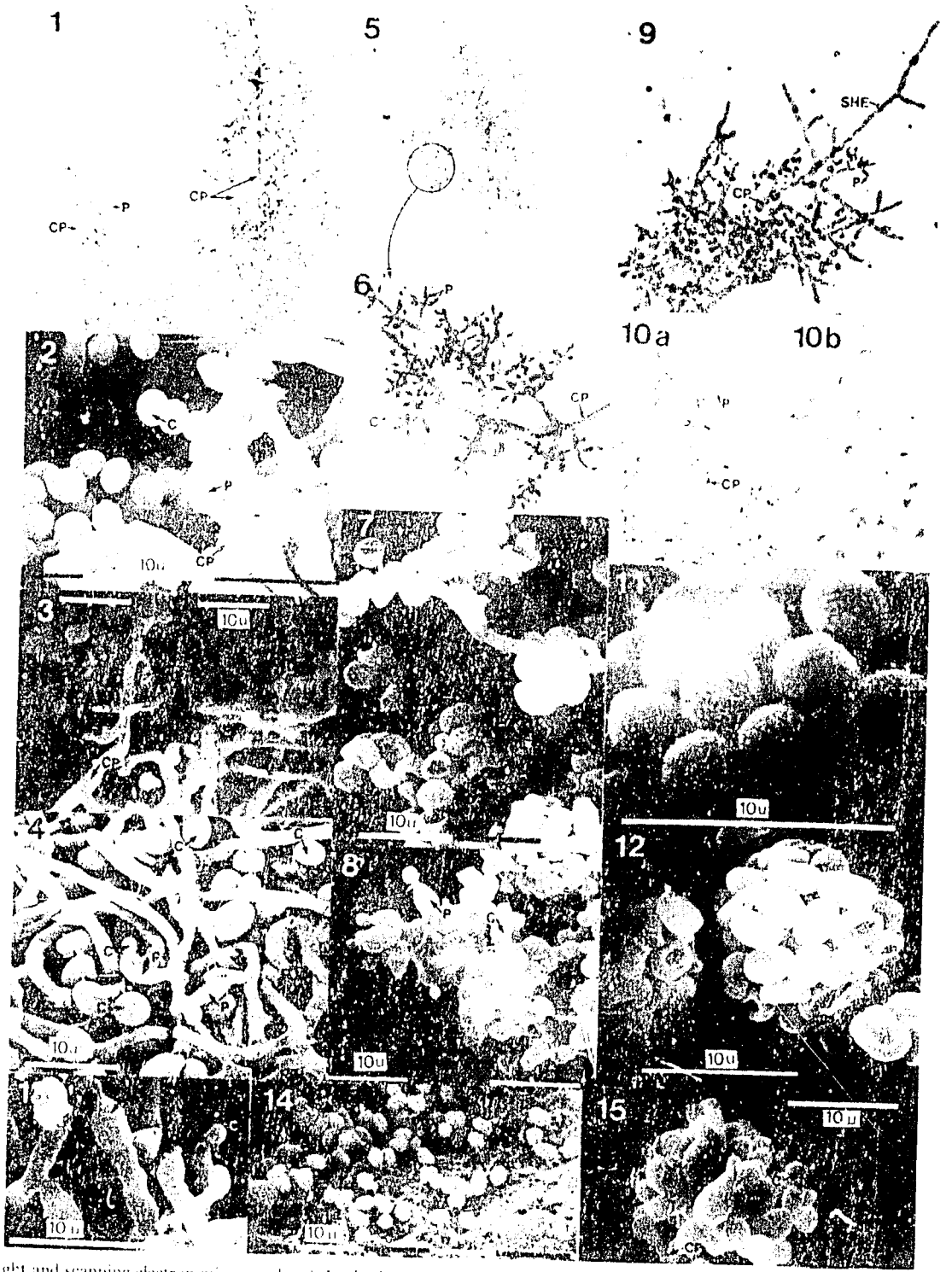
Isolate no.	Locality	Inhibition zone (mm)			Suppression of ShB lesion
		R. solani	*P. oryzae*	*F. moniliforme*	
22	Bu-An	2	9	4	+
41	Hae-nam	11	14	3	+
55	Kwang-san	8	11	5	+
72	Go-chang	8	2	3	+
91	Jin-yang	5	8	3	+
125	Kim-hae	8	12	4	+
127	Kim-hae	6	3	3	+
145	Sang-ju	3	2	2	+
162	Jin-yang	9	12	6	+
165	Jin-yang	10	11	6	+
166	Young-cheon	2	3	2	+
167	Jin-yang	5	10	7	+
Check (sterile distilled water)		0	0	0	–

continue to investigate their biology, ecology, and potential for disease management. Thirteen species of *Trichoderma* have been isolated from ricefields in the Philippines (Table 4). The organism is more common in upland than lowland soils. In rainfed lowland soils, the number increases when fields become dry (Annual report for 1983). They are present in submerged rice soils, but in low numbers. Soil pH may range from 4.3 to 8.0, and soil moisture from 16 to 100% (dry weight) with a population of $0.5\text{-}8.0 \times 10^3$ colony-forming units (CFU) g of soil (dry weight). *T. longibrachiatum*

Table 4. Distribution of *Trichoderma* species in ricefields of the Philippines, 1985-86.[a]

Trichoderma sp.	Distribution in the provinces																			
	Ilocos Norte[b]	Ilocos Sur[b]	La Union[d]	Benguet[c]	Ifugao[c]	Pangasinan[d]	Tarlac[d]	Nueva Ecija[d]	Bulacan[b]	Laguna[d]	Quezon[b]	Batangas[b]	Camarines Sur[b]	Palawan[d]	Iloilo[d]	Aklan[b]	Capiz[b]	Leyte[c]	Misamis Oriental[d]	South Cotabato[c]
T. aureoviride	+	+	+	–	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+
T. glaucum	–	+	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–
T. hamatoferum	–	+	–	–	–	–	–	–	–	+	+	–	–	–	–	–	+	–	–	–
T. harnatum	–	–	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
T. harzianum	+	+	+	–	–	+	–	+	–	+	+	+	–	+	+	+	–	+	+	–
T. koningii	–	+	–	–	–	–	–	+	+	+	–	–	+	–	–	–	–	–	–	–
T. longibrachiatum	+	+	+	–	–	–	+	–	–	+	+	–	–	–	–	–	–	–	–	+
T. piluliferum	+	+	+	–	+	–	–	+	–	+	+	–	+	–	–	+	–	–	–	–
T. polysporum	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–
T. pseudokoningii	+	+	+	–	+	–	+	+	+	+	+	–	+	–	–	–	–	–	–	–
T. reesei	–	+	+	–	–	–	–	–	–	+	–	+	–	–	–	–	–	–	–	–
T. venox	–	+	–	–	+	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
T. viride	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–

[a] + = present, – = absent. [b]Soils collected in 1986. [c]Soils collected in Oct-Dec 1985. [d]Soils collected from Oct 1985 to Dec 1986.



1. Light and scanning electron micrographs of *Trichoderma* species, IRRI, 1986. 1. *T. aureoviride* tufts of conidiophores × 540. 2. *T. aureoviride* phialides and spores. 3. *T. pseudokoningii*. 4. *T. longibrachiatum*. 5. *T. harzianum* tufts of conidiophores × 1342. 6. *T. harzianum*. 7. *T. piluliferum*. 8. *T. piluliferum*. 9. *T. polysporum* × 335. 10a. *T. koningii* × 262; 10b. *T. koningii conidia* × 700. 11 *T. viride* conidia. 12. *T. reesei* conidia. 13. *T. venox*. 14. *T. hamatoferum* conidia. 15. *T. hamatoferum*. 1, 5, 6, and 10 are photomicrographs, others are scanning electron micrographs. CP = conidiophore, P = phialides, C = conidia SHE = sterile hyphal elongations.

and *T. piluliferum* are common in both lowland and upland culture types, while *T. pseudokoningii* is mostly restricted to the lowlands. Two new species, *T. venox* and *T. hamatoferum*, were rarely found in rice soil (Fig. 1). The cellulolysis adequacy index (CAI), an indication of the capacity to decompose plant debris, varied among species and among isolates of the same species. *T. reesei* 206 produced the highest CAI (Table 5).

Table 5. Cellulolysis adequacy index (CAI) of *Trichoderma* species. IRRI, 1986.

Trichoderma sp.	Isolate no.	Weight loss (%) of filter paper	Growth rate on filter paper (mm)	CAI
T. aureoviride	274	9.92	8.1	1.22
T. aureoviride	103	10.70	5.5	1.94
T. glaucum	1	18.49	4.6	4.02
T. hamatum	235	2.51	4.2	0.60
T. hamatum	230	5.06	3.3	1.53
T. hamatoferum	88	2.08	1.3	1.60
T. harzianum	253	4.20	7.8	0.54
T. harzianum	82	8.90	7.2	1.24
T. harzianum	118	8.27	7.9	1.04
T. koningii	265	9.66	8.2	1.17
T. koningii	187	9.50	5.1	1.86
T. longibrachiatum	60	6.38	6.0	1.06
T. longibrachiatum	254	13.60	6.2	2.20
T. longibrachiatum	83	14.09	5.6	2.52
T. polysporum	166	0.21	1.4	0.15
T. piluliferum	268	5.99	7.1	0.84
T. piluliferum	233	2.83	1.5	1.88
T. pseudokoningii	280	0.35	3.0	0.17
T. pseudokoningii	234	1.41	5.0	0.28
T. reesei	206	25.10	4.3	5.37
T. reesei	201	8.87	4.8	1.85
T. venox	229	4.73	7.1	0.67
T. sp.	105	1.28	1.0	1.28

CULTURAL CONTROL

Plant Pathology Department

Sheath blight. *Crop management and sheath blight response.* Yield loss to ShB varied according to growth duration and variety. When disease pressure was high, both early- and late-maturing varieties suffered the same yield reduction in both upland and irrigated rices.

Sheath blight development was higher with close than with wide spacing. In both upland and lowland environments, the incidence increased with higher N application. When disease pressure was high, there was good correlation between N percentage in the leaf blades and in the sheath at maturity. ShB was more severe with early-maturing varieties at close spacing when more N was applied (Table 6). In the lowland environment, there was a strong variety-spacing-N interaction; although grain yield was high at high N and close spacing, the loss due to ShB was also high.

Varietal resistance to inoculum production. Varietal effects on the buildup of sclerotial bodies of *R. solani* and *Trichoderma* spp., the antagonists

Table 6. Yield loss due to ShB in 3 rice varieties at 2 spacings and 2 N rates in a lowland field. IRRI, late 1985 DS.[a]

Variety	Mean yield loss[b] (%) at				Mean ShB severity[c] at					
	60 kg N/ha		120 kg N/ha		60 kg N/ha			120 kg N/ha		
	DL-3 – DL-1	DL-2 – DL-1	DL-3 – DL-1	DL-2 – DL-1	DL-1	DL-2	DL-3	DL-1	DL-2	DL-3
				25 × 25 cm						
IR54	9.3 ab	19.5 a	16.7 a	27.4 b	34.2 a	5.7 a	1.0 a	44.7 a	5.3 a	0.7 a
IR58	3.[illegible] a	21.1 a	14.4 a	28.9 b	36.9 a	11.1 a	9.8 a	44.9 a	10.6 a	0.6 a
IR62	15.5 b	14.4 a	15.9 a	17.9 a	41.3 a	8.4 a	0.0 a	42.9 a	10.8 a	0.9 a
Mean	10.5	18.3	15.7	24.7	37.5	8.4	0.6	44.2	8.9	0.7
				20 × 15 cm						
IR54	9.6 a	20.2 a	13.6 a	15.8 a	28.9 a	7.8 a	1.3 a	1.6 a		
IR58	5.9 a	23.0 a	17.5 ab	32.3 b	45.6 b	15.8 a	1.9 a	52.8 a	117.5 a	1.7 a
IR62	16.9 b	25.1 a	24.4 b	29.5 b	40.6 b	13.7 a	0.4 a	46.1 ab	12.9 a	1.4 a
Mean	10.8	22.8	18.5	25.9	38.3	12.5	1.2	46.0	13.5	1.6

[a]DL-1 = inoculated, DL-2 = inoculated and sprayed with triphenyltin acetate, DL-3 = control. [b]Means of 3 replications. Within each spacing, means in a column followed by a common letter are not significantly different at the 5% level. [c]Severity = relative lesion height/plot × proportion of tillers infected/plot.

in the soil, were studied in three successive croppings. A heavily damaged crop produced more sclerotial bodies than less damaged crops (Table 7). Thus, ShB-susceptible cultivar IR36 produced a higher number of sclerotial bodies than moderately resistant IR62 or IR64. The *Trichoderma* population was also higher in the IR36 plot, perhaps because of the addition of the rice-hull medium in the inoculum.

The positive relationship between inoculum production and ShB development was clear in the first and second cropping seasons, but not in the third, when overall disease level was extremely low because of low humidity during the crop season (Table 8). Hence, the increase in sclerotial bodies in the third planting was probably caused by a saprophytic increase on crop debris in the soil.

Tungro. *Timing of planting and disease incidence.* To determine the best time of planting and the best variety to control tungro virus (RTV) disease in the first and second transplanted rice crops, the first crop at the Guimba cropping systems site, Nueva Ecija, Philippines, was established in the second weeks of June, July, August, and September, and the second crop in October, November, December, and January. For each planting date, 21-d-old seedlings of IR36, IR42, IR50, IR58, IR64, and susceptible check TN1 were planted in 2- × 2-m plots at 20- × 20-cm distance between hills, and at 2-3 seedlings/hill. The experiment was established in a randomized complete block design with 3 replications. At 30 d after transplanting (DT), the vector leafhopper population at the site was estimated by average leafhopper number per 10 sweeps in the plots, and the incidence of RTV-associated viruses was determined serologically.

Two leafhopper species, *Nephotettix virescens* and *N. nigropictus*, were present in the area, the former being predominant. Less than 1 insect/sweep was obtained in plots planted in June, and the leafhopper catches were continuously low in the July and August plantings. The leafhopper population increased in the September planting,

Table 7. ShB severity, increase of sclerotia of *R. solani*, and change of *Trichoderma* population in 3 successive croppings.[a] IRRI, 1985-86.

Variety	Disease severity				Increase of sclerotia[b] (10^2/5 m^2)				*Trichoderma* colony count[b] (10^9/5 cm^2)		
	1	2	3	Average	1	2	3	Average	2	3	Average
IR64	0.4	22.5	1.6	6.1	137.5	12.5	43.8	64.6	3.5	7.5	5.5
IR62	62.6	22.4	0	21.3	125.0	12.5	0	45.8	1.5	6.0	3.8
IR68	88.2	13.5	12.8	38.2	187.5	6.3	100	97.9	1.1	19.0	10.1
IR36	86.2	44.3	1.6	44.0	212.5	62.5	18.8	97.9	4.0	8.0	6
Average	59.4	25.7	4	27.4	165.6	23.5	40.7	76.6	2.5	10.1	6.4

[a]The first crop was inoculated artificially with *R. solani* LR-1 in rice-hull medium. [b]Monitored at harvest. No data were taken for the first cropping.

Table 8. Varietal effect on the production of sclerotial bodies of *R. solani* and *Trichoderma* population. IRRI, 1985.[a]

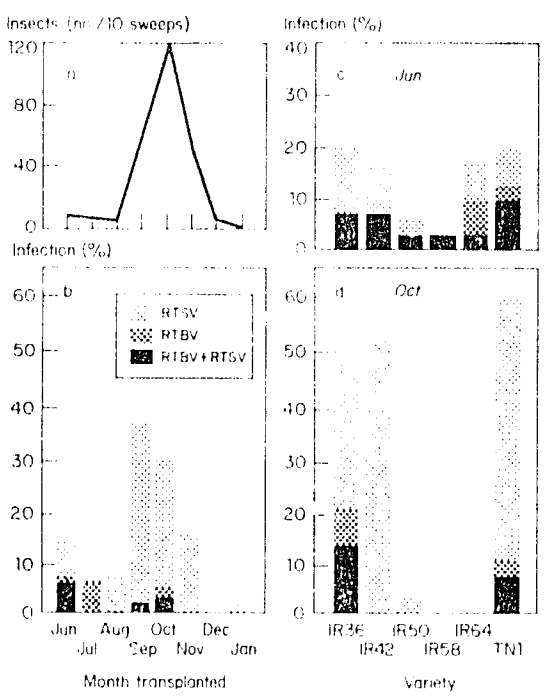
Treatment	IR64			IR62			IR36			Mean		
	DS	S	T	DS	S	T	DS	S	T	DS	S	T
Inoculation	68.9	81.3	4.8	76.8	62.5	4.7	90.8	93.8	8.5	78.8	79.2	6.0
Inoculation + spray	45.6	37.5	3.5	62.6	25.0	1.5	68.2	87.5	8.0	58.8	50.0	4.3
No inoculation	22.5	12.5	1.6	22.4	12.5	2.5	44.3	62.5	4.0	29.7	29.2	2.7
No inoculation + spray	0	18.8	0.7	0.9	6.3	1.3	1.4	12.5	2.1	0.8	12.5	1.4
Mean	34.3	37.5	2.7	40.7	26.6	2.5	51.2	64.1	5.7			

[a]Data from the second crop (Jul-Nov, 1985). DS = disease severity (% relative lesion height), S = sclerotia (no.) monitored at harvest (10^2/5 m^2), T = *Trichoderma* colony count (10^9/5 m^2).

reached 12 insects/sweep in the October planting, and declined during the relatively cool months of December and January (Fig. 2a).

The incidence of rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV) increased with increase in the leafhopper population. Regardless of month of planting, RTSV incidence was prevalent (Fig. 2b). Infection with RTSV alone did not cause RTV symptoms. Dual infection with RTBV and RTSV was observed in the June and October plantings; during these months TN1 was most infected, followed by IR36 and IR42. IR50 and IR58 were seldom infected (Fig. 2c,d).

From these results, the best time for transplanting the first crop to avoid RTV infection at the Guimba cropping systems site is late June or July, when the leafhopper population is very low and virus incidence is relatively low; the best time for the second crop is in December or January, when both the leafhopper population and virus incidence are also very low.



2. Average density of the vector leafhoppers (a) and incidence of RTBV and RTSV (b) in 6 varieties transplanted monthly from Jan 1985 to Jan 1986 at 30 d after transplanting, and incidence in each variety established in Jun (c) and Oct (d). Guimba, Nueva Ecija, Philippines, 1985-1986.

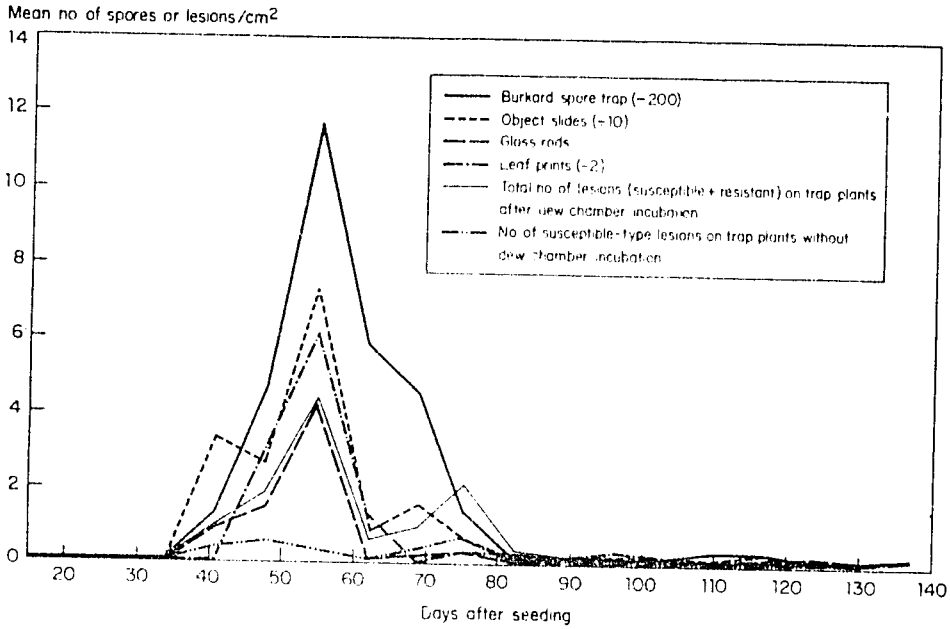
EPIDEMIOLOGY

Plant Pathology, Agronomy, and Entomology Departments

Blast (*Plant Pathology and Agronomy*). In a continuing study of the epidemiology of blast (Bl) in upland rice, the reliability of different spore trapping methods for monitoring the development of the Bl pathogen population was examined. The spore traps were a Burkard spore trap, horizontally exposed object slides, vertically exposed glass rods, and trap plants. All were exposed simultaneously in the field. Leaf prints of trap plants were taken to estimate the total number of landed spores. After exposure in the field, trap plants were either incubated in the dew chamber to provide optimum infection conditions for all compatible spores, or placed directly in a glasshouse to measure spores that could complete the infection process under the conditions of a particular night.

Although the spore trap systems revealed similar catch patterns, differences existed among methods at certain observation times (Fig. 3), probably depending on meteorological features that affect the catch. For example, rain might wash spores from leaf surfaces of trap plants and from object slides, but not affect the results of the Burkard trap. Wind would also diminish the efficiency of trap plants and object slides while enhancing the efficiency of the Burkard trap. On the other hand, little wind, long periods of high relative humidity, optimum temperature, and leaf wetness might result in comparatively high lesion numbers on trap plants, indicating high efficiency of the inoculum during the conditions of a particular night.

Three field experiments were conducted, during which leaf Bl was measured. In the first experiment, IR52, C22, and Denorado were planted. Differences were evident in the amount of inoculum caught by trap plants in the stands of the three varieties during the season (Fig. 4). The inoculum level in Denorado remained low during the whole growing season, but in IR52 and C22 it began increasing at tillering, reached a peak at about maximum tillering, and declined slowly thereafter. In IR52, the highest amount of inoculum was caught during all phases of the epidemic. Even during and after heading, when the

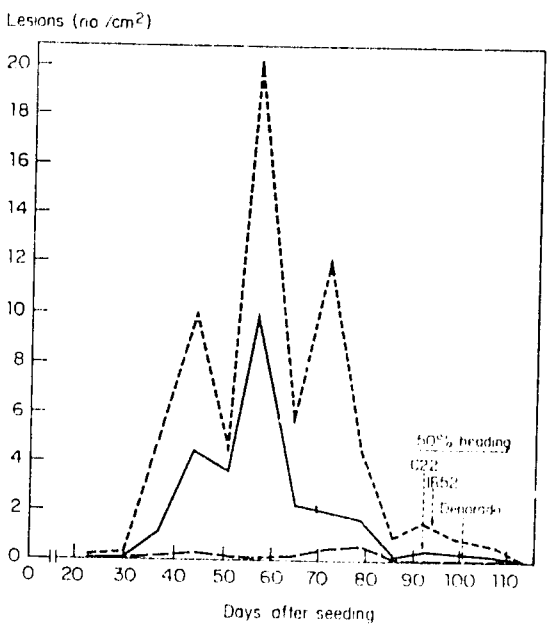


3. Mean weekly *Pyricularia oryzae* spore catch by different spore trapping methods in an upland field of variety C22. IRRI, 1986.

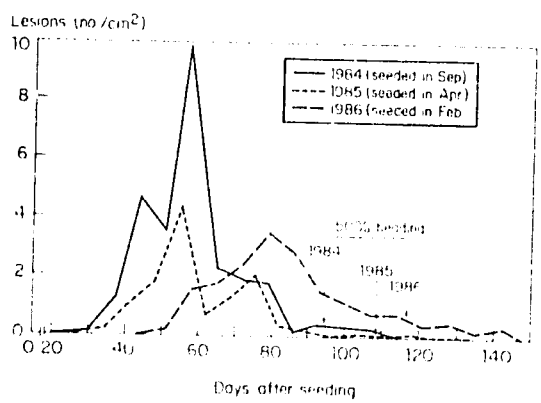
inoculum level was zero in Denorado and quite low in C22, it was comparatively high in IR52.

In each of the three field experiments, BI development in C22 differed as reflected by trap plant spore catches (Fig. 5). The epidemic started at about early tillering in 1984 and 1985, but the peak, at around late tillering, and the general level of spore catch were much higher in 1984 than in 1985. In 1986 the pattern of epidemic development was different, starting at about maximum tillering and reaching a peak long after tillering. The inoculum level remained relatively high thereafter and declined more slowly than in the 2 other years.

Heading progress and panicle BI development were observed in the three experiments and in one



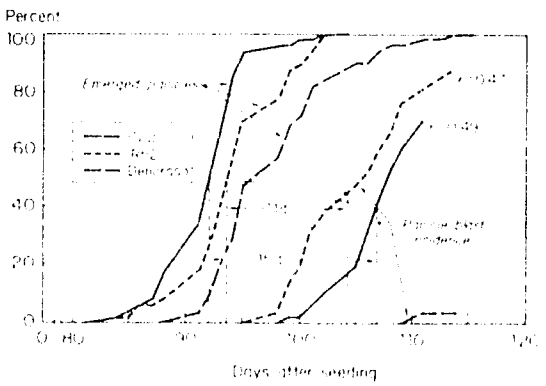
4. Mean weekly lesion number on trap plants exposed over stands of varieties C22, IR52, and Denorado grown under upland conditions. IRRI, 1986.



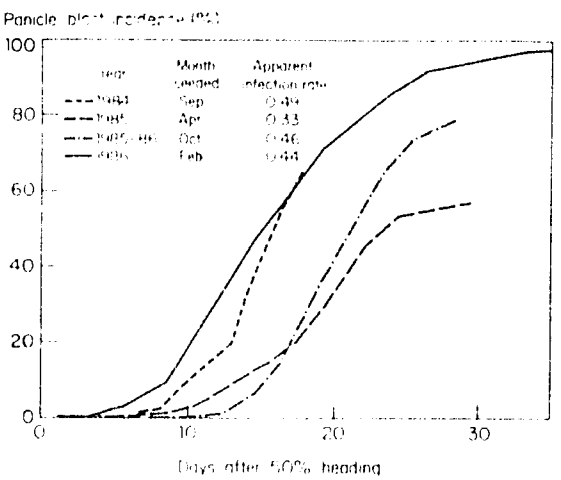
5. Mean weekly lesion number on trap plants exposed over stands of variety C22 in 3 upland experiments. IRRI, 1986.

additional planting. In 1984, the speed of panicle Bl progress, expressed as the apparent infection rate (r), was similar in IR52 and C22 (Fig. 6). Through extrapolation, the final panicle Bl incidence probably reached about 90-95% in IR52 and about 80-85% in C22, but was nearly zero in Denorado. The time from 50% heading until 50% of the final panicle Bl incidence level was 11 d in IR52 and 15 d in C22. Thus, although IR52 showed somewhat delayed heading compared with C22, panicle Bl in IR52 started earlier and reached a higher final level than in C22, probably reflecting the higher Bl susceptibility of IR52.

For C22, typical sigmoid disease progress curves were observed in all four seasons (Fig. 7). Using the



6. Heading progress and panicle blast development in C22, IR52, and Denorado grown under upland conditions. IRRI, 1986.



7. Comparison of panicle blast development in C22 in 4 upland experiments. IRRI, 1986.

time when 50% of all panicles have emerged as a reference point, characteristics of panicle Bl development in different seasons can be compared the time when panicle Bl started, the speed of progress of panicle Bl, and the final incidence level. For example, panicle Bl in 1986 started earlier than in 1984, but differences in the rate of progress caused the disease progress curve of 1984 to overtake that of 1986. The same is observed between 1985 and 1985-86. Using the apparent infection rate, the seasons can be ranked according to the speed of panicle Bl development as follows: 1984 > 1985-86 > 1986 > 1985.

For each field experiment, detailed measurements were taken of disease, crop development, and micrometeorological parameters. Further analysis of the data should give insights into the influence of host development and weather on disease increase and yield loss caused by Bl.

Effects of blast and drought stress on yield in upland rice. We examined the effects of vegetative stage drought on the yield of upland rice variety C22 in plots inoculated with *P. oryzae* and in plots protected with fungicides. Plots were inoculated at 27 d after seeding (DAS), and water was withheld from the stress treatments for 16 d from 42 to 58 DAS.

Although the leaf Bl epidemic was not severe, the unprotected stressed treatments showed the highest disease incidence (Fig. 8). Disease progress peaked at about 86 DAS, and the secondary tillers were more affected than the primary tillers (Fig. 8). Collar Bl incidence and the incidence of severe neck node infection were increased by stress and decreased by fungicide treatment (Table 9). The yield components most affected by Bl and stress were 1,000-grain weight and filled grain percentage (Table 10). Panicle number was unaffected, presumably because the leaf Bl epidemic was not severe enough to cause significant reduction in the number of fertile tillers (Table 10). Although total dry matter was relatively high, grain yield was low because of high sterility, even in the fully irrigated and protected plots. The high sterility was probably caused by insufficient irrigation at flowering, since the crop flowered during a period of hot, windy weather and was irrigated only twice a week. Thus, even though the water applied was high, the frequency of irrigation probably was not sufficient to prevent sterility due to stress.

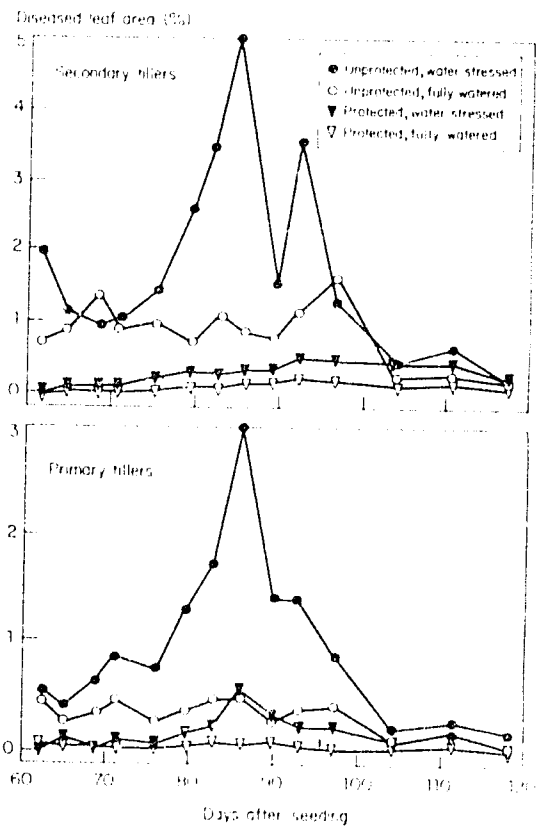
Leaf wetness and disease on trap plants. Before differential irrigation, the period of leaf wetness ranged from 5 to 15 h and was the same in all plots. During differential irrigation, the period of leaf wetness in the stressed plots was shorter than in the irrigated plot (Fig. 9). When rainfall occurred at 46 DAS, the treatments had similar leaf wetness periods. When full irrigation was restored, the leaf wetness periods were again the same between plots.

The leaf wetness periods influenced the amount of disease on trap plants exposed in the plots. During the 16-d stress period, trap plants exposed in unprotected irrigated plots produced more lesions than those exposed in stressed plots (Fig. 10). When full irrigation was resumed, and as the epidemic progressed, the relationship was reversed, with more lesions produced on trap plants exposed in the stressed plots than on those in irrigated plots. After about 100 DAS, the number of lesions on trap plants declined and was again the same between plots.

Similarly, during differential irrigation, inoculated trap plants that were exposed in protected irrigated plots developed more lesions than those exposed in stressed plots (Table 11).

The data indicate that the microclimate during differential irrigation favored spore production and infection in the irrigated plots. Consequently, the higher disease level observed later in the stressed plots was caused, not by microclimatic differences between plots, but probably by increased susceptibility of plants that had been stressed.

Viral diseases (*Plant Pathology and Entomology*). *Onset and development of tungro in the field* (*Plant Pathology*). A field trial in 1986 DS determined when RTV infection occurred in the field. Seedlings from net-covered and uncovered



8. Leaf blast disease progress on primary and secondary tillers of C22 in protected and unprotected upland plots subjected to either water stress or irrigation from 42 to 58 d after seeding. IRRI, 1986.

Table 9. Collar and neck Bl incidence on C22 at harvest in protected and unprotected plots subjected to either irrigation or stress from 42 to 58 DAS.[a] IRRI, 1986.

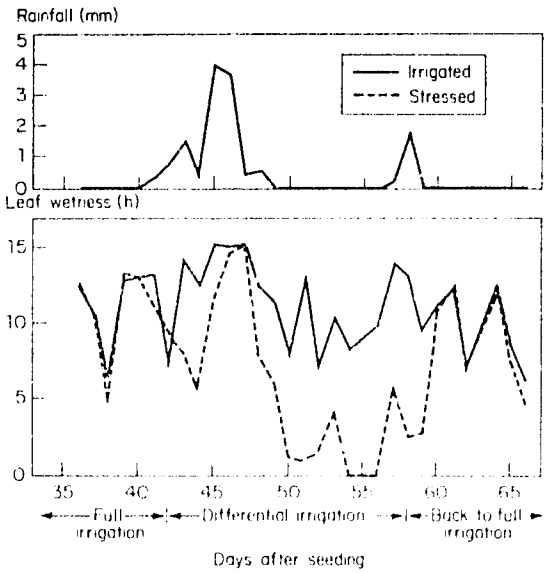
Treatment[b]	Collar blast (%)	Neck blast (%)
Protected	1.3	8.0
Unprotected	32.9	37.8
Stressed	22.8	28.6
Irrigated	11.5	17.2
LSD (0.05)	13.0	6.6

[a]Collar Bl on flag leaves and neck Bl on panicle axis of all tillers in 12 hills at harvest. Analysis of variance showed no Bl × water level interaction; thus only main effect means are presented. [b]Fungicides were applied to protected treatments; water was withheld from the stressed treatment from 42 to 58 DAS.

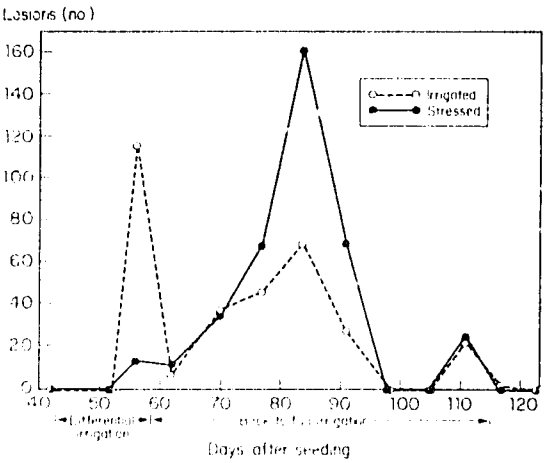
Table 10. Effect of Bl and water level on yield components, grain yield, and total dry matter in C22 grown under upland conditions.[a] IRRI, 1986.

Treatment[b]	1,000-grain weight (g)	Filled grain (%)	Panicles (no./m²)	Grain yield (t/ha)	Total dry matter (t/ha)
Protected	19.9	43.2	373	2.0	9.7
Inoculated	18.9	30.6	338	1.3	7.8
Stressed	18.8	34.7	347	1.4	7.9
Irrigated	20.0	39.2	365	1.9	9.6
LSD (0.05)	1.1	8.1	--	0.3	0.9

[a]Analysis of variance showed no Bl × water level interaction; thus only main effect means are presented. [b]Fungicides were applied to protected treatments; water was withheld from the stressed treatment from 42 to 58 DAS.



9. Rainfall and leaf wetness periods in irrigated plots of upland rice and in plots stressed from 42 to 58 d after seeding. IRRI, 1986.



10. Lesions on trap plants exposed in irrigated plots of upland rice and in plots stressed from 42 to 58 d after seeding. IRRI, 1986.

seedbeds were divided into 2 lots and transplanted 1 mo after sowing in a screenhouse and in the field. RTV incidence was scored visually at 22, 37, and 65 DT.

RTV incidence in covered seedbed plots was zero at 22 DT in both the screenhouse and the field; in uncovered seedbed plots, it was 0.2% in the screenhouse and 0.1% in the field. RTV incidence in the field was 13% in covered plots and 12% in uncovered plots at 37 DT. At 65 DT, the incidence increased dramatically to 77% in covered plots and 79% in uncovered plots.

Monitoring grassy stunt virus and ragged stunt virus in Laguna (Plant Pathology and Entomology). Light trapping was continued in Liliw, Laguna, to monitor brown planthopper (BPH) carrying grassy stunt (GSV) and ragged stunt (RSV) viruses. The light trap was set 5 m above the ground in an isolated ricefield to catch high-flying BPH. The site was cropped twice annually. Trapped BPH were individually tested by enzyme-linked immunosorbent assay (ELISA) after homogenization with 0.5 ml of 0.02 M phosphate buffer containing 0.15 M NaCl, 0.05% Tween 20, and 2% polyvinylpyrrolidone (molecular weight = 10,000) at pH 6.5. RSV and GSV incidence were also monitored in farmers' fields around Laguna.

As in 1985, trap catches were higher in March-April and in September-October; however, total catches were lower for 1986 (Fig. 11). A low BPH population coincided with the start of the cropping seasons, generally in December-January and in June-July. RSV carriers were 2.4% and GSV carriers were 1.0% of a total of 206 BPH tested.

Table 11. Lesion number on trap plants of cultivars C22 and CO 39 inoculated with dry spores of *Pyricularia oryzae* and placed overnight in either irrigated or stressed plots of upland rice.[a] IRRI, 1986.

Day of exposure	Lesions (no.)					
	C22			CO 39		
	Irrigated	Stressed	Difference	Irrigated	Stressed	Difference
56	293	110	183^{ns}	297	152	145^{ns}
57	74	0	74**	216	3	213**
58	5	0	5^{ns}	14	0	14**

[a]Lesion number/40 leaves examined 6 d after field treatment; mean of 6 replications. Plots were protected from *P. oryzae* infection with fungicide; uninoculated checks were disease free.

GSV and RSV incidence was zero to trace.

Green leafhopper "biotype" and tungro transmission in Indonesia (*Plant Pathology*). As part of the Indonesian Agency for Agricultural Research and Development-IRRI Collaborative Project on RTV at the Maros Research Institute for Food Crops (MORIF), South Sulawesi, Indonesia, GLH colonies selected from GLH-resistant IR varieties at MORIF were used to transmit RTV. Test plants were indexed by latex serology for the presence of RTV to study the differential transmission of RTBV and RTSV on the resistant varieties. For details see Cooperative Country Projects.

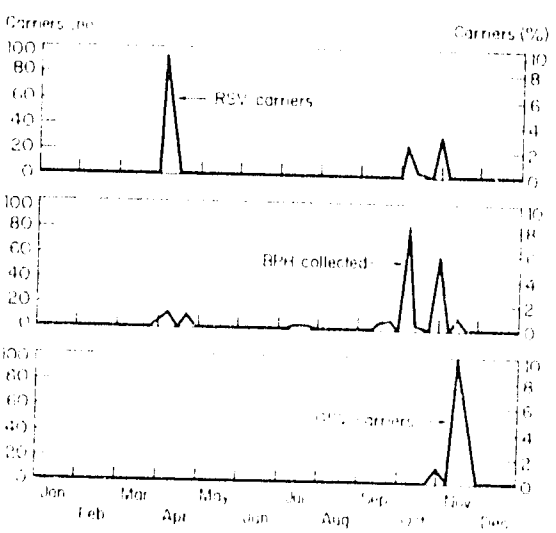
Green leafhopper "biotype" and tungro in the Philippines (*Plant Pathology*). During October 1985, we collected about 50 adult green leafhopper (GLH) from a field of IR64 in Koronadal, South Cotabato. The GLH were then continuously reared on IR64 seedlings. After about 7-10 overlapping generations, transmission of RTV-associated viruses by this IR64 colony was compared with the greenhouse colony that had been maintained on TN1 seedlings for several years.

Young adults of the two colonies that had been exposed to RTV-infected plants were individually tested for their feeding sites and virus transmission in IR64 and TN1 plants. The IR64 colony excreted more basic honeydew on IR64 than the TN1 colony (Fig. 12a). During the feeding test, the IR64 colony efficiently transmitted RTBV + RTSV to both IR64 and TN1 seedlings, while the TN1 colony transmitted them inefficiently to IR64 seedlings (Fig. 12b).

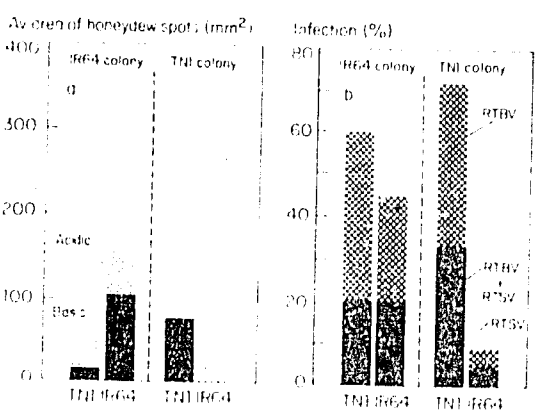
Transmission of tungro by Nephotettix nigropictus (*Plant Pathology*). Adult *Nephotettix virescens* and *N. nigropictus* were allowed a 4-d acquisition access to the same plants infected with both RTBV and RTSV, and were then confined in test tubes with 5-d-old seedlings of 14 varieties at 1 insect seedling for 1 d. One month after inoculation, inoculated seedlings were indexed by the latex test.

N. nigropictus transmitted either RTBV and RTSV together, RTBV or RTSV alone, but its transmission efficiency was lower than that of *N. virescens* (Table 12). *N. nigropictus* preferentially transmitted RTBV alone to almost all varieties tested. IR26, IR56, IR62, and IR64 were not infected with either virus when *N. nigropictus* was used to inoculate them, but they were mostly infected with RTBV alone when *N. virescens* was used.

Distribution of viruses in tungro-infected plants (*Plant Pathology*). Five-day-old TN1 seedlings were inoculated with RTV, and plants that became infected with both RTBV and RTSV were selected 4 wk after inoculation. The plants were at the 4- or 5-leaf stage. All leaf blades and sheaths were collected from each plant. Leaves or sheaths of the



11. Percent grassy stunt virus (GSV) and ragged stunt virus (RSV) carriers in trapped brown planthopper (BPH), Liliw, Laguna, Philippines, 1986.



12. Feeding behavior of IR64 and TN1 colonies of green leafhopper *N. virescens* on IR64 and TN1 (a) and RTV transmission during the feeding test (b), IRRI, 1986

Table 12. RTV infection of IR varieties by 2 leafhopper species 4 d after acquisition feeding. IRRI, 1986.

Variety	*N. virescens*				*N. nigropictus*			
	Plants inoculated (no.)	Plants (no.) infected[a] with			Plants inoculated (no.)	Plants (no.) infected[a] with		
		RTBV+RTSV	RTBV	RTSV		RTBV+RTSV	RTBV	RTSV
IR8	30	1	14	1	28	0	2	0
IR20	29	0	19	1	28	0	8	0
IR26	30	0	12	0	30	0	0	0
IR30	29	0	12	0	30	0	5	0
IR36	25	2	9	1	30	0	3	1
IR42	30	6	11	2	29	1	2	0
IR50	26	1	3	0	29	0	4	0
IR54	27	0	5	0	23	0	3	0
IR56	28	1	9	1	28	0	0	0
IR58	29	0	5	0	28	0	3	0
IR60	30	0	11	0	30	0	1	5
IR62	29	1	7	1	30	0	0	0
IR64	29	0	7	1	30	0	0	0
TN1	26	6	9	1	26	2	7	0
Total	397	18	133	9	399	3	39	6

[a]Indexed by the latex serological test at 1 mo after inoculation.

same position (1st, oldest; 5th, youngest) from 5 plants were combined and homogenized with phosphate-buffered saline solution (pH 7.4), and extracts at 1:10 dilution were directly tested by ELISA. The relative amount of the viruses was indicated by absorbance values at 405 nm.

Relative amounts of RTBV and RTSV were higher in the second or third youngest leaves, and lower in older or youngest leaves (Table 13), indicating that the best leaf positions for sampling for serodiagnosis are the second and third youngest.

Transmission of rice tungro bacilliform virus by green leafhopper (Plant Pathology). RTBV can be transmitted only when GLH acquire RTSV previously or at the same time. To screen rice varieties for resistance to RTBV, a technique must be developed to inoculate test varieties with RTBV alone with high efficiency. Adult GLH given sequential access feedings as follows were allowed an inoculation feeding on 7-d-old TN1 seedlings at 1 GLH seedling: 1) access to RTSV-infected plants for different durations and then to RTBV-infected plants; 2) access to RTSV-infected plants for 3 d, to healthy TN1 seedlings for different durations, and then to RTBV-infected plants for 24 h; and 3) access either to both RTBV and RTSV or to RTSV alone, and then to anti-RTSV serum through a membrane for 16 h. Inoculated seedlings were indexed by the latex test 1 mo after inoculation.

Among the trials conducted, infectivity neutralization (the last method) gave the highest percentage of infective GLH with high proportion of RTBV transmitters (Table 14, 15). However, this

Table 13. Relative amounts of RTBV and RTSV in leaf blades and sheaths at different positions in TN1 plants 4 wk after infection with both RTBV and RTSV. IRRI, 1986.

Leaf position	Absorbance at 405 nm by ELISA			
	Leaf blades		Leaf sheaths	
	RTBV	RTSV	RTBV	RTSV
		Test 1		
1st	0.26	0.45	0.36	0.39
2d	0.32	0.41	0.32	0.37
3d	0.43	0.50	0.40	0.41
4th	0.44	0.44	0.34	0.35
5th	0.40	0.42	-	-
		Test 2[a]		
1st	0.6 ± 0.1	0.8 ± 0.4	0.7 ± 0.3	0.6 ± 0.3
2d	0.9 ± 0.1	0.8 ± 0.4	0.7 ± 0.1	0.7 ± 0.4
3d	0.7 ± 0.1	0.8 ± 0.4	0.5 ± 0.2	0.4 ± 0.1
4th	0.6 ± 0.2	0.7 ± 0.2	0.5 ± 0.5	0.1 ± 0.1

[a]In test 2, mean absorbance ± standard deviation in 4 replications.

method required a considerable amount of the antiserum and was too complicated for screening for RTBV resistance. Moreover, with this method, only three varieties can be screened at a time using present facilities. Other trials gave GLH populations that transmitted only RTBV, but the percentage of infective GLH in the population was lower (Table 16, 17). Screening for RTBV resistance can be done at higher rates of GLH that have been given sequential feedings on RTSV- and then RTBV-infected plants.

SEED PATHOLOGY

Plant Pathology Department

Detection of *Xanthomonas campestris* pv. *oryzae* in rice seed. The bacterial blight (BB) pathogen *Xanthomonas campestris* pv. *oryzae* (Xco) was believed to be seedborne, although evidence was not conclusive. Last year we reported that many bacteria isolated from rice seed produced on peptone sucrose agar yellow colonies resembling those of Xco. None of them, however, were pathogenic (Annual report for 1985). We continued to investigate methods to detect Xco in or associated with rice seed. We isolated bacteriophages of Xco as well as Xco from naturally diseased plants. Seeds were freshly harvested from farmers' fields and from experiments where severe BB occurred.

A standard procedure was followed to detect free phages and the phages that are released from infected host cells, designated as adsorbed phages. Adsorbed phages are assumed to be associated with seed. Free phages were isolated from the 38 samples collected from IRRI, Nueva Ecija, Laguna, and Palawan. Adsorbed phages were also detected from crushed seed, husks, and surface washings, but 50% fewer than free phages (Table 18), suggesting that bacterial cells were associated with the specimen. The detection was positive until 2 wk after seed storage at both 6 and 28 °C, regardless of sample size (maximum 1,000 seeds). No free phages were detected from seed that was harvested from plants with a disease score of 3 or less (Table 19).

ETIOLOGY AND SEROLOGY

Plant Pathology Department

Antiserum of Xco. Xco in pure culture (117 isolates) and in extracts of naturally infected rice leaves (27 samples) of 6 rice varieties was easily detected and identified by a direct fluorescent (fluorescein isothiocyanate)-antibody (immunoglobulin from antiserum to glutaraldehyde-fixed

Table 14. RTBV transmission by GLH given sequential access feedings on RTBV+RTSV or RTSV for 3 or 4 d, on anti-RTSV serum for 16 h, and on RTBV for 0, 8, or 24 h. IRRI, 1986.

Duration of access to RTBV (h)	GLH tested (no.)	GLH[a] (no.) transmitting		Infective insects (%)	GLH transmitting RTBV (%)
		RTBV+RTSV	RTBV		
0	245	7	53	24.4	88.3
8	193	6	117	63.7	95.1
24	150	3	96	66.0	96.9

[a]None transmitted RTSV.

Table 15. RTBV transmission by GLH given sequential access feedings on RTSV for 3 d, on anti-RTSV serum for 16 h, and on RTBV for 8 or 24 h. IRRI, 1986.

Duration of access to RTBV (h)	GLH tested (no.)	GLH[a] (no.) transmitting		Infective insects (%)	GLH transmitting RTBV (%)
		RTBV+RTSV	RTBV		
8	28	3	22	89.3	88.0
24	35	6	22	80.0	78.5

[a]None transmitted RTSV.

Table 16. RTBV transmission by GLH given sequential access feedings on RTSV and RTBV at different time combinations. IRRI, 1986.

Feeding duration (h)		GLH tested (no.)	GLH[a] (no.) transmitting		Infective insects (%)	GLH transmitting RTBV (%)
On RTSV	On RTBV		RTBV+RTSV	RTBV		
8	16	20	0	4	25.0	100.0
8	24	18	0	3	16.6	100.0
8	48	18	0	2	11.1	100.0
16	24	20	2	6	40.0	75.0
16	48	17	0	3	17.6	100.0
24	24	40	26	10	90.0	27.7

[a]None transmitted RTSV.

Table 17. RTBV transmission by GLH given sequential access feedings on RTSV source plants for 3 d, on healthy TN1 seedlings for 0-7 d, and on RTBV-infected plants for 24 h. IRRI, 1986.

Days on healthy TN1 seedlings	GLH tested (no.)	GLH (no.) transmitting			Infective insects (%)	GLH transmitting RTBV (%)
		RTBV+RTSV	RTBV	RTSV		
0	36	5	15	1	58.3	71.4
1	36	1	11	0	33.3	91.6
2	40	0	9	0	22.5	100.0
3	36	0	5	0	13.8	100.0
7	36	0	1	0	2.7	100.0

Table 18. Isolation of free phages and adsorbed phages — incubated at 28 °C for 10 h after removing the free phages — from seed samples collected from 4 locations in the Philippines where the mother plants were infected with bacterial blight.[a] 1986.

Collection site	Grains (no.)	Total samples (no.)	Samples (no.) showing presence or absence of phages							
			Crushed whole seeds		Surface washings		Husks		Grains	
			Supernatant	Pellet	Supernatant	Pellet	Supernatant	Pellet	Supernatant	Pellet
IRRI	45-50	26	17+	8+	4+	3+	16+	9+	7+	2+
			2±	3+		2±	4±	1±	4±	
Nueva Ecija	45-50	10	9+	2+	2+	2+	8+	2+	4+	2±
				1±	1±	2±	1±	1±		
Mabitac	100	1	+	–	+	–	+	–	+	–
Palawan	100	1	+	–	+	–	+	–	+	–

[a]+ = positive increase in plaques, ± = little increase in plaques, – = no plaques.

Table 19. Isolation of bacteriophages of *Xanthomonas campestris* pv. *oryzae* from seed samples harvested from plants with different levels of bacterial blight. IRRI, 1986.

Disease index	Seed lot (no.)	Positive (no.)	
		Free phages	Adsorbed phages[a]
7	9	9	7
3	4	0	0
1	13	11	1

[a]Phages detected after removing the free phages and incubating for 10 h.

cells) staining (FAS) procedure. Xco cells mixed with *X. campestris* pv. *oryzicola* (1×10^6 CFU) or isolates of common bacterial flora from rice seeds or added to ricefield water or in rice seed washings from artificially inoculated panicles were detected at a concentration of 40-50 cells/ml.

Stained cells of *X. campestris* pv. *begoniae*, *campestris*, *cerealis*, *citri*, *graminis*, *glycines*, *malvacearum*, *oryzicola*, *phaseoli*, *phlei*, and *vesicatoria* were not fluorescent, while pv. *arrhenatheri*, *hyacinthi*, and *poae* had doubtful fluorescence. No

precipitating immunogen was detected from the antigens of all these pathovars, using the fluorescein isothiocyanate-immunoglobulin conjugate in antiserum wells in Ouchterlony double-diffusion tests.

The data indicate that the FAS procedure using immunoglobulin from antiserum to glutaraldehyde-fixed Xco cells is highly specific for pv. *oryzae* and could be used for its rapid detection and identification. However, it could not distinguish Xco races.

Rice tungro bacilliform virus. Large numbers of RTBV-infected TN1 plants were obtained by exposing them to GLH that had been given sequential access to TN1 plants infected with both RTBV and RTSV for 4 d and then to anti-RTSV serum for 16 h through a membrane (Parafilm M). RTSV infectivity was neutralized after the feeding on antiserum, and the GLH transmitted mostly RTBV alone. All inoculated seedlings were tested by ELISA to confirm the presence of RTBV and absence of RTSV.

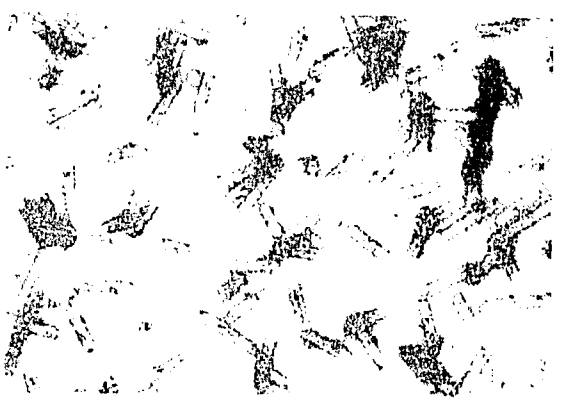
Infected plants (500 g) were harvested (without roots) about 50 d after inoculation and homogenized in 1 liter of 0.01 M EDTA (pH 8.0). The leaf extract was clarified by heating at 40 °C for 1 h after treatment with 5 g Driselase for 1 h at room temperature. After centrifugation at 15,000 g for 10 min, polyethylene glycol 8,000 (7% wt/vol), NaCl (0.02 M), and Triton X-100 (1% vol/vol) were added to the supernatant and stirred for 1 h at room temperature. The mixture was centrifuged at 30,000 g for 30 min, and the pellet was suspended in 20 ml 0.01 M EDTA (pH 8.0). The suspension was subjected to low (11,000 g, 10 min)- and high (100,000 g, 60 min)-speed centrifugation. The resulting pellets were resuspended in 2 ml 0.01 M phosphate buffer (PB) at pH 7.4 and again centrifuged at 11,000 g for 10 min. The supernatant was layered on a 10-50% linear sucrose density gradient (prepared in 0.01 M PB, pH 7.4) and centrifuged at 90,400 g for 2.5 h at 4 °C in a Beckman SW27 rotor. The tube contents were scanned at 254 nm in an ISCO (Model 640) fractionator. The virus-containing fraction was recovered, diluted with 0.01 M PB (pH 7.4), and centrifuged at 130,000 g for 1 h. The concentrated virus was suspended in 1 ml of 0.01 M PB (pH 7.4) and centrifuged at 11,000 g for 10 min. The resulting supernatant contained RTBV particles, 30-35 nm in width, with varying length (Fig. 13). The purified RTBV fraction had maximum ultraviolet light absorption at 258-259 nm and minimum absorption at 243-244 nm. The UV absorption ratio at 260 nm and 280 nm ($A_{260/280}$) ranged from 1.13 to 1.20.

Two rabbits were immunized against RTBV by five injections (four intramuscular and one intravenous) given at weekly intervals. Purified virus suspension (A_{260} = 0.7) was emulsified with an equal volume of Freund's complete adjuvant for intramuscular injections. Rabbits were bled 1 wk after the last injection. The antiserum had a titer of 1:2,560 in the precipitin ring interface test.

Latex particles (Difco Bacto Latex, 0.82 μ) were sensitized with partially purified anti-RTBV immunoglobulin diluted 1000× for serological detection of RTBV in infected plant sap. RTBV was detected by the latex test in infected sap diluted 80×. Sap from healthy plants gave a negative reaction.

ELISA tests were also conducted to detect RTBV antigens in leaf extracts. Immunoglobulin was purified and labeled with alkaline phosphatase following standard procedures. Purified immunoglobulin (coating immunoglobulin) at 1 μg/ml and enzyme-labeled immunoglobulin diluted 1000×, detected RTBV in infected sap diluted 320×. Healthy sap (20× dilution) and purified RTSV (A_{260} nm = 0.3) gave negative reactions.

Rice ragged stunt virus. RSV was purified from RSV-infected TN1 plants following the procedure of Omura et al with some modifications. Whole

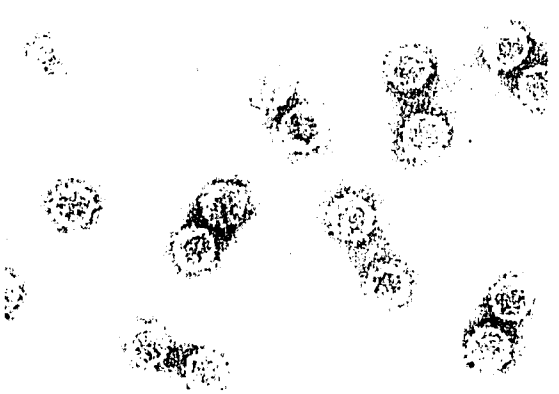


13 Purified RTBV (×50,000). IRRI, 1986.

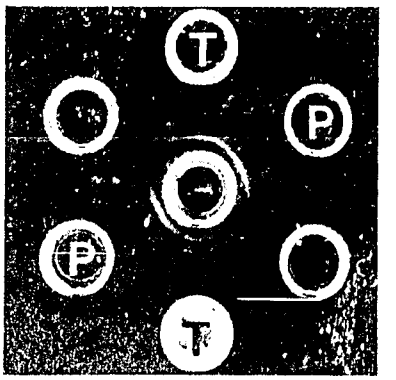
plants including roots were homogenized with 0.1 M PB (pH 7.0) in 0.01 M $MgCl_2$. The sap was clarified by freezing overnight and defrosting at room temperature, and treated with 1% Triton X-100 for 30 min. The virus precipitated in 6% polyethyleneglycol 6000 and 0.3 M NaCl was suspended in 0.1 M histidine buffer in 0.01 M $MgCl_2$ (pH 7.0). The suspension was treated with 20% CCl_4 and subjected to differential centrifugation. Then the virus fraction was layered on a 20-50% linear sucrose density gradient and centrifuged at 25,000 rev/min for 90 min in a Beckman SW27 rotor.

The zone containing virus particles was recovered with an ISCO Model 640 UA5 scanner and centrifuged at 40,000 rev/min for 60 min. The purified virus fraction had maximum UV adsorption at 260 nm, and the $A_{260/280}$ was 1.9-2.1. Purified particles were about 60 nm in diameter (Fig. 14).

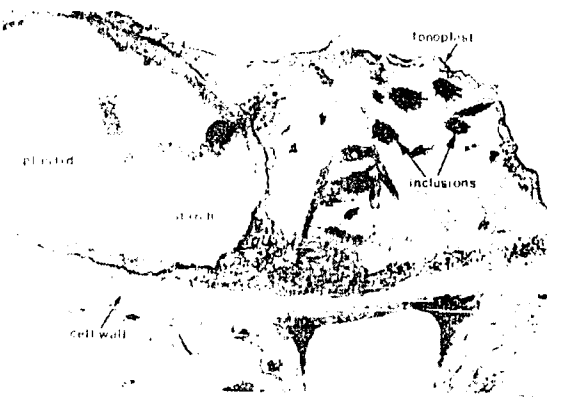
Five 1-ml aliquots of purified virus fractions of which A_{260} nm was adjusted to 1.0 were injected into 2 rabbits at 2-wk intervals. The first four injections were made intramuscularly and the last intravenously. One week after the last injection, antisera were collected. The antisera had a titer of 1:1,280 in both the ring-interface precipitin and double agar gel diffusion tests. In the gel diffusion test, a single band was formed between purified RSV and the antisera, and between RSV and antiserum to RSV from Thailand. The reaction bands fused with each other (Fig. 15), indicating that RSV in the Philippines and in Thailand are serologically indistinguishable.



14. Purified RSV (×50,000). IRRI, 1986.



15. Agar gel diffusion test showing serological relation between RSV from the Philippines and from Thailand. The center well contains purified RSV from the Philippines and the outer wells contain antisera to RSV from the Philippines (P) and Thailand (T), and phosphate buffer.



16. Part of a rice cell infected with GSV, showing inclusions composed of the fine filaments in the cytoplasm. ×40,000. IRRI, 1986.

HOST-PATHOGEN INTERACTIONS

Plant Pathology Department

Inclusions in grassy stunt-infected plants. Ultrathin sections of leaf tissue from GSV-infected TN1 plants were examined under the transmission electron microscope. Inclusions were observed in the mesophyll and vascular bundle cells but not in similar cells from healthy and RTV-infected plants. The inclusions were composed of fine filaments and arranged in a paracrystalline array (Fig. 16). Inclusions were abundant in the nucleus and vacuole, less in the cytoplasm, and often in close association with chloroplasts. The results suggest that the filamentous inclusions are specific to GSV infection in rice.

Control and management of rice pests

Insects

Entomology, Agronomy, Agricultural Economics, Statistics, and Plant Pathology Departments

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ECOLOGY AND BIOLOGY

Entomology Department

Rice whorl maggot food web. The food web of the rice whorl maggot (RWM) *Hydrellia philippina* Ferino in the Philippines comprises 114 species: 13 parasites, 71 predators, and 62 secondary parasites and predators (32 spiders double as both predators and secondary predators) (Fig. 1). Predators outnumber the parasites by almost 6:1 and the secondary predators by 2:1. The dominant predators are the 32 spiders comprising hunters (17), orb-web (12), and space-web (3) species; odonatans (10); and true bugs, flies, and vertebrates (8 each). Ants and mites also prey on RWM.

Ochthera sauteri, an ephydrid fly, preys on adults, and the dolichopodids *Capsicenemus* and *Medetera* attack eggs.

Nine wasps are larval-pupal parasites. These are the braconid *Opius* sp. (the most abundant); eulophids *Tetrastichus* spp. and two undetermined species; pteromalids *Trichomalopsis* sp. and *T. apanteloctena* Crawford; and the diapriids *Diapriid* spp. A eulophid solitary wasp, tentatively identified as *Ootetrastichus*, parasitizes eggs.

Biology of the gold-fringed borer. The gold-fringed borer *Chilo auricilius* Dudgeon (= *Diatraea*, *Chilotraea auricilia*, *Chilo popescugorji*) is a newly recorded pest of dryland and wetland rice in the Philippines. The larva is morphologically similar to the dark-headed stem borer: *Chilo polychrysus* (Meyrick). *C. auricilius* occurs in India, Nepal, Thailand, Malaysia, the Philippines, and Taiwan, China, overlapping with *C. polychrysus* in India and Thailand. It is suspected that *C. polychrysus* does not occur in the Philippines, as no specimen was found out of 1,316 moths whose genitalia were dissected.

C. auricilius, which also feeds on maize and sorghum, was reared in the greenhouse on an artificial diet and on 26 rice varieties, mostly upland. The moths are straw colored with silver lines near the terminal area of the fore wing. Eggs are laid in masses of 5-233 overlapping eggs; they hatch in 8 d. A female moth averages eight egg masses in a lifetime. The dirty-white larvae with 5 longitudinal pinkish stripes on the body dorsum pass through 5 instars in 22-24 d. The larvae prepupate for about a day and soon pupate within 9 d (Fig. 2). The moths live for 6-9 d.

The grass *Leptochloa chinensis* (L.) Nees is the only potential host that supported complete development of the gold-fringed borer from egg to adult in 42 d. The larvae, however, developed to the 4th instar in *Echinochloa glabrescens* Munro ex Hook f., *E. crus-galli* (L.) Beauv. ssp. *hispidula* (Retz.) Honda, and *Fimbristylis miliacea* (L.) Vahl. The female moths showed oviposition preference for the small but smooth leaf surfaces of *Paspalum conjugatum* Berg (Table 1).

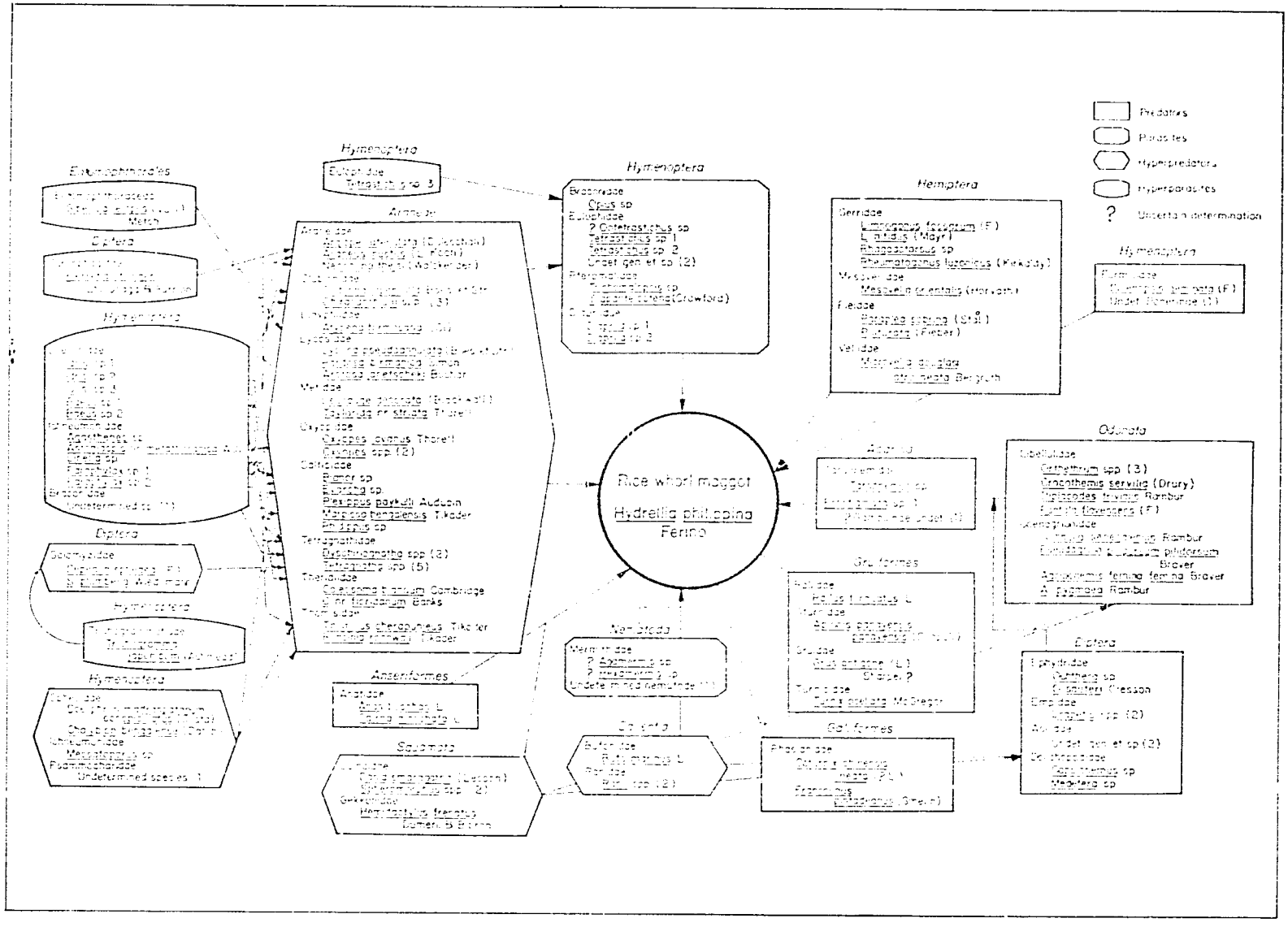
Four natural enemies of *C. auricilius* were recorded. The gryllid *Metioche vittaticollis* (Stål) fed on eggs, and two *Euborellia* earwigs preyed on larvae. *Planerotoma* sp., a braconid wasp, parasitized the larvae.

Life history of the long-horned grasshopper. The long-horned grasshopper *Conocephalus longipennis* is abundant in upland and flooded rice in most parts of the Philippines. Although this species is reported to feed on rice, it is generally

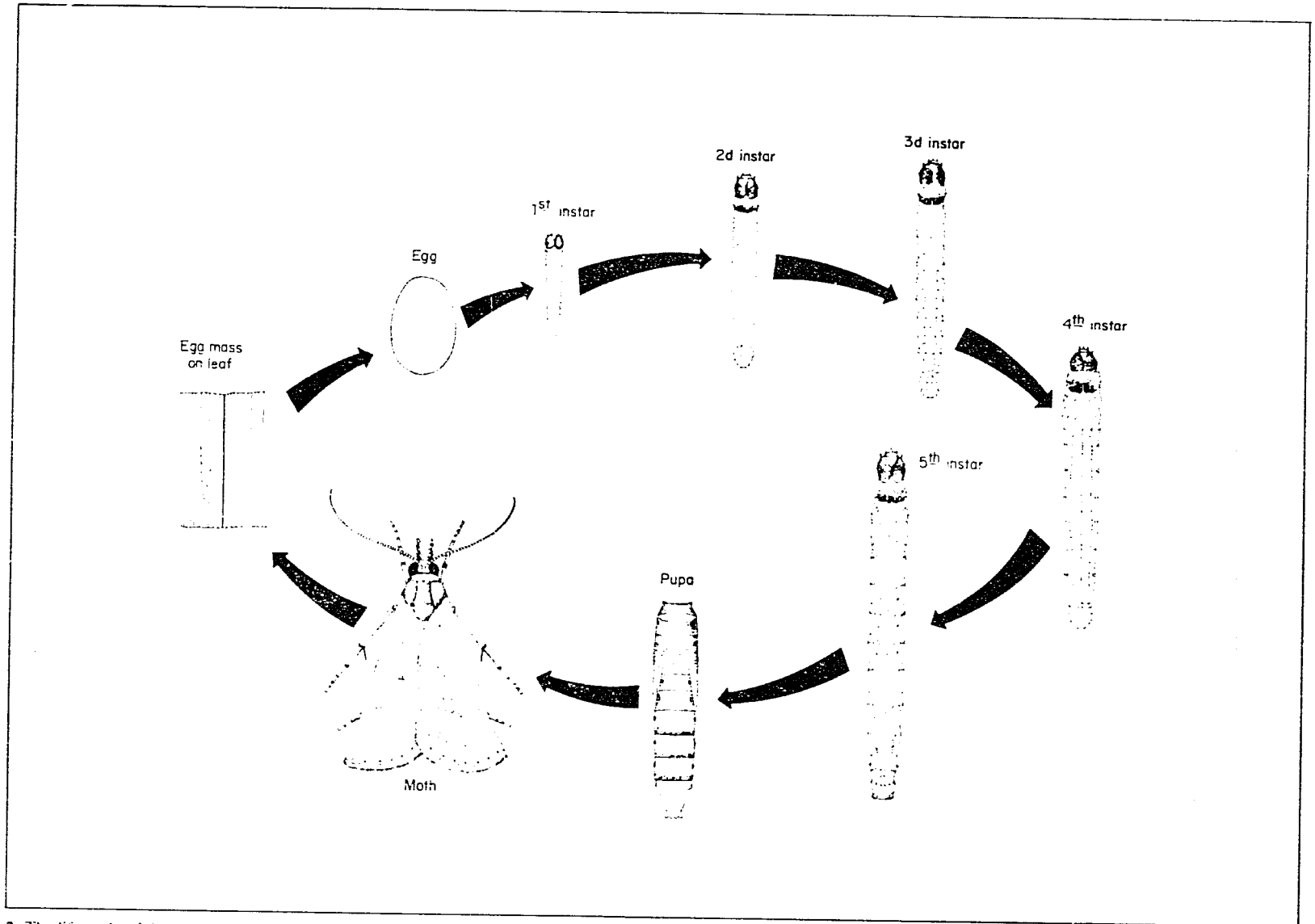
Table 1. Host plants of *Chilo auricilius* Dudgeon.[a] IRRI greenhouse, 1986.

Host species	Eggs laid (no.)	Survival (%)	Growth index
Cyperus rotundus L.	192	–	–
Cyperus iria L.	90	–	–
Dactyloctenium aegyptium (L.) Beauv.	11	–	–
Digitaria ciliaris (Retz.) Koel.	32	–	–
Echinochloa colona (L.) Link	86	–	–
E. crus-galli (L.) Beauv. ssp. *hispidula* (Retz.) Honda[b]	91	–	–
E. glabrescens Munro ex Hook f.[b]	60	–	–
Eleusine indica (L.) Gaertn.	80	–	–
Fimbristylis miliacea (L.) Vahl[b]	62	–	–
Leersia hexandra Swartz	24	–	–
Leptochloa chinensis (L.) Nees	101	26 c	0.62 c
Paspalum conjugatum Berg	204	–	–
Oryza sativa L.	158	70 a	2.03 a
Sorghum bicolor (L.) Moench.	116	48 b	1.15 b
Triticum aestivum L.	110	27 c	0.67 c
Zea mays L.	146	60 a	1.42 b

[a]Av of 4 replications. [b]Supported 2d-4th instar development only.



1. Food web of the rice whorl maggot *Hydrellia philippina* Ferino in the Philippines.



2. The life cycle of the gold-fringed borer *Chilo auricilius* Dudgeon. IRRI, 1986.

recognized as a predator. *C. longipennis* was cultured in the laboratory in mylar cages, using an artificial diet originally developed for the maize borer.

Eggs, deposited in clusters of 2-14 in the rice leaf sheath, hatch in 18-34 d (n = 22). Development progresses through 5 nymphal stages, with first stage development requiring 8 d, second stage 9 d, third stage 11 d, fourth stage 10 d, and fifth stage 8 d.

Females have a long ovipositor, and males are smaller than females. Adult longevity is 39 d for males and 43 d for females.

Behavior and bionomics of a leaffolder parasite. The bionomics and behavior of the bethylid parasite *Goniozus triangulifer* Kieffer were studied in the laboratory with leaffolders (LF) *Cnaphalocrocis medinalis* (Guenée) and *Marasmia patnalis* (Bradley) as hosts. Female parasitoids lived twice as long (22 d) as males (11 d) and laid about 80 eggs during their lifetime. Single male broods occurred in 66% of the samples.

Females exhibited complex behavior upon encountering a host. A host larva was malaxated by the female parasite after she paralyzed it by stinging. Parasites laid an average of 4.5 eggs on unparasitized hosts and 2.4 eggs on previously parasitized ones. When a parasite already had experience with parasitizing a host, the time required to do so was significantly shorter.

G. triangulifer was able to discriminate between parasitized and unparasitized hosts.

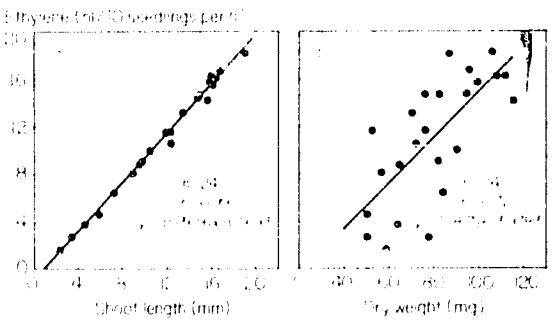
Insect migration. Our studies of insect migration, based on 10 voyages conducted in the Philippine archipelago, showed that long-distance brown planthopper (BPH) migration occurs in the tropics during the wet season (WS), which has bearing on the spread of pest biotypes and pest-transmitted virus diseases.

Ethylene as a marker for estimating level of insect infestation. The amount of ethylene produced by rice seedlings has been used as an indicator of seed vigor. We found a correlation between the degree of rice seed infestation by the primary storage pest *Rhizopertha dominica* F. and ethylene production from seedlings grown from infested seeds. Ethylene production, shoot length, and seedling dry weight all decreased progressively with an increase in insect infestation (Table 2, Fig. 3). Ethylene could thus serve as a marker for estimating the degree of insect infestation and seedling vigor. It could also serve as a tool in screening for varietal resistance to storage insects.

Table 2. Effect of *Rhizopertha dominica* infestation level on seed vigor.[a] IRRI, 1986.

Storage period (wk)	Ethylene (ml/10 seedlings per h)	Shoot length (mm)	Dry weight (mg)
	With infestation		
0	15.44 b	15.75 b	107.52 a
6	8.72 d	9.38 d	67.19 c
7	5.05 e	5.93 e	66.20 c
8	2.46 f	3.15 f	61.56 c
	Without infestation		
0	17.66 a	18.10 a	104.59 a
6	15.45 b	15.53 b	90.75 ab
7	11.83 c	12.62 c	64.68 c
8	12.22 c	12.35 c	80.33 bc

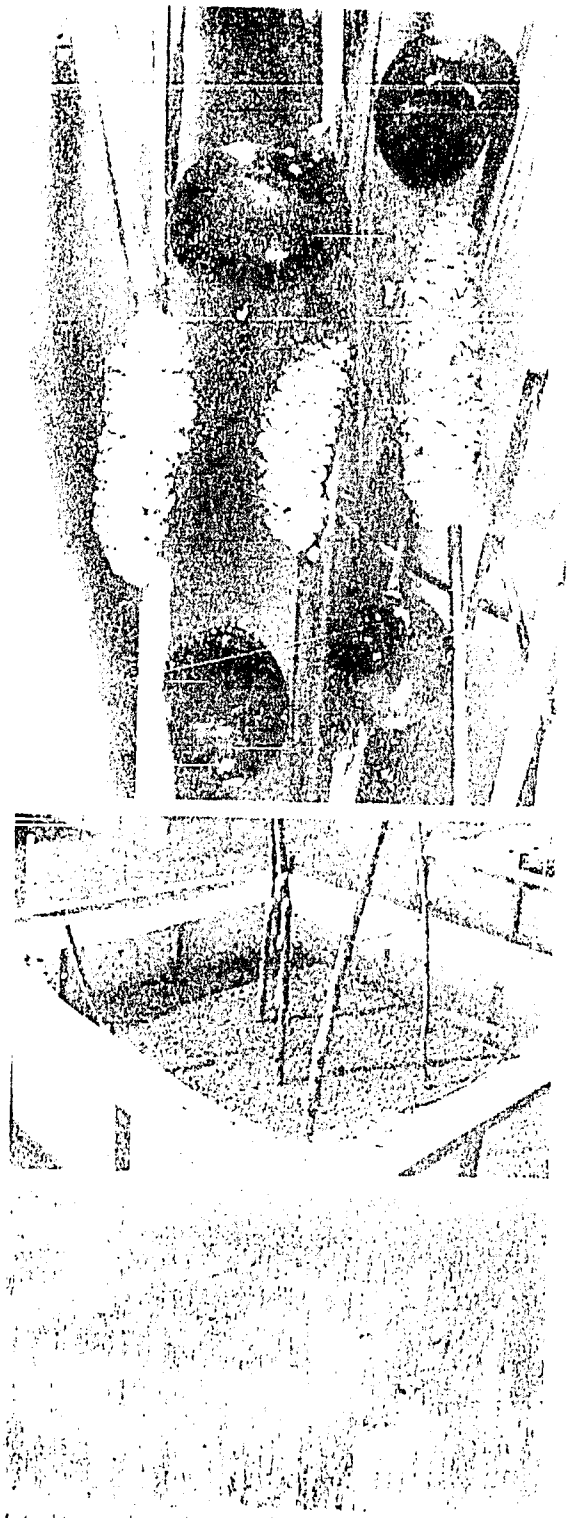
[a]Ethylene production and seedling length were determined after 4 d and dry weight after 16 d. Mean values in a column followed by a common letter are not significantly different at the 1% level by DMRT.



3. Regression line showing correlation of ethylene produced by seedlings with shoot length (a) and weight of the seedlings (b). IRRI, 1986.

Golden apple snail: a new pest of rice. The golden apple snail *Pila leopordvillensis* D'Orbigney is an aquatic gastropod. The snail was introduced to the Philippines from South America to be farmed in cement tanks, ponds, and other controlled environments. The snail and its egg masses (Fig. 4a) were seen in abundance in the azolla propagation ponds of the University of the Philippines at Los Baños (UPLB) (Fig. 4b) and in adjoining irrigated ricefields on the IRRI farm.

The snail feeds voraciously on azolla. Adults measuring 22-26 mm can consume up to 15 g of



4. Golden apple snail: (a) females and their egg masses on rice plants, (b) cluster of egg masses on bamboo stakes in an azolla propagation pond, (c) missing seedlings because of feeding by full grown snails. IRRI, 1986.

azolla fronds in 12-24 h. If azolla is not present, the snail feeds on other succulent aquatic vegetation, such as newly transplanted rice. A full-grown snail can consume a blade of rice in 3-5 min. The snail is most active from dusk through dawn. Damage is severe in low-lying portions of newly transplanted fields. Damaged plots are characterized by missing seedlings and floating cut leaves (Fig. 4c).

The snail can be controlled with organotin molluscicides, but these chemicals are toxic to fish and tadpoles. Regular picking up of snail egg masses is recommended.

INTEGRATED PEST MANAGEMENT

Entomology, Agronomy, Agricultural Economics, Statistics, and Plant Pathology Departments

Integrated pest management trials in farmers' fields (*Entomology, Agronomy, Agricultural Economics, Statistics, and Plant Pathology*). In Calauan, Laguna, Philippines, seven plots were monitored on each of four farms. Each of the 4 farmers sprayed his rice either 0, 2, 3, or 5 times during the season. Insects were monitored weekly by yellow pan sampling and visual counts to determine the necessity and impact of insecticide use. Pest insect populations were low on all farms, and insecticide treatments were clearly unwarranted. Furthermore, there was no relationship between yield and number of insecticide sprays.

An additional interdisciplinary and interagency integrated pest management (IPM) study was carried out in Gumba, Nueva Ecija, Philippines, during the 1986 dry season (DS) and WS. Personnel from the Philippine Ministry of Agriculture and Food, the National Crop Protection Council, UPLB, and the Food and Agriculture Organization of the United Nations were involved. All IPM work was carried out in farmers' fields, with half of each of six farms under IPM while farmers managed the remaining halves.

During 1986 DS, farmers applied fertilizers at unrealistically high rates and used insecticides more than necessary. Although some of the farmers' fields yielded slightly higher than those

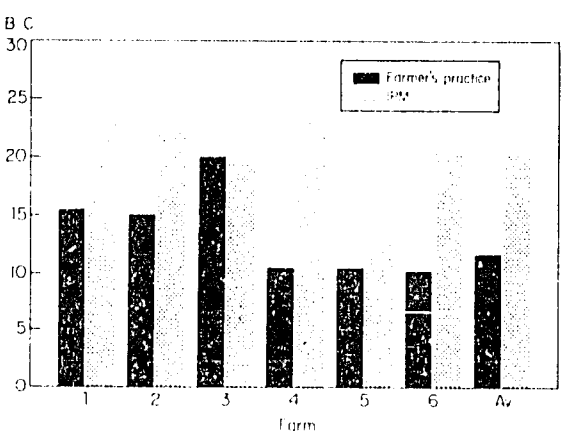
under IPM, the benefit-to-cost ratio (B:C) for the 6 farms averaged 5.6 for the farmers' practice and 8.0 for the IPM fields.

During 1986 WS, another six farms were selected for a similar experiment. Insects were sampled using sequential sampling, and diseases were monitored weekly. All farmers used IR64. The B:C for the six farms can be seen in Figure 5. The farmers made 10 insecticide applications (range of 0-2 each), but only 2 plots were treated with insecticide on the IPM portions. The average B:C was 13.5 when the farmer followed his usual practice, and 20.4 when IPM was employed. The major difference in inputs came from higher rates of fertilizer, herbicides, and insecticides used by farmers.

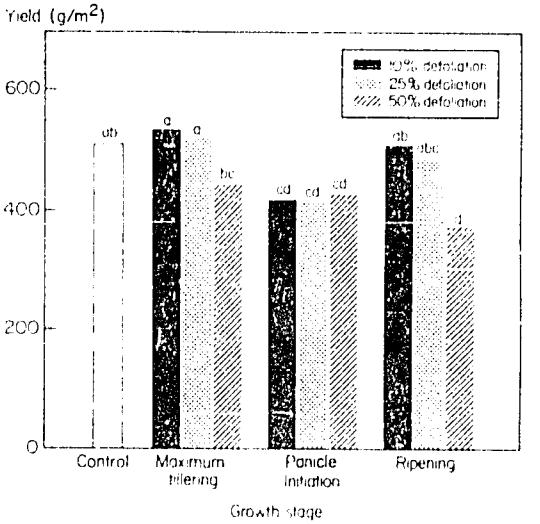
Defoliation (*Entomology*). To determine the effects of defoliation on yield and to refine action thresholds for defoliating insects, IR64 was transplanted at distances of 25 × 25 cm at 20 d after seeding (DAS), and mechanically defoliated (using scissors) to levels of 0, 10, 25, and 50%. Defoliation was carried out at maximum tillering, panicle initiation, and ripening.

Yield was most seriously affected by all defoliation levels when the plants were at panicle initiation (Fig. 6). However, removal of 50% of the foliage at all 3 stages caused significant yield reduction.

The implication from these studies is that insect pests that attack the crop early in the season (before maximum tillering) may not be important unless



5. Benefit-to-cost ratio (B:C) of fields managed by farmers and those under integrated pest management (IPM). Guimba, Nueva Ecija, Philippines, 1986.



6. Effect of mechanical defoliation on IR64 yields at different growth stages. IRRI, 1986.

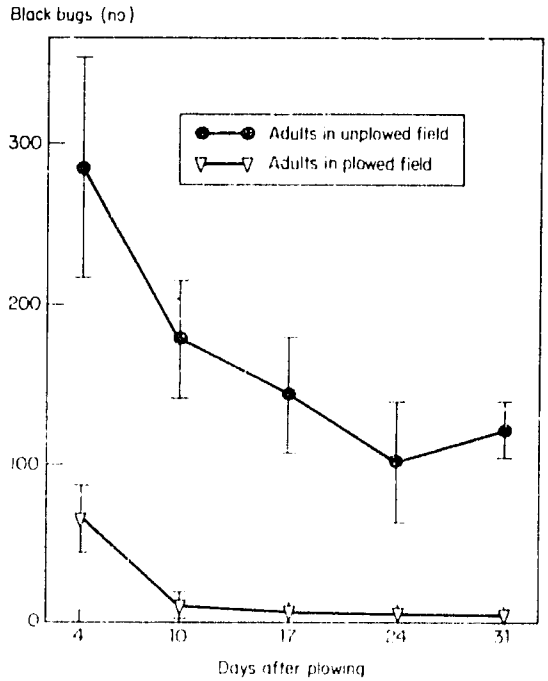
the infestation level is high. Refraining from applying insecticide could allow communities of natural enemies to build up, thereby reducing the likelihood of resurgence of insect pests later in the season.

Control by cultivation (*Entomology*). Black bugs *Scotinophara coarctata* remain in rice stubble after the crop is harvested. If fields containing stubble are not plowed, the crop ratoons and the bugs continue to feed and reproduce.

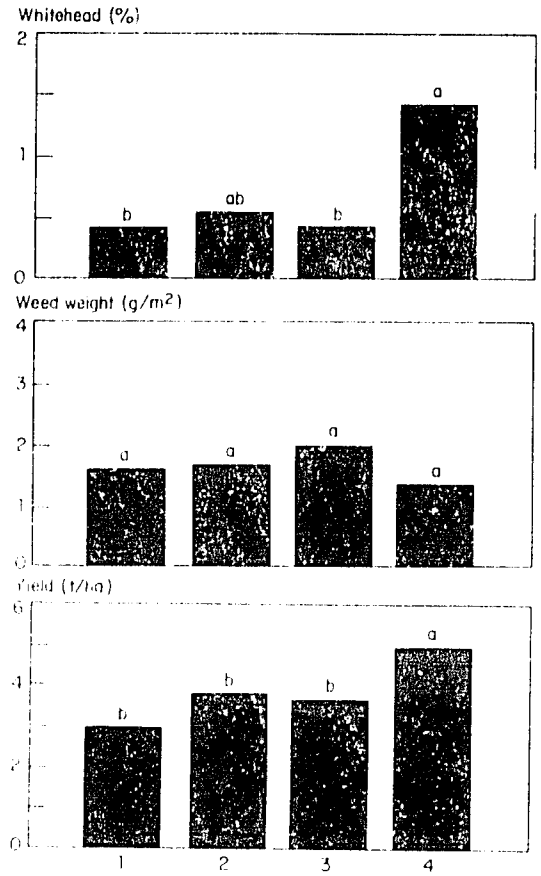
About 1/8 ha of a ricefield was plowed once using a carabao immediately after harvest. Fourteen 1-m cages were placed at random in this portion of the field. Another 14 cages were placed in an unplowed section of the same field. Numbers of live black bug adults in the cages were recorded at 4, 10, 17, 24, and 31 d after plowing.

There were significantly ($P < 0.05$) fewer black bugs inside the cages in the plowed field (Fig. 7). Cultivation of ricefields immediately after harvest could cause significant reductions in black bug populations, especially if this practice is adopted on a community-wide basis.

Influence of insects and weeds on rice yields (*Entomology and Agronomy*). The impact of stem borer (SB) *Tryporyza incertulas* and weeds on rice yield was assessed in 1986 DS in Nueva Ecija, Philippines. Plots were 100 m^2, and the 4 treat-



7. Reduction in number of black bug adults after plowing Palawan, Philippines, 1986.



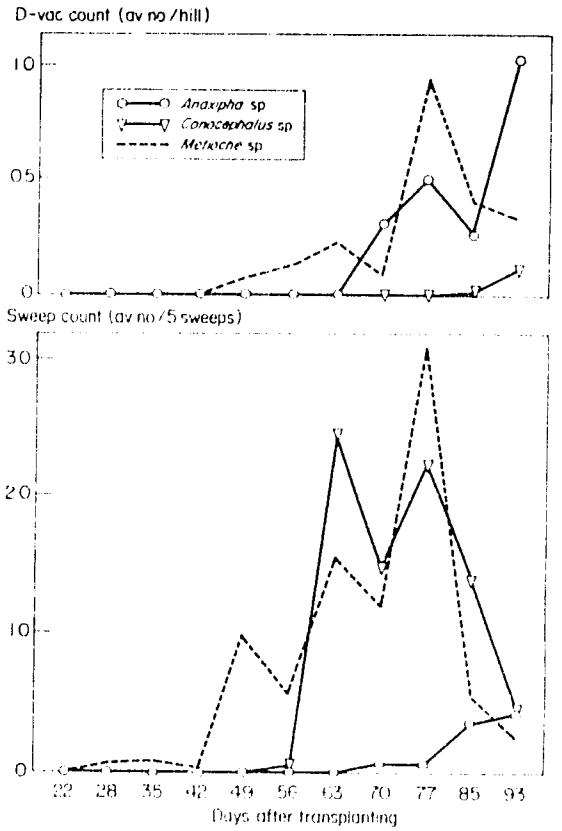
8. Effect of whitehead and weeds on the yield of IR64 in relation to insect and weed control. 1 = weed and insect control; 2 = weed control, no insect control; 3 = no weed control, with insect control; and 4 = no weed and insect control. Santa Rita, Jaen, Nueva Ecija, Philippines, 1986 DS.

ments were weed control, with and without insect control; and no weed control, with and without insect control. Weeds were controlled using 0.75 kg butachlor/ha at 10 DAS followed by (fb) 0.5 kg MCPA/ha at 40 DAS. Insect control was carried out by applying monocrotophos at 0.75 kg/ha at 10, 16, 24, 31, and 41 DAS fb chlorpyrifos at 51, 61, and 71 DAS.

Although the percentage of whiteheads was significantly higher in treatment 4 (no weed or insect control) than in treatment 1 (weed and insect control) or treatment 3 (no weed control with insect control), SB infestations at this level (<2%) did not affect yields (Fig. 8). However, plots with the lowest weed weight (although not significantly lower) produced significantly higher grain yields. Thus, it is likely that the presence of weeds was the major factor in reducing yields.

Sampling methods for predators (*Entomology*). Populations of three species of predatory orthopterans were monitored in fields near Nueva Ecija to compare sweep net and vacuum sampling (D-Vac) techniques. The sample unit was five sweeps for the sweep net, and the hill for vacuum sampling. During each sampling, 50 samples were taken with the vacuum sampler and 20 with the sweep net.

Results from sampling the predators (*Anaxipha* sp., *Conocephalus longipennis*, and *Metioche vittaticollis*) are shown in Figure 9. Both sampling techniques detected the major population peak of *M. vittaticollis* at 77 d after transplanting (DT), but sweep net sampling produced overall greater mean numbers with a lower coefficient of variability. *Anaxipha* sp. was effectively sampled by the vacuum sampler, but sweep net sampling was not able to detect it until very late in the season. Sweep net sampling was appropriate for *C. longipennis* populations, while the vacuum sampler could hardly detect the species.



9. Comparison of vacuum sampling (D-Vac) with sweep net sampling for 3 species of predatory orthopterans. Zaragoza, Nueva Ecija, Philippines, 1986.

It is important to understand the behavior and biology of the target species before appropriate sampling techniques can be developed. These results illustrate the necessity of using more than one type of sampling device for estimating the populations of several species.

Trap crop for green leafhopper and rice tungro virus management (*Entomology*). We tested the concept of using a trap crop as an alternative to intensive chemical control of green leafhopper (GLH). Tungro (RTV)-susceptible IR42 was used as both the trap crop and the main crop. Trap fields had 2, 3, or 4 trap crop border rows, planted 15 d earlier than the main crop, and were sprayed weekly up to 60 DT with cypermethrin at 0.05 kg ai/ha. The main crop in fields with a trap crop was not treated with insecticide. Fields without a trap crop but sprayed with cypermethrin were the treated control; unsprayed fields were the untreated control. Each treatment was replicated four times using a randomized complete block design.

At 65 DT, RTV incidence was significantly higher in the untreated control than in the trap or insecticide-treated fields (Table 3). Relatively more GLH nymphs and adults were recorded in the untreated control. Yield was significantly higher in trap and in insecticide-treated fields than in the untreated control (Table 4). Although the yield was highest in insecticide-treated fields, the cost of cypermethrin applied lowered the net gain from the yield.

We can thus divert GLH to a trap crop, where it can be destroyed with an insecticide. Besides the significant gain in yield and saving of insecticide, the restricted use of insecticide conserves the pest's natural enemies.

Yield loss to rice bug (*Entomology*). We evaluated rice bug (RB) *Leptocorisa* sp. damage in IR36 in 1.5- × 1.5-m plots covered with net cages during infestation from flowering to harvest. At 10 RB/m^2, yield was reduced by 12% by initial infestation of either eggs, nymphs, or adults (Fig. 10). Yield loss ranged from 49 to 70% with infestation of 225 nymphs/m^2 or adults/m^2, and was 29% with egg infestation. The F_1 of nymphs and adults caused additional damage to the crop. Yield reduction was caused mainly by unfilled grains.

Table 3. RTV incidence at 65 DT in ricefields with and without a trap crop.[a] IRRI, May-Sep 1986.

Treatment[a]	Date planted	Proportionate area (ha)	Proportionate RTV incidence[b] (%)	Combined RTV incidence (%)
TC 2	9 May	0.074	0.3	8.5 b
MC	23 May	0.926	8.2 b	
TC 3	9 May	0.109	0.5	7.5 b
MC	23 May	0.891	7.0 b	
TC 4	9 May	0.144	0.5	5.2 b
MC	23 May	0.856	4.7 b	
Treated control	9 May	1.000	6.4 b	6.4 b
Untreated control	23 May	1.000	36.8 a	36.8 a

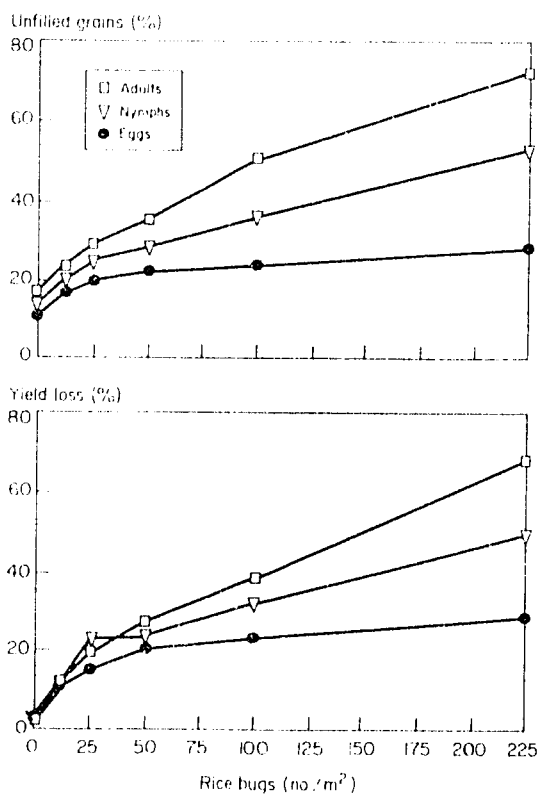
[a]TC = trap crop, MC = main crop. Number following TC is the number of rows of the trap crop in trap fields. [b]Not analyzed in TC.

Table 4. Comparative value of yield after deducting cost of cypermethrin applied in ricefields with and without trap crop. IRRI, May-Sep 1986.

Treatment	Proportionate area (ha)		Combined yield (t/ha)	Value of yield[a] ($/ha)	Cypermethrin applied[b] (liters/ha)	Cost of treatment[c] ($/ha)	Value of yield less cost of treatment ($/ha)
	TC	MC					
2 TC,MC	0.074	0.926	4.5 a	787.50	0.592	14.21	773.29 a
3 TC,MC	0.109	0.891	4.2 a	735.00	0.872	20.93	714.07 a
4 TC,MC	0.144	0.856	4.4 a	770.00	1.152	27.65	742.35 a
Treated control	0	1.000	4.9 a	857.50	8.000	192.00	665.50 ab
Untreated control	0	1.000	3.3 b	577.50	0	0	577.50 b

[a]US$ = ₱20, cost of palay = $0.175/kg. [b]Cypermethrin was applied 8 times to trap crop rows only and to the treated control fields at 0.05 kg ai/ha during cropping. [c]Cost of treatment includes only cost of cypermethrin applied throughout the cropping; cost of cypermethrin (as of Jul 1986) = $24/liter.

Yield losses in the Philippines (*Entomology*). Yield losses from farmers' field trials were measured as the difference between insecticide-protected and unprotected treatments in 60 crops representing dryland, rainfed wetland, and irrigated environments with traditional and modern varieties. The lowest and highest yield losses were recorded in dryland rice 2% (0.05 t/ha) for traditional and 23% (1.00 t/ha) for modern varieties (MVs) (Table 5). In the rainfed wetland environment, yield losses also were higher with MV than with traditional plant types. Irrigated ricefields planted to MVs experienced an 18% yield loss.



10. Percentage of unfilled grains and yield loss on IR36 damaged by rice bug *Leptocorisa oratorius*. IRRI, 1986.

Losses from MV plant types averaged over all sites were greater than those from traditional types. There was no significant difference between losses in WS and DS at the irrigated sites.

Using the relative percentage of total rice production in the Philippines from 1976 through 1985 in which irrigated wetlands planted to MVs averaged 54% of total production and rainfed wetlands with MVs another 29%, we calculated a weighted overall yield loss from insects to be 18.7% (0.57 t/ha) for 1976-86.

A consistent trend in magnitude of loss by growth stage, averaged over sites, emerged between rice environments (Table 6). The greatest relative yield loss occurred in the vegetative phase (50%), followed by that in the reproductive (30%) and ripening (20%) phases. This is significant because, in the vegetative phase, dryland and wetland rice are attacked by quite different pest guilds. Dryland vegetative pests remove seed, feed on roots and root sap, and kill young tillers. Wetland pests remove foliage, injure developing growing points, and kill tillers. Greater compensation from insect injury : the vegetative phase may not occur.

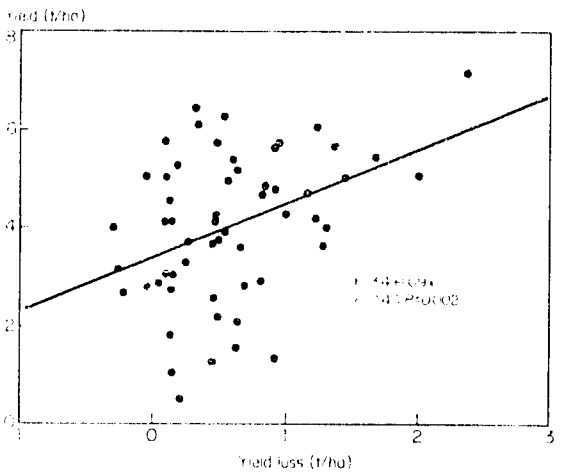
Correlations of insect abundance and yield loss among the sites showed very significant relation-

Table 5. Yield losses determined from the insecticide check method in farmers' fields in 3 rice environments and 2 plant types. Philippines, 1976-86.

Environment	Plant type	Sites (no.)	Crops (no.)	Yield (t/ha)		Yield loss	
				Protected	Check	t/ha	%
Dryland	Traditional	1	5	2.90	2.85	0.05	2
	Modern	2	5	4.20	3.21	1.00	23
Rainfed wetland	Traditional	2	5	2.21	1.83	0.38	18
	Modern	3	12	3.74	3.03	0.71	21
Irrigated	Modern	5	33	3.86	3.29	0.57	18

Table 6. Yield loss from insect pests measured by crop growth stage in 3 rice environments and 2 plant types. Philippines, 1976-86.

Environment	Plant type	Proportion of yield loss (%)		
		Vegetative	Repro-ductive	Ripening
Dryland	Traditional	61	20	19
	Modern	48	35	18
Rainfed wetland	Traditional	56	28	16
	Modern	44	33	23
Irrigated	Modern	43	33	24
	$\bar{X}$ =	50	30	20



11. Relationship between yield loss and yield in 60 crops representing 10 sites and 3 rice environments with traditional and modern cultivars. Philippines, 1976-86.

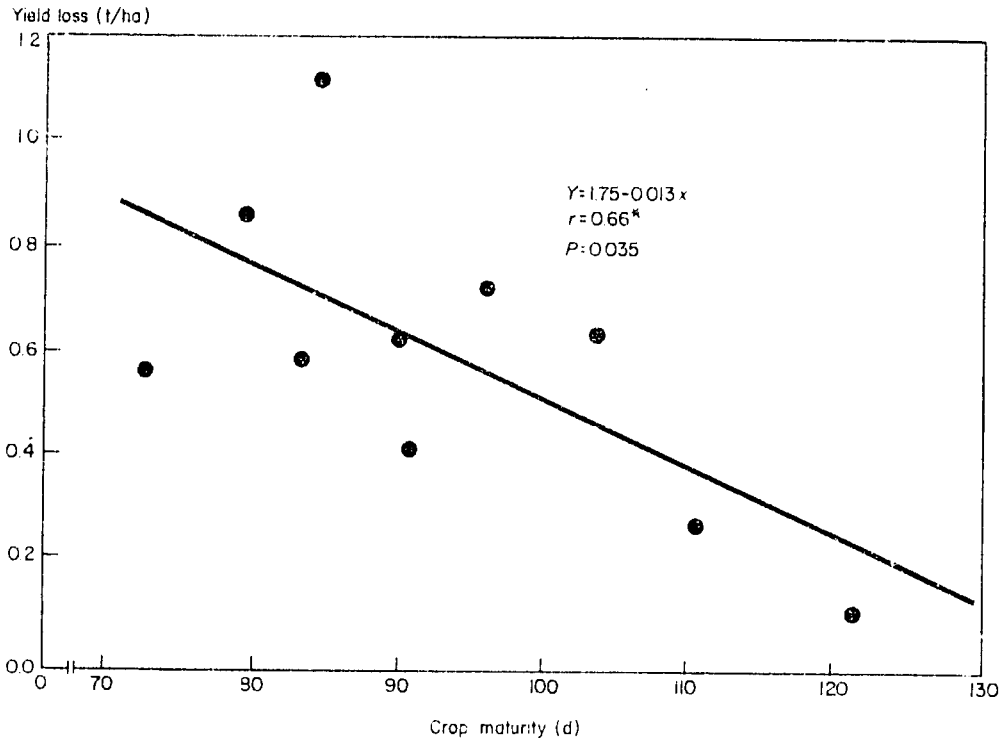
ships, leading us to look for other explanatory factors. This result is consistent with findings on other cereals worldwide.

There was a highly significant but very weak ($r = 0.40^{**}$) positive relationship between the magnitude of yield loss and yield measured over the 60 crops (Fig. 11). Higher yield losses were only partially explained by higher yield. However, a trend emerged in the 3 environments with a highly significant positive correlation in the drylands ($r = 0.81^{**}$), significant correlation in the rainfed wetlands ($r = 0.56^{*}$), but insignificant correlation in the irrigated environment ($r = 0.33$ ns).

In the drylands, high yield losses were associated with high yields, but for the irrigated area the results involved only two sites. With five sites, yield loss was not correlated with yield. The degree of correlation may become weaker with more sites.

Yield losses were negatively correlated ($R^2 = -0.44^{*}$) with the average maturity of the cultivars grown at each site (Fig. 12). Only transplanted crops were compared, and maturity was measured in DT. Difference in maturity among cultivars was almost 50 d. The traditional photoperiod-sensitive cultivars matured latest, being adapted to rainfed wetland environments. The very early modern cultivars IR36 and IR58 matured soonest and were chosen for this trait by farmers using expensive electric pumps. Lower yield loss in longer-maturing crops is explained by compensation. Early-maturing rices have less time to compensate for pest damage, while longer-maturing cultivars can photosynthesize and tap energy reserves to overcome the detrimental effects of pest injuries.

High explanatory correlations between insect abundance and yield loss have been consistently found only when single insect species were studied on a crop that was otherwise stress-free. But the same level of insect abundance can produce a loss in one year and none in the following year.



12. Relationship between yield loss and crop maturity at 10 sites and in 2 rice environments with traditional and modern cultivars. Philippines, 1976-86.

Previous trials have shown a synergistic effect on a particular growth stage if several insect pests, each below a damaging level, infest rice. Each additional insect species damaging the crop lowers the plants' ability to compensate, particularly if the added pest affects a different physiological growth process.

This hypothesis can be extrapolated beyond insect pests to embrace other crop stresses: diseases, weeds, soil disorders, infertility, drought, and flooding.

Most stresses damage a vigorously growing crop more than a weak one. With few exceptions, insects, diseases, weeds, soil toxicities, and infertility cause greater yield loss to a vigorous crop. On the other hand, drought, thrips, termites, mealybugs, and narrow brown leaf spot cause relatively greater yield loss in a poorly growing crop.

The cultivar is another important variable. Traditional indicas tolerate wetland stresses better than do modern high yielding indicas. Japonicas tolerate dryland stresses more than do indicas. Cultivars adapted to the environment in question and managed so as to prevent such stresses as drought can better compensate for insect damage. Insecticide usage could perhaps be replaced by an application of Zn or an additional hand weeding.

Tolerant cultivar, pathogen, and neem oil against black bug (*Entomology*). We evaluated the efficacy of integrating the tolerant cultivar IR13149-71-3-2, the pathogen *Metarhizium anisopliae*, and the Electrodyn formulation of neem oil against the black bug in farmers' fields at three sites in Palawan. Simultaneously, we evaluated *M. anisopliae* and neem oil for protecting susceptible IR64 against the pest.

Black bug infestation was significantly lower in plots sprayed every 2 wk with neem oil than in control plots at the 3 sites (Table 7). Yields were significantly higher in plots sprayed with neem oil than in control plots, irrespective of whether the cultivar was tolerant or susceptible. A single spray of *M. anisopliae* was not enough to protect the

Table 7. Efficacy of integrating a susceptible (IR64) or tolerant (IR13149-71-3-2) cultivar, an insect pathogen, and an Electrodyn formulation of neem oil against black bug.[a] Malinao, Palawan, Philippines, Apr-Sep 1986.

Treatment	Bugs[b] (no./10 hill)					Egg parasitization (%)	Unfilled grains (%)	Yield (t/ha)
	30 DT	45 DT	60 DT	75 DT	90 DT			
				IR64				
M. anisopliae (MA)	1 a	82 b	60 ab	41 b	47 ab	6.8 a	65 b	1.03 b
Neem oil	0 a	48 a	45 a	24 a	24 a	4.4 a	53 a	1.49 a
MA and neem oil	0 a	103 bc	84 b	33 b	50 b	5.6 a	63 bc	1.07 b
Untreated control	1 a	145 c	84 b	73 c	55 b	7.0 a	66 b	0.92 b
				IR13149-71-3-2				
MA	0 a	89 b	79 ab	49 a	57 ab	8.2 a	46 c	1.66 b
Neem oil	0 a	51 a	48 a	35 a	40 a	5.1 a	30 a	2.34 a
MA and neem oil	0 a	83 b	90 ab	58 a	58 ab	8.3 a	40 b	1.89 b
Untreated control	0 a	136 c	125 b	84 b	73 b	10.2 a	49 c	1.98 b

[a] Av of 3 replications. [b] DT = days after transplanting.

crop from black bug damage. Egg parasitization was low and was not adversely affected by the treatments.

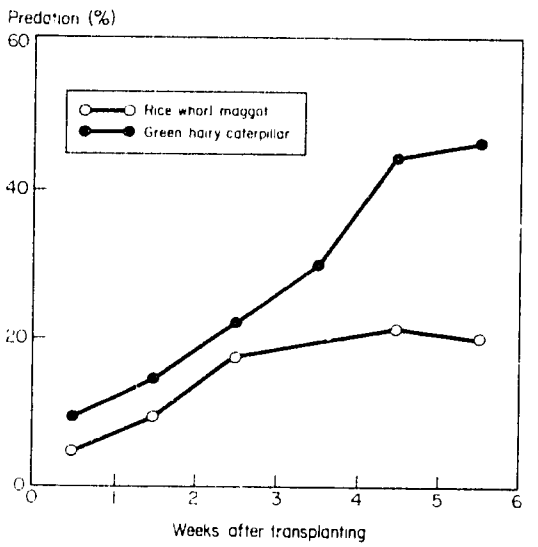
BIOLOGICAL CONTROL

Entomology Department

Impact of predators on eggs of insect pests. The impact of indigenous predators was assessed at two field sites. Hills of rice (n = 50/wk) were collected each week from fields and brought to the greenhouse. RWM and green hairy caterpillar (GHC) adults were allowed to oviposit on the plants. Plants with eggs of the pests were returned to the field and then examined for missing eggs 3 d later.

In general, predation of RWM increased as the season progressed, and was about 20% in the last 2 wk of sampling (Fig. 13). For GHC, predation increased each week and leveled off at about 45% after 6 wk. Parasitization of the eggs of both species was almost nondetectable. Clearly, indigenous predators are the major mortality factors on the eggs of these species.

Predation by *Cyrtorhinus lividipennis* and *Microvelia douglasi atrolineata* on brown planthopper. Predation by *C. lividipennis* increased with increasing BPH egg density, which ranged from 17 to 166/cage. One *Cyrtorhinus* adult attacked 4.4 eggs each day when egg density was 17/cage. This attack rate increased to 7.6 when 115



13. Predation by indigenous predators on RWM and GHC eggs in the field. Laguna, Philippines, 1986.

BPH eggs were available. No increase in predation was noted at BPH densities higher than 115/cage.

Interactions of two or more predator species are common in the field. Some predator species utilize the less important ones as food, thereby ensuring that major predators are abundant when fields are colonized by insect pests.

Spiders are generalist predators that attack both pests and beneficial insects, depending on their relative availability. The wolf spider *Lycosa*

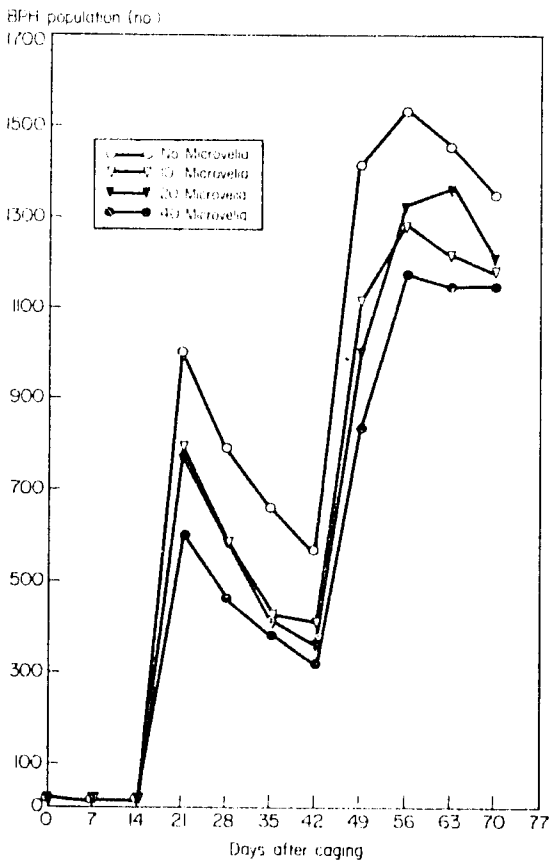
pseudoannulata consumed about three *Cyrtorhinus* predators a day when no other prey was available in mylar cages over rice plants in the insectary.

Other laboratory tests with *T. pseudoannulata* revealed that LF *Cnaphalocrocis medinalis* larvae can escape predation by hiding inside folded leaves a few hours after hatching. Only about 25% of the LF larvae were attacked and killed by spiders when the larvae were allowed 4 h to fold leaves around themselves. However, when prey and predators were released simultaneously, spiders attacked over 85% of the LF larvae.

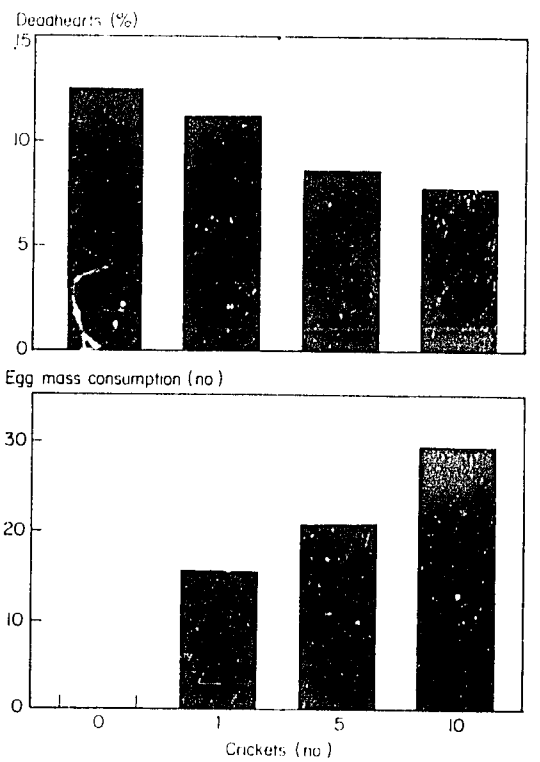
Studies of BPH predation by *M. douglasi atrolineata* were conducted in the laboratory for 70 d, allowing observations on the influence of the predator on BPH population buildup. Predator densities were 0, 10, 20, and 40 per cage. Initial BPH density was 20/cage. *Microvelia* suppressed the population growth of BPH, especially at higher predator densities (Fig. 14). However, at the predator densities used in this study, *Microvelia* would not be able to control BPH.

Cricket predation on stem borer eggs. Gravid striped stem borers (SSBs) were caged with 45-d-old IR1917 rice plants for 24 h to allow for oviposition. Plants with known densities of SSB egg masses (2, 4, and 6 per cage) were placed in a field with plants of the same age in 1-m^2 fiberglass screened cages. Egg masses were exposed to adult female crickets *Metioche vittaticollis* at 1, 5, or 10 per cage. Plants inside the cages were checked daily, and records were made of missing egg masses and SSB damage to the plants.

Deadheart percentage decreased as the density of crickets and their consumption of egg masses increased (Fig. 15). Thus, *M. vittaticollis* is an important predator of SSB, which may help to explain why SSB is not a dominant species on the IRRI farm.



14. Influence of densities of the veliid predator *Microvelia douglasi atrolineata* on population buildup of the brown planthopper (BPH). IRRI greenhouse, 1986.



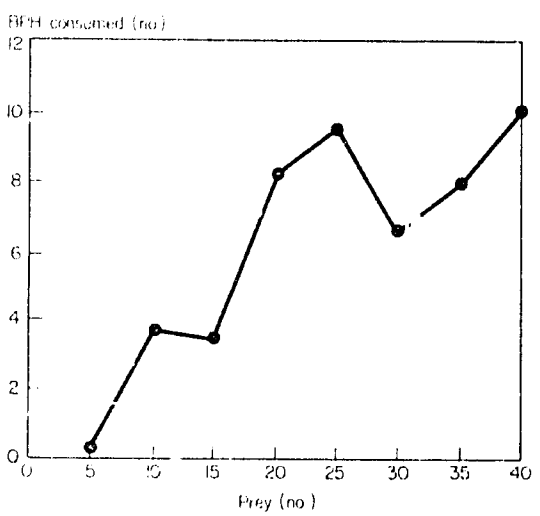
15. Percentage of deadhearts from the striped stem borer in relation to density of the predatory cricket *Metioche vittaticollis*. IRRI, 1986.

Predation by *Conocephalus longipennis* on brown planthopper and green leafhopper. BPH and GLH adults were exposed in 10- × 47-cm mylar cages to the predatory grasshopper *C. longipennis* in the laboratory. Densities of BPH and GLH per cage were 5, 10, 15, 20, 25, 30, 35, and 40. Hoppers consumed were counted after 24 h.

The number of BPH adults attacked and eaten by the grasshoppers increased as the prey density increased (Fig. 16). The same general trend was observed on GLH (Fig. 17). Over 10 BPH and GLH were consumed per day at the highest densities. This common grasshopper is clearly an important predator, but its importance has been largely overlooked.

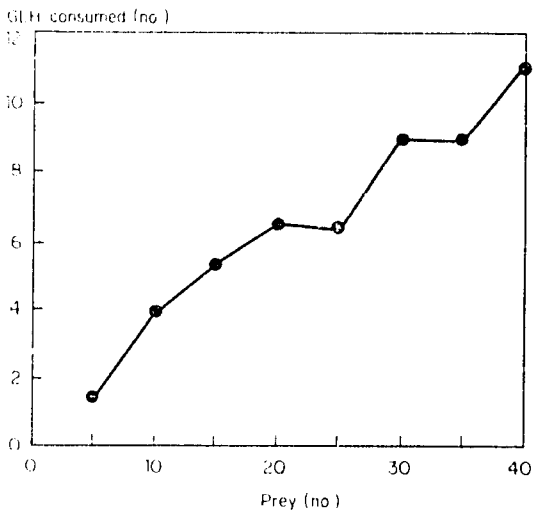
Predation by orthopterans on leaffolder eggs. Adult females of each of three species of orthopteran predators — *M. vittaticollis*, *Anaxipha* sp., and *C. longipennis* — were caged in the insectary with 45-d-old TN1 potted rice plants, each containing 30 newly laid LF eggs. The number of eggs consumed by each predator was recorded every 24 h for 3 d.

The predatory orthopterans reduced the number of LF eggs from 30 to about 25 in 3 d. The crickets *M. vittaticollis* and *Anaxipha* sp. consumed slightly more eggs than the grasshopper *C. longipennis*, especially on the second day of caging (Fig. 18).

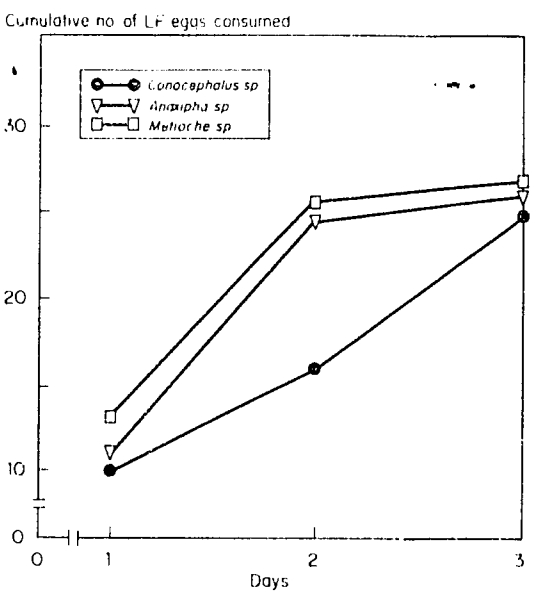


16. Predation by the grasshopper *Conocephalus longipennis* on adult BPH at different densities in cages in the insectary. IRRI, 1986.

Predator-predator interaction. Most arthropod predators are generalists, feeding on a range of prey including other predators. This not only helps to regulate the numbers of certain predators — which become prey at certain times — but ensures that some species of predators are present in a field when pests begin to colonize it.



17. Predation by the grasshopper *C. longipennis* on adult green leafhopper (GLH) at different densities in cages in the insectary. IRRI, 1986.



18. Consumption of leaffolder (LF) eggs by the predatory orthopterans *C. longipennis*, *Anaxipha* sp., and *M. vittaticollis*. IRRI insectary, 1986.

We conducted a test in the insectary to determine the extent of predation by the mirid predator *Cyrtorhinus lividipennis* on eggs of the orthopteran predators *C. longipennis* and *M. vittaticollis*.

Ten pairs of *C. lividipennis* adults were caged with 45-d-old TN1 plants containing eggs of *C. longipennis* and *M. vittaticollis*. The egg predator *C. lividipennis* attacked 18% of the eggs of *M. vittaticollis*, but only 8% of the *C. longipennis* eggs.

Parasitization and predation of the rice leaf-folder *Cnaphalocrocis medinalis* eggs in transplanted and direct seeded rice. At 55 DAS, 5 potted plants, each bearing 25 LF eggs, were exposed in fields of transplanted (TPR) and direct seeded rice. Forty-eight hours after exposure, the plants were collected and brought into the laboratory, and the numbers of eggs attacked by predators were recorded. The remaining eggs were reared in individual tubes.

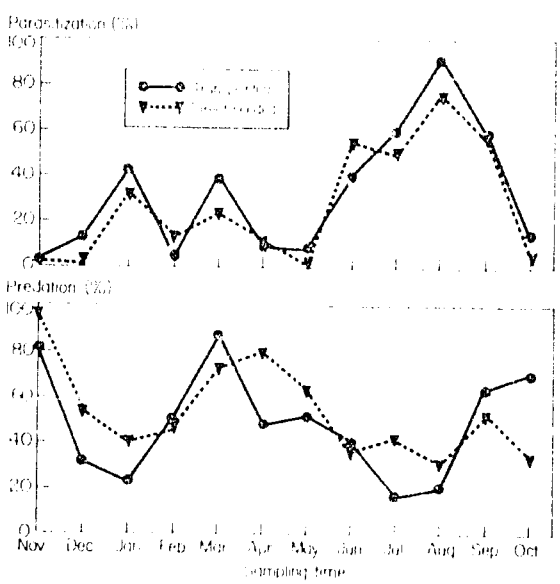
The seasonal incidences of parasitization and predation are shown in Figure 19. The patterns were similar in both TPR and direct seeded rice. The highest levels of predation occurred in November and March-April. Peak parasitization occurred in July-September. Overall, egg parasitization was slightly lower than predation.

The most abundantly occurring egg parasites of *C. medinalis* were *Copidosomopsis nacoliae* and *Trichogramma* spp. (Fig. 20). Peak parasitization by *Trichogramma* was about 80% in direct seeded rice and TPR. Although parasitization by *Copidosomopsis* was always less than 10% in both direct seeded rice and TPR, and while there are slight differences in the action of predators and parasites in the two crop establishment methods, such differences are not likely to be important.

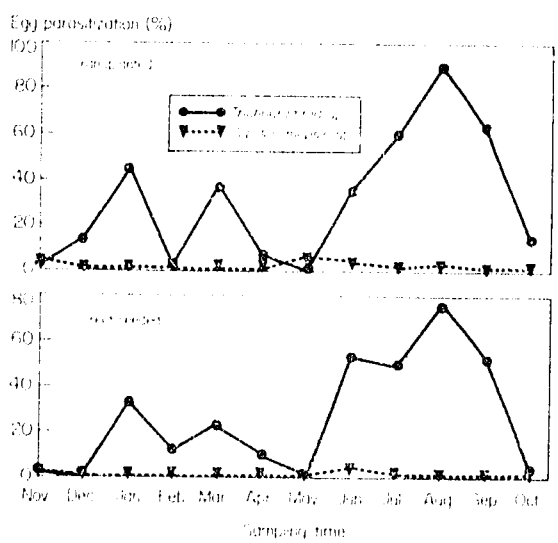
Black bug egg parasitoids. *Parasite with and without female guarding the egg mass.* In an earlier experiment (Annual report for 1985) with a female black bug guarding the egg mass, adult *Telenomus triptus* parasites seemed to be unaffected by the presence of the female host. However, that study was conducted using glass tubes, thereby limiting the space provided for both host and parasite.

We conducted the same study again, plus a separate trial using mylar cages to enclose plants bearing black bug egg masses with and without females guarding them. In mylar cages with egg masses guarded by the female bug, egg mass and egg parasitization was higher than with unguarded egg masses (Table 8). Because parasite searching was required in the larger cages, the presence of the female bug may provide an olfactory cue for the parasite to better locate the egg mass.

Competition among five species of black bug egg parasites. We introduced one gravid female of each of five parasitoid species (*Telenomus triptus*, *T. cyrus*, *Trissolcus basalis*, *Psix lacunatus*, and



19. Percentage of parasitization and predation of eggs of rice LF *Cnaphalocrocis medinalis* in transplanted and direct seeded rice, IRRI, 1985-86.



20. Parasitization of LF *C. medinalis* eggs in transplanted and direct seeded rice, IRRI, 1986.

Table 8. Parasitization of black bug *Scotinophara coarctata* eggs in the laboratory using test tubes and mylar cages with and without a female bug guarding the egg mass, Palawan, Philippines, 1986.

Parasitoid	Parasitization[a] (%)			
	Test tube		Mylar cage	
	Egg mass	Egg	Egg mass	Egg
T. triptus alone	95.0	77.0	15.3	3.8
T. triptus + female black bug	95.0	76.0	66.6	23.0

[a] Av of 20 replications.

T. chloropus) into mylar cages with potted plants bearing one egg mass guarded by a female black bug. After 24 h the egg masses were removed and held until the parasites emerged. *T. triptus* parasitized over 90% of the eggs, followed by *T. cyrus* and the other species, which parasitized <10%.

Effect of location of Scotinophara latiuscula *egg masses on the host-finding ability of egg parasitoids. S. latiuscula* egg masses (6 eggs/mass) were glued at the bottom of the stem, in the middle, and at the upper portion of rice plants. The plants were then enclosed in mylar film cages, and one gravid female of each of four species of parasitoids was released inside the cage. After 24 h, egg masses were removed and placed individually in tubes until parasite emergence (n = 202).

No significant differences in the degree of parasitization occurred among locations of egg masses on the plant. However, *T. cyrus* parasitized more eggs at all locations than did the other parasitoid species. *Psix lacunatus* was next in abundance. These two species are indigenous parasites of *S. latiuscula* black bugs in Laguna, Philippines.

Natural parasitization of black bug *Scotinophara coarctata* eggs in Palawan, Philippines. Egg masses of black bug were collected from October 1984 to December 1986 in heavily infested ricefields in Aborlan and Narra, southern Palawan, and in Roxas, northern Palawan. The egg masses were placed individually in glass tubes plugged with cotton and brought to the laboratory for parasite emergence.

A total of 68,753 eggs (1,746 egg masses) were collected in Aborlan and Narra. Egg parasitization was 23.4%, but 62.3% of the egg masses were parasitized.

Collection in December 1986 in Roxas yielded 447 egg masses with 20,864 eggs. Parasitization of egg masses was 86%; that of eggs was 27%.

Biological control-resistant plant interaction. A greenhouse study was conducted to determine the effect of the combined action of resistant plants and the predator *Cyrtorhinus lividipennis* on BPH survival. The mortality of first-instar BPH biotype 3 nymphs on susceptible TN1 and resistant Mudgo varieties with and without predators was measured. Without the predator, mortality was 9% for the susceptible variety and 15% for the resistant. When *C. lividipennis* was added, mortality increased to about 37% on the susceptible variety and 41% on the resistant.

Insect pathogens. *Collections and cultures.* Several new and rare fungi were collected and isolated from rice insects, and epizootics in pest populations were observed. Fungi isolates are preserved in the IRRI Entomology Department's "Collection of Pathogens of Rice Insects." The new collections include *Metarhizium flavoviride* Gams and Rozsypal, which, with *M. anisopliae* (Metschn.) Sorokin and the common species *Hirsutella citriformis* Speare, is predominant on BPH and other rice hoppers in the Philippines. The new fungus *M. flavoviride* var. *minus* Rombach, Humber, and Roberts was introduced.

Also, the rare fungus *Metarhizium album* Petch was collected from planthoppers and leafhoppers. *M. album* is becoming common on GLH in the Philippines. In Indonesia, it was collected from *Cofana spectra* on Sulawesi.

New *Hirsutella* and *Cordyceps* species were collected from leafhoppers in Indonesia and from BPH in Korea. *Aphanocladium* sp. was predominant on BPH and the smaller BPH in Korea. During recent years, *Hirsutella strigosa* Petch commonly occurred on GLH and BPH in the IRRI insectary and on the IRRI farm. The mycoparasite *Calcarisporium ovalisporum* Petch was collected on *H. citriformis* in the Solomon Islands.

Cultures of all established species and varieties are in the IRRI collection.

Dry mycelium of entomogenous Hyphomycetes was mass produced in the laboratory. The mycelium, which was applied in the field, sporulated on the rice plant and the conidia

subsequently infected the insects. *M. anisopliae* was field tested for control of BPH in the Philippines (Fig. 21).

Bacillus thuringiensis, *a microbial insecticide*. Over 300 local isolates of *Bacillus thuringiensis* (Bt) have been collected from soil by the Institute of Biotechnology and Applied Microbiology of UPLB. The isolates were screened in the laboratory against lepidopterous rice pests with the goal of identifying toxic ones that could be produced on a commercial scale by local companies and sold at low cost to rice farmers.

Test larvae were fed leaves dipped in a 100-ml water suspension of 1-2 wire loopfuls of bacteria removed from agar cultures. Toxicity was determined after 6 d.

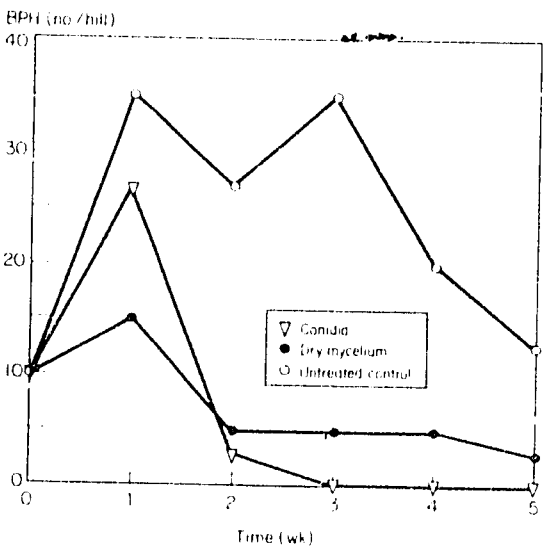
Indigenous strains were toxic to all six of the foliage-feeding rice pests tested (Table 9). GHC was susceptible to 150 strains (53%), the green semilooper to 93, the caseworm to 72, and LF to 71. SB was susceptible to the fewest strains.

Bioassay of entomopathogenic fungi. Bioassays of several species of fungi that attack BPH were carried out in collaboration with the Rural Development Administration, Korea. Conidia of the fungi were produced on standard mycological media in 12-liter "bubbler" fermentors.

Fungal species and rates of application were as follows: *Metarhizium anisopliae* (strain D2-4), 7.5×10^{12} conidia/ha; *M. flavoviride* (strain M-12), 4.0×10^{12} conidia/ha; *Beauveria bassiana* mycelium (strain E), 1000 g/ha; *B. bassiana* conidia (strain E), 7.5×10^{12} conidia/ha; *B. bassiana* (strain *Phassus*), 7.7×10^{10} conidia/ha; *B. bassiana* conidia (strain Elaterid), 5.2×10^{10} conidia/ha; and *Paecilomyces farinosus* (strain *H. cunea*), 4.3×10^{11} conidia/ha.

The material was applied to rice plants. Then 20 two-day-old BPH were caged on the plants. Mortality was tabulated after 7 and 14 d.

The low mortality after 7 d increased significantly after 14 d (Table 10). Mortality in all



21. *Metarhizium anisophae* (conidia and dry mycelium) for BPH control in the Philippines. Victoria, Laguna, Philippines, 1986.

Table 9. Screening of 300 isolates of *Bacillus thuringensis* for toxicity to lepidopterous pests of rice. IRRI, 1986.

Insect pest	Isolates[a]	
	Screened (no.)	Toxic (%)
Green semilooper *Naranga aenescens*[b]	287	34
Green hairy caterpillar *Rivula atimeta*[b]	285	53
Leaffolder *Cnaphalocrocis medinalis*[c]	276	26
Caseworm *Nymphula depunctalis*[c]	265	27
Striped stem borer *Chilo suppressalis*[c]	181	3
Yellow stem borer *Scirpophaga incertulas*[c]	55	13

[a] n = 20 in 2 replications of 10 3d-instar larvae each. [b] One loopful of Bt isolate in 100 ml water. [c] Two loopfuls of Bt.

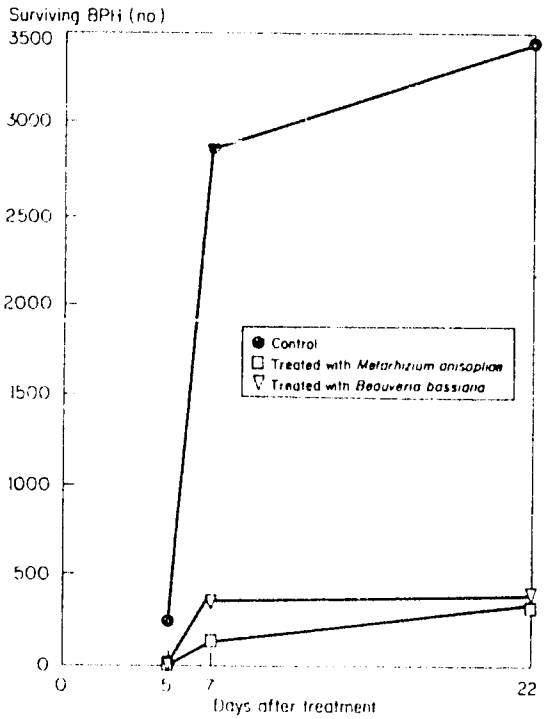
Table 10. Bioassay of entomogenous fungi against BPH in Korea. Suweon, Korea, 1986.

Isolate[a]	BPH mortality[b] (%)	
	7 DAT	14 DAT
M. anisopliae D2-4 conidia	16 bc	34 d
M. flavoviride M-12 conidia	19 bc	33 d
B. bassiana strain E mycelium	39 a	50 bcd
B. bassiana strain E conidia	25 b	41 cd
B. bassiana strain *Phassus* conidia	15 bcd	68 ab
B. bassiana strain elaterid conidia	6 cd	58 abc
P. farinosus strain *H. cunea* conidia	25 b	74 a
Untreated	1 d	4 d

[a] *Metarhizium flavoviride* (M-12) from the Philippines, *Beauveria bassiana* E from BPH in China; *M. anisopliae* (D2-4), *B. bassiana* (*Phassus*, elaterid), and *Paecilomyces farinosus* (*H. cunea*) from Korea. [b] Av of 4 replications. DAT = days after treatment.

treatments was significantly greater than in the control.

Results from companion field experiments conducted in Korea substantiated the results from the laboratory bioassays. Application of conidia from *B. bassiana* caused significantly greater BPH mortality than treatment with conidia from *M. anisopliae* (Fig. 22).



22. Response of a field population of BPH to treatment with entomogenous fungi. Korea, 1986.

CHEMICAL CONTROL

Entomology Department

Botanical pesticides. *Neem seed kernel extract vs brown planthopper, whitebacked planthopper, and green leafhopper.* A simple procedure was developed for extracting neem seed "bitters" (limonoids) as a crystalline powder that is water soluble, relatively photostable, and nonphytotoxic. Only 10-20% first-instar nymphs of BPH, WBPH, and GLH reached the adult stage when caged on rice plants sprayed with a 500 ppm solution of this neem seed kernel extract (NSKE) (Table 11). Nymphs died at concentrations ≥ 2500 ppm. NSKE residual activity persisted on treated plants kept outdoors for 6 d. Soaking rice seedling roots in NSKE solution also disrupted the growth of GLH nymphs, indicating systemic action (Table 12). A similar effect on the growth and development of BPH, WBPH, and GLH nymphs was observed when they were caged on rice plants grown in soil treated with NSKE (Fig. 23). The fecundity of BPH, WBPH, and GLH females was markedly reduced on NSKE-treated plants. The increase of

Table 11. Growth and development of 1st- instar BPH, WbPH, and GLH nymphs on TN1 rice plants sprayed with neem seed kernel extract (NSKE).[a] IRRI, 1986.

Days after spraying	Nymphs becoming adults (%) at each concentration (ppm)					
	0	100	500	2,500	5,000	10,000
			BPH			
0	82 b A	82 ab A	23 b B	0 d C	0 cC	0 b C
2	93 a A	82 ab A	78 a B	33 c C	2 cD	0 b D
4	87 ab A	77 b A	82 a A	60 b B	33 b C	0 b D
6	90 ab A	90 a A	85 a A	82 a A	62 a B	17 a C
			WBPH			
0	87 a A	90 a A	28 b	7 c B	0 b B	0 a B
2	92 a A	93 a A	58 a	25 b B	0 b C	0 a C
4	90 a A	85 a A	78 a	48 a B	3 ab C	2 a C
6	92 a A	87 a AB	73 a	30 b C	13 a C	2 a D
			GLH			
0	93 a A	85 a B	10 b C	0 c C	0 b C	0 a C
2	92 a A	93 a A	83 a A	2 c B	0 b B	0 a B
4	93 a A	87 a A	88 a A	17 b B	3 b C	0 a C
6	92 a A	90 a A	87 a A	60 a B	17 a C	0 a D

[a] In a column, means followed by a common lowercase letter are not significantly different at the 5% level by DMRT. In a row, means followed by a common uppercase letter are not significantly different at the 5% level by DMRT. Av of 6 replications, 10 1st-instar nymphs per replication.

Table 12. Growth and development of 1st-instar GLH nymphs on rice seedlings root-soaked in NSKE,[a] IRRI, 1986.

Dosage[b] (ppm)	Nymphs becoming adults (%)	Growth period (d)	Growth index[c]
0 (control)	90 b	16 b	5.7 c
100	57 b	16 b	3.5 b
1000	13 a	6 a	0.8 a
5000	0 a	0 a	0 a

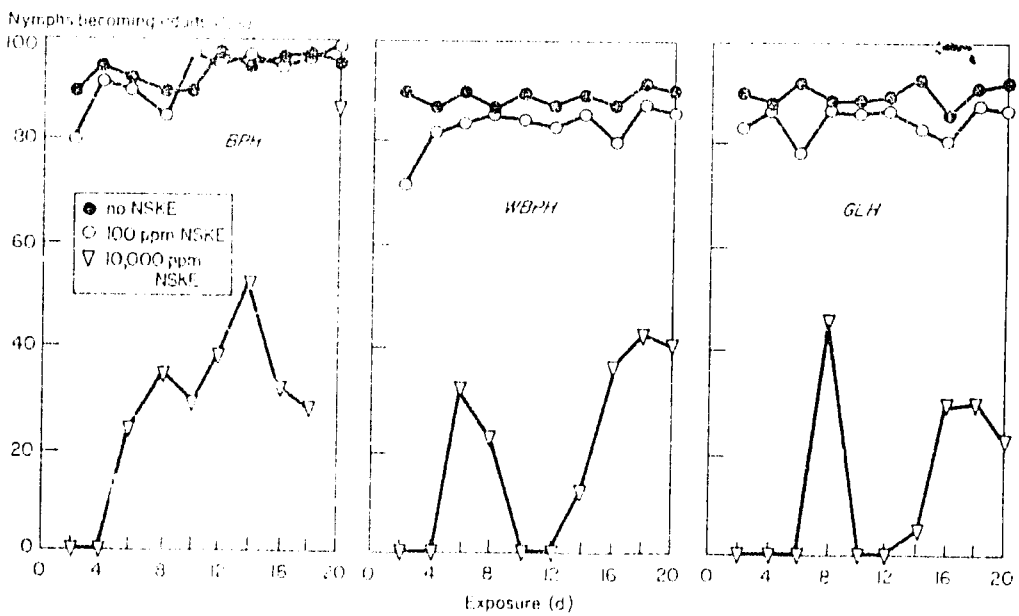
[a]Av of 3 replications, 10 1st-instar nymphs per replication. [b]Batches of 150 fourteen-day-old TN1 seedlings were soaked separately in different concentrations of NSKE. [c]Growth index = percentage of nymphs becoming adults/mean developmental period (d).

planthopper and leafhopper populations was negligible on NSKE-treated plants, in contrast to the population increase on untreated controls (Fig. 24).

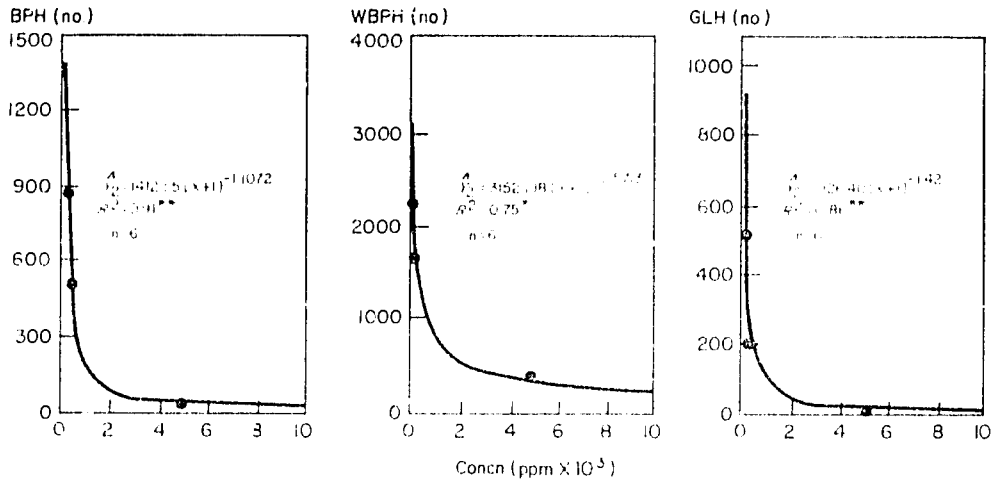
Effect of neem oil and neem seed kernel extract on brown planthopper mating. Neem seed derivatives are known to affect insect behavior and physiology. We tested the effect of neem oil and NSKE on BPH mating behavior. Fifteen newly emerged females were treated topically with 1, 2.5, or 5 μg NSKE or neem oil in 0.2 μl of acetone-water solution (for NSKE) or acetone (for neem oil). Control females were treated with acetone-water or acetone. Two days later, each female was paired singly with a responsive male on a 30-d-old TN1 plant to which was attached a single-needle-type ceramic cartridge. Mating signals emitted by both sexes were recorded and fed to a direct current chart recorder.

In controls, the males emitted 2- to 3-s-long "croaking" signals, to which females responded with 15- to 35-s "drumming" sounds (Fig. 25a). Copulation was completed after 6-10 min of characteristic alternate mating calls. The NSKE- or neem oil-treated females produced an initial 3- to 10-s-long signal (Fig. 25b), followed by extremely prolonged signals which lasted up to 65 s (Fig. 25c). Female signals were interspersed with faint male croaking sounds. Mating calls continued for more than 30 min without successful copulation. The initial female signal that prompted the male to initiate mating was altered in NSKE- or neem oil-treated females. This delayed or disrupted mating, as evidenced by repeated prolonged female calls. Hatchability of eggs was reduced to 76% in females treated with 5 μg of neem oil.

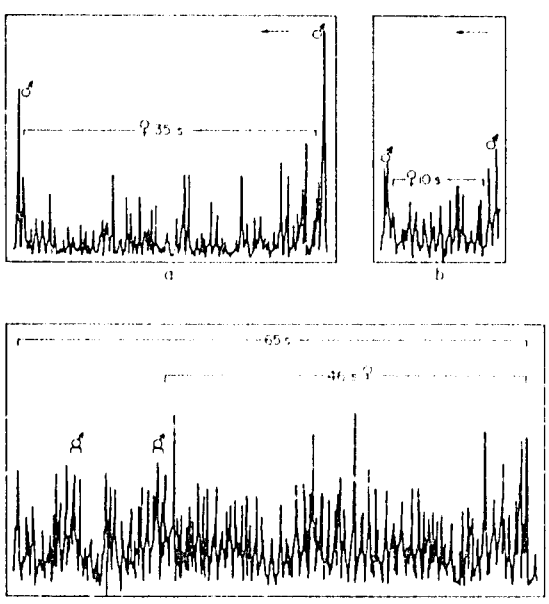
Effect of neem seed kernel extract on brown planthopper reproductive potential. The first-generation BPH males emerging on rice plants sprayed with 100 or 500 ppm NSKE solution had significantly lower frequencies of meiotic cells than



23. Systemic effect of neem seed kernel extract (NSKE) on the growth of first-instar BPH, whitebacked planthopper (WBPH), and GLH. IRRI, 1986.



24. Population increase in 30 d from 6 pairs of male and female BPH, WBPH, and GLH on NSKE-sprayed plants. IRRI, 1986.



25. BPH mating patterns: control (a) and when female was treated with 5 μg of NSKE (b) or neem oil (c). IRRI, 1986.

Table 13. Frequencies of meiocytes and nonmeiocytes in BPH males reared on plants sprayed with NSKE.[a] IRRI, 1986.

NSKE (ppm)	Nonmeiocytes (no.)	Meiocytes (no.)	Meiotic index
0 (control)	375 a	233 a	0.384 a
100	221 a	82 b	0.278 b
500	273 a	81 b	0.224 b

[a]In a column, means followed by a common letter are not significantly different at the 1% level by the t-test. Av of 10 replications.

the untreated control (Table 13). This may account for the reduced reproduction fitness of BPH individuals observed on rice plants sprayed with neem derivatives.

Effect of neem oil and neem seed kernel extract on a brown planthopper predator. We evaluated the effect of neem seed derivatives on *Cyrtorhinus lividipennis*, a BPH predator. In toxicity tests, the highest dose of 20 μg neem oil caused 83% mortality of BPH adults, but only 26% mortality of the mirid bug (Table 14). The predator's mortality with the same dose of NSKE was negligible. The growth and development of mirid nymphs on rice

Table 14. Mortality of BPH and *C. lividipennis* 24 h after topical application of neem oil or NSKE.[a] IRRI, 1986-87.

Treatment[b] (μg/female)	Mortality (%) Neem oil	NSKE
	BPH	
0 (control)	20 bc	2 d
5	15 bc	18 bc
10	25 b	24 b
20	83 a	55 a
	C. lividipennis	
0 (control)	9 c	11 cd
5	22 bc	15 bc
10	20 bc	11 cd
20	26 b	8 cd

[a]Av of 10 replications, 10 females per replication. [b]For BPH, μg of neem oil/0.2 μl of acetone *or* μg of NSKE/0.2 μl of acetone-water mixture (1:1). For *C. lividipennis*, μg of neem oil/0.1 μl of acetone *or* μg of NSKE/0.1 μl of acetone-water mixture (1:1).

plants sprayed with 10,000 ppm NSKE were not affected (Table 15). However, spray applications of ≥ 6% neem oil considerably reduced the development of mirid nymphs. This reduced viability was due to the failure of BPH nymphs the food source of the predator to survive on neem oil-treated plants. Spraying neem oil or NSKE did not affect the egg predation ability of adult mirid bugs. BPH nymph mortality was significantly higher on plants treated with NSKE and provided with the predator than on untreated control plants or on plants without a predator (Table 16). BPH population buildup on NSKE-treated plants was significantly lower than on the unsprayed control plants or on plants with no predator (Fig. 26). The BPH population was lowest on plants sprayed with NSKE and provided with the mirid bug.

Effect of selected plant derivatives on red flour beetle. Oils of turmeric (*Curcuma longa*), sweet flag (*Acorus calamus*), and neem, and the neem-based insecticide Margosan O were tested for their repellency, insecticidal effect, and growth- and reproduction-inhibiting activity against the red flour beetle *Tribolium castaneum*. During an 8-wk test period, turmeric oil and sweet flag oil showed strong repellency for the first 2 wk, but their repellency decreased thereafter, and faster than that of neem oil or Margosan O (Table 17). Margosan O was the most repellent at 1,000 ppm. Compared with the insecticide check, pirimiphos-methyl 25 EC, the oils, and Margosan O lacked insecticidal effect, but adversely affected the growth and development of *T. castaneum*.

Laboratory evaluation of commercial insecticides. Coded and commercial insecticides were evaluated in the laboratory against BPH, GLH, WBPH, LF, and RB.

Contact toxicity Insecticide effectiveness as contact spray was evaluated using Potter's spray

Table 15. Physiological responses of *C. lividipennis* to neem oil and NSKE treatments.[a] IRRI, 1986.

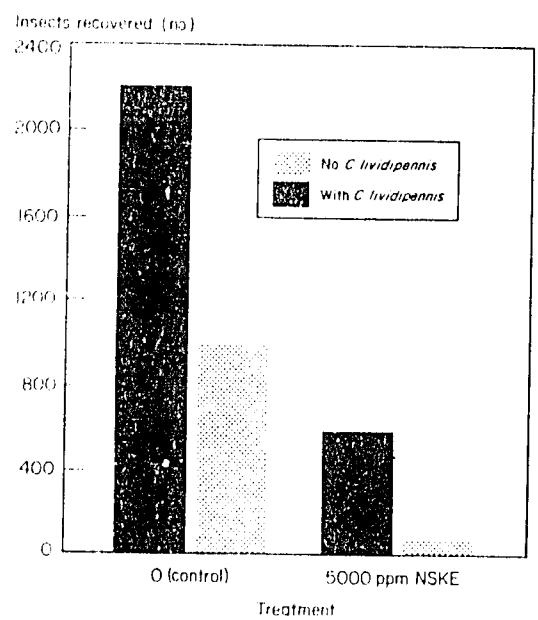
Treatment	Developmental period (d)	Nymphs becoming adults (%)	Growth index
Neem oil (%)			
0 (control)	6.00	96.6 a	16.7
3	6.33	85.0 ab	12.9
6	6.78	55.0 bc	13.5
12	–	0 c	–
25	–	0 c	–
50	–	0 c	–
NSKE (ppm)			
0 (control)	7.15 a	92.0 ab	12.84
100	6.86 a	79.2 abc	13.70
500	7.35 a	96.6 a	13.05
2,500	6.31 ab	66.0 abc	10.17
5,000	5.93 ab	58.4 abc	10.33
10,000	5.13 b	37.2 c	8.85

[a] Av of 5 replications.

Table 16. Mortality of BPH nymphs on NSKE-treated rice plants with or without *C. lividipennis* 10 d after treatment.[a] IRRI, 1986-87.

Concentration (ppm)	Predator[b]	Mortality (%)
0 (control)	+	2.5 d
100	+	2.3 d
500	+	6.5 cd
2,500	+	12.5 bc
5,000	+	18.0 b
10,000	+	16.4 b
0 (control)	–	6.5 cd
100	–	7.0 cd
500	–	8.5 cd
2,500	–	18.6 b
5,000	–	25.2 a
10,000	–	26.1 a

[a] Av of 5 replications. [b] + = present, – = absent.



26. Cumulative increase in BPH population (total from 5 replications) on rice plants treated with NSKE. IRRI, 1986.

Table 17. Repellency of turmeric oil, sweet flag oil, neem oil, and Margosan O to *Tribolium castaneum* adults at different rates of application and time intervals.[a] IRRI, 1986.

Treatment	Rate ($\mu g/cm^2$ paper)	Repellency (%) at given time after treatment			
		1 wk	2 wk	4 wk	8 wk
Turmeric oil	800	92 a	73 a	70 a	51 bc
	400	88 ab	70 a	64 ab	46 b-e
	200	81 cd	60 c	54 d-f	42 de
Sweet flag oil	800	88 ab	75 a	69 a	48 b-d
	400	86 bc	68 ab	60 b-e	45 b-e
	200	79 de	58 c	50 f	40 e
Neem oil	800	80 de	72 a	70 a	59 a
	400	78 de	70 a	63 a-c	54 ab
	200	70 f	60 c	56 c-f	45 b-e
Margosan O	800	78 de	69 a	66 ab	53 a-c
	400	72 ef	61 bc	61 b-d	50 bc
	200	66 f	56 c	52 ef	44 c-e
Control	0	5 g	6 d	2 g	4 f

[a]Av of 4 replications.

tower. Of 11 insecticides and 1 mixture, 2 were effective on BPH, 5 on GLH, and 6 on WBPH (Table 18).

Foliar spray. TN1 plants were sprayed with insecticide and infested with untreated insects in cages 1 d after spraying. Of the 11 insecticides and 1 mixture, 1 was effective on BPH and 4 on GLH (Table 19).

Nine insecticides and two mixtures were evaluated against LF. Monocrotophos, fenpropathrin, and ethoproxyfen were effective at 48 h after caging.

Four insecticides and two mixtures were evaluated against RB. SSI 117 and monocro-

Table 18. Laboratory evaluation of 11 insecticides and 1 mixture by contact toxicity against adult female BPH, GLH, and WBPH. IRRI insectary, 1986.

Insecticide[a]	Formulation	Mortality at 48 HT[b]		
		BPH	GLH	WBPH
	Test 1			
Monocrotophos	30 EC	●	○	●
Sumibas	60 EC			●
Trimethacarb	50 WP			●
Phosphamidon + BPMC	45 + 30 EC			○
Cartap	50 SP			
Mexacarbate	25 WP			●
	Test 2			
Ethoproxyfen	10 EC	○	○	
Fenpropathrin	2.5 EC		●	
Monocrotophos	30 EC		●	○
Fenvalerate	3 EC			
Fenpropathrin	5 EC		○	
Mexacarbate	2 EC		○	○
Thiodicarb	3.2 F			

[a]Insecticides in test 1 and monocrotophos in test 2 were applied at 0.15% ai. All others were applied at 0.01% ai. Spray volume was 2 ml/replication. EC = emulsifiable concentrate, F = flowable, SP = soluble powder, WP = wettable powder. [b]Av of 4 replications, 20 insects/replication. ● = ≥ 80% mortality, ○ = 100% mortality. HT = hours after treatment.

Table 19. Laboratory evaluation of 11 insecticides and 1 mixture as foliar spray against BPH and GLH. IRRI insectary, 1986.

Insecticide[a]	Formulation	Mortality[b]	
		BPH	GLH
		3	3
Monocrotophos	30 EC		○
Sumibas	60 EC		●
Trimethacarb	50 WP	●	○
Phosphamidon + BPMC	45 + 30 EC		●

[a]Applied at 0.75 kg ai/ha except for ethoproxyfen 10 EC, fenpropathrin 2.5 EC, fenvalerate 3 EC, fenpropathrin 5 EC, mexacarbate 2 EC, and thiodicarb 3.2 F applied at 0.05 kg ai/ha. These insecticides, together with cartap 50 SP and mexacarbate 25 WP, produced 80% mortality. Spray volume was 500 liters/ha (3.125 ml/potted plant). [b]Recorded 48 h after infestation at 3, 7, 12, and 17 d after insecticide treatment (DAT). Residual effect did not go beyond 5 d. Av of 4 replications. ● = ≥ 80% mortality, ○ = 100% mortality.

tophos were effective, but their residual effect was less than 5 d.

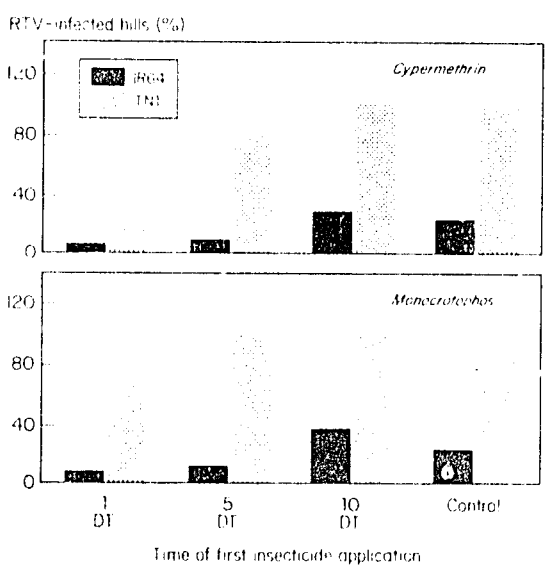
Field evaluation of commercial insecticides. GLH control and RTV prevention were attempted using pyrethroids and conventional insecticides.

Foliar spray for preventing rice tungro virus. Timing of insecticide application considerably affected the incidence of RTV on IR64 and TN1. RTV was significantly lower in IR64 than in TN1 on plots treated with cypermethrin or monocrotophos when the first insecticide application was done at 5 DT (Fig. 27).

More frequent insecticide application resulted in significant differences on the moderately resistant IR42, but not on the highly resistant IR64 or the susceptible TN1 (Fig. 28).

Susceptibility of brown planthopper and green leafhopper to insecticides. BPH macropterous adult females from the field at IRRI were compared with the susceptible greenhouse population. The relative resistance ratios ranged from 1.2 to 1.5, indicating that the BPH field population at IRRI did not show high resistance to the test insecticides (Table 20).

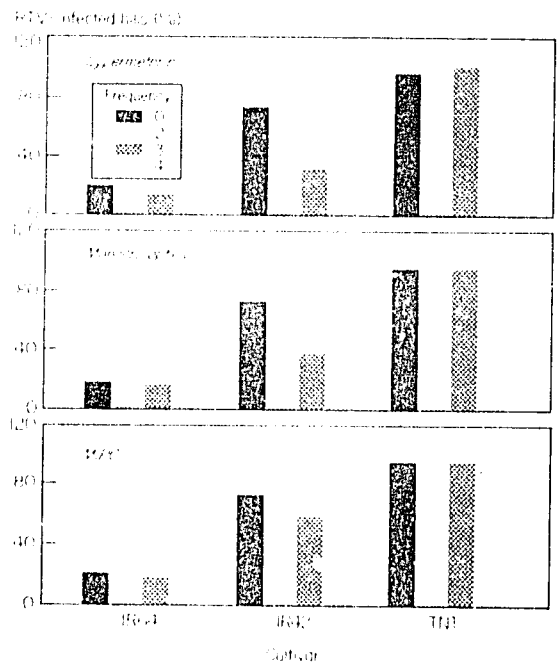
GLH field populations collected at IRRI in April showed low sensitivity to BPMC + chlorpyrifos, carbofuran, carbaryl, and monocrotophos (Table 21).



27. Effect of time of insecticide application on 2 rice cultivars in preventing tungro (RTV) disease, IRRI, 1986. Percentage of infected hills was recorded at 60 DT. Insecticides were applied 4 times at 10-d intervals.

GLH field populations at IRRI showed low sensitivity to MIPC and chlorpyrifos (Table 22).

LD_{50} values of 3 insecticides on brachypterous brown planthopper and green leafhopper adult females when applied at different volumes. Based on actual concentration of insecticide (ppm), LD_{50} values were lowest at the highest volume applied on both BPH and GLH for all the insecticides tested.



28. Effect of frequency of insecticide application on 3 rice cultivars in preventing RTV, IRRI, 1986. Percentage of infected hills recorded at 60 d after transplanting. Insecticides were applied 2, 3, and 4 times at 10-d intervals.

Table 20. Insecticide susceptibility levels of BPH macropterous adult females.[a] IRRI, 1986.

Insecticide	LD_{50} (µg/g, 24 h)		
	2d generation from field population[b]	Insecticide-free greenhouse population	Resistance ratio[c]
Carbofuran	0.55	0.82	1.50
BPMC	2.96	3.54	1.20
Diazinon	6.42	9.59	1.49
Monocrotophos	2.35	3.42	1.46

[a]Av of 3 replications 20 adults/replication. [b]The field population was collected in March (carbofuran) and October (BPMC, diazinon, and monocrotophos).

[c]Resistance ratio = $\frac{LD_{50}\text{'s for field-collected population}}{LD_{50}\text{'s for greenhouse population}}$

Table 21. Susceptibility of greenhouse (GH)[a] and field (F)[b] GLH populations to 9 common insecticides applied as contact spray by Potter's spray tower. IRRI insectary, Apr 1986.

Insecticide[c]	Formulation	Adult cumulative mortality (%) at indicated time[d]					
		24 HT			48 HT		
		GH	F	Difference	GH	F	Difference
Acephate	40 EC	82.5	70.0	12.5 ns	90.0	87.5	7.5 ns
BPMC	50 EC	95.0	90.0	5.0 ns	95.0	90.0	5.0 ns
BPMC + chlorpyrifos	10.5 + 21 EC	77.5	30.0	47.5 *	87.5	35.0	52.5 *
BPMC	50 WP	35.0	10.0	25.0 ns	47.5	15.0	32.5 ns
Carbofuran	12 F	50.0	20.0	30.0 ns	55.0	20.0	35.0*
Carbaryl	85 SP	50.0	7.5	42.5 *	52.5	15.0	37.5 *
Monocrotophos	30 EC	82.5	32.5	50.0 *	90.0	32.5	57.7 *
Cypermethrin	5 EC	100.0	100.0	0.0 ns	100.0	100.0	0.0 ns
Chlorpyrifos	40 EC	25.0	20.0	5.0 ns	45.0	30.0	15.0 ns
No insecticide (check)		0.0	0.0	0.0 ns	0.0	0.0	0.0 ns

[a]GLH population was collected at the IRRI farm and has been maintained in the IRRI greenhouse since 1975. [b]Adults were collected at the IRRI farm (Block III) on 8 Apr 1986. [c]Applied at 0.25% ai except cypermethrin at 0.017% ai. [d]Av of 4 replications. HT = hours after treatment, * = significant, ns = not significant.

However, computed LD_{50} values based on $\mu g/g$ showed almost comparable values for the lowest and highest volume applied. Thus, applying the lowest volume possible for hoppers was sufficient for toxicity evaluation (Table 23).

LD_{50} values of 3 insecticides on 4th-instar larvae of striped stem borer when applied at different volumes. For SSB larvae, the LD_{50} values based on actual concentration (ppm) were comparable when applied at 0.5 and 1.0 μl per larva (at 24 and 48 h). At 0.1, however, the LD_{50} values (ppm) were significantly high for carbofuran and diazinon (48 h) such that higher doses were needed. Thus, 0.5 and 1.0 μl of insecticide at lower doses could be used for toxicity evaluation of SSB larvae, depending on their stage. Likewise, LD_{50} values based on $\mu g/g$ were comparable when 0.5 and 1.0 μl of insecticides were applied at lower doses (Table 24).

Table 22. Susceptibility of greenhouse (GH)[a] and field (F)[b] GLH populations to 9 common insecticides applied as foliar spray. IRRI insectary, Apr 1986.

Insecticide[c]	Formulation	Adult cumulative mortality[d] (%)		
		GH	F	Difference
Acephate	40 EC	100.0	100.0	0.0 ns
BPMC	50 EC	22.5	7.5	15.0 ns
BPMC + chlorpyrifos	10.5 + 21 EC	22.5	17.5	5.0 ns
MIPC	50 WP	85.0	65.0	20.0 *
Carbofuran	12 F	92.5	80.0	12.5 ns
Carbaryl	85 SP	100.0	92.5	7.5 ns
Monocrotophos	30 EC	100.0	97.5	2.5 ns
Cypermethrin	5 EC	97.5	95.0	2.5 ns
Chlorpyrifos	40 EC	57.5	35.0	22.5 *
Check		0.0	15.0	−15.0 ns

[a]GLH population was collected at the IRRI farm and has been maintained in the IRRI greenhouse since 1975. [b]Adults were collected at the IRRI farm on 8 Apr 1986. [c]Applied at 0.75 kg ai/ha except cypermethrin at 0.05 kg ai/ha. Spray volume was 500 liters/ha. [d]Recorded 48 h after caging at 1 d after treatment. Av of 4 replications. * = significant, ns = not significant.

Susceptibility of different ages of brachypterous brown planthopper adult females to carbofuran. The lowest LD_{50} value of 0.84 was observed with 7-d-old BPH and the highest (1.74) with 6-d-old BPH. There was an increasing trend (1.03 to 1.23) from 1-d-old to 4-d-old BPH, and a slightly lower value (1.22) for 5-d-old BPH. The relatively low value of 0.84 for 7-d-old BPH was due to high mortality noted even in untreated insects. Thus, 2- to 4-d-old BPH could be used to avoid a population that is too young or too old for toxicity evaluation (Table 25).

Development of resistance in brown planthopper and green leafhopper under selection pressure. BPH and GLH were treated alone or alternately with monocrotophos, diazinon, carbofuran, and BPMC, using Potter's spray tower and at dosages expected to give 40-60% mortality in each generation. The insecticide selection pressure was continued up to the 24th generation for BPH

Table 23. LD_{50} values of 3 insecticides on brachypterous BPH and GLH adult females.[a] IRRI insectary, Mar-May 1986.

Volume of insecticide (µl)	LD_{50} (24 h)					
	Carbofuran		Diazinon		Monocrotophos	
	ppm	µg/g	ppm	µg/g	ppm	µg/g
			BPH			
0.1	10.72	0.41	214.98	8.27	88.88	3.42
0.2	17.38	1.34	232.02	17.85	40.30	3.10
0.3	1.42	0.16	60.78	7.01	20.37	2.35
			GLH			
0.2	30.24	1.96	254.11	16.45	141.60	9.16
0.4	13.98	1.81	149.71	19.38	83.58	10.82
0.6	7.21	1.40	83.58	16.23	43.57	8.46

[a]Av of 3 replications, 20 insects/replication.

Table 24. LD_{50} values of 3 insecticides on 4th-instar larvae of SSB. IRRI insectary, Jun-Jul 1986.

Volume (µl)	LD_{50}[a]			
	24 h		48 h	
	ppm	µg/g	ppm	µg/g
		Carbofuran		
0.1	7224.34 a	13.01	3936.99 a	7.10
0.5	788.02 b	7.10	521.27 b	4.70
1.0	796.38 b	14.34	432.87 b	7.80
		Diazinon		
0.1	5136.83 a	9.26	5815.34 a	10.49
0.5	975.41 a	8.79	727.55 b	6.56
1.0	645.07 a	11.62	410.59 b	7.40
		Monocrotophos		
0.1	3214.29 a	5.79	1792.08 a	3.22
0.5	1068.11 a	9.62	500.00 a	4.49
1.0	1090.91 a	19.66	407.48 a	7.33

[a]Av of 2 replications, 10 larvae/replication. In a column, values followed by a common letter are not significantly different, based on the interval between the limits of relative potency.

Table 25. Susceptibility of different ages of brachypterous BPH adult females to carbofuran.[a] IRRI insectary, Nov 1986.

Age (d after emergence)	LD_{50} (µg/g, 24 h)
1	1.03
2	1.11
3	1.19
4	1.23
5	1.22
6	1.74
7	0.84

[a]Av of 3 replications, 20 BPH/replication.

and the 12th for GLH. The relative resistance ratios based on LD_{50} values were observed up to the 36th generation in BPH and the 24th in GLH; they

Table 26. Development of BPH resistance to 4 insecticides, under selection pressure. IRRI insectary, 1984-86.

Selection pressure[a]	Relative resistance ratio at given generation					
	6th	12th	18th	24th	33d	36th
			Monocrotophos			
A 1.0	2.16	0.94	2.42	3.26	0.76	0.82
A*B 1.0	–	1.07	1.44	3.11	0.74	0.77
A*C 1.0	2.03	1.12	2.35	2.75	0.78	0.89
A*D 1.0	1.06	1.73	1.39	1.84	0.80	0.95
			Diazinon			
B 1.0	2.63	1.35	1.32	1.00	0.37	0.38
B*A 1.0	--	0.65	4.85	3.05	0.19	0.27
B*C 1.0	3.61	--	0.86	0.96	0.79	0.61
B*D 1.0	1.17	--	–	1.05	0.20	0.23
			Carbofuran			
C 1.0	1.16	--	0.31	1.63	0.43	0.37
C*A 1.0	0.75	1.44	1.12	2.14	0.27	0.35
C*B 1.0	2.23	-	1.50	2.24	0.31	0.32
C*D 1.0	1.06	3.42	2.64	–	0.44	0.42
			BPMC			
D 1.0	1.97	–	3.60	4.68	1.20	1.01
D*A 1.0	1.27	2.83	1.91	4.78	0.44	0.48
D*B 1.0	2.42	2.92	1.55	3.31	0.28	0.44
D*C 1.0	–	–	–	4.74	1.22	0.99

[a]Insecticide was treated at dosages expected to give 40-60% mortality. A = monocrotophos-treated population, A*B = population alternately treated with monocrotophos and diazinon, A*C = population alternately treated with monocrotophos and carbofuran, A*D = population alternately treated with monocrotophos and BPMC, B = diazinon-treated population, B*C = population alternately treated with diazinon and carbofuran, B*D = population alternately treated with diazinon and BPMC, C = carbofuran-treated population, C*D = population alternately treated with carbofuran and BPMC, D = BPMC-treated population.

increased in BPH up to the maximum of 4.8 in the 24th generation but decreased rapidly (Table 26). Those in GLH increased to the maximum of 5.5 in the 12th generation and decreased in the 20th (Table 27).

BPH and GLH populations highly resistant to the 4 insecticides were not obtained with 24 and 12 generations, respectively, whether the 4 insecticides were applied alone or alternately.

Application equipment. Three kinds of equipment for foliar spraying were tested at IRRI. For BPH, the Electrodyn sprayer was superior at the early stages of rice growth. For GLH, Electrodyn, knapsack, and Pulsfog sprayers were effective (Table 28).

Table 27. Development of GLH resistance to 4 insecticides, under selection pressure. IRRI insectary, 1984-86.

Selection pressure up to 12th generation[a]	Resistance ratio at given generation[b]				
	4th	8th	12th	20th	24th
		Monocrotophos			
A	1.62	4.93	2.05	0.72	0.97
A•B	2.70	3.76	5.08	1.20	0.82
A•C	2.26	3.19	5.48	0.98	0.86
A•D	3.56	2.94	4.49	0.77	0.79
		Diazinon			
B	0.79	0.92	2.58	1.03	0.60
B•A	2.86	1.94	1.46	0.33	0.50
B•C	2.23	1.58	0.76	1.18	0.55
B•D	–	1.26	–	0.32	0.37
		Carbofuran			
C	1.03	5.92	5.47	2.47	2.18
C•A	4.42	3.57	3.82	2.00	2.32
C•B	–	5.64	2.06	2.74	1.39
C•D	6.77	6.09	–	1.97	1.75
		BPMC			
D	3.12	3.70	–	1.46	1.40
D•A	1.93	2.54	2.90	0.73	2.11
D•B	1.03	2.11	–	1.00	1.65
D•C	–	2.07	–	1.23	1.51

[a]Insecticide was treated at dosages expected to give 40-60% mortality up to the 12th generation. A = monocrotophos-treated population, A•B = population alternately treated with monocrotophos and diazinon, A•C = population alternately treated with monocrotophos and carbofuran, A•D = population alternately treated with monocrotophos and BPMC, B = diazinon-treated population, B•C = population alternately treated with diazinon and carbofuran, B•D = population alternately treated with diazinon and BPMC, C = carbofuran-treated population, C•D = population alternately treated with carbofuran and BPMC, D = BPMC-treated population. [b]As populations were very low, the 16th generation was not tested for LD_{50}.

Table 28. Field evaluation of spray equipment using cypermethrin for BPH and GLH control on IR22. IRRI, 1986 DS.

Treatment[a]	Flow rate (ml/s)	Swath width (m)	Walking speed (m/s)	Volume applied (liters/ha)	BPH mortality (%) for 48 HAC[b]					GLH mortality (%) for 48 HAC[b]				
					15 DT	28 DT	42 DT	56[c] DT	70 DT	14 DT	28 DT	42 DT	56 DT	70 DT
Electrodyn	0.05[c]	1	0.5	1	90.0 a	77.5 a	47.5 ab	70.0 a	42.5 a	100.0 a	100.0 a	97.5 a	82.5 a	90.0 a
Electrodyn	0.10[c]	2	1	0.5	72.5 ab	72.5 ab	72.5 a	47.5 ab	72.5 a	100.0 a	100.0 a	95.0 a	100.0 a	67.5 ab
Knapsack	10.00[d]	1	–	300-500[e]	35.0 bc	17.5 c	65.0 a	60.0 ab	70.0 a	97.5 a	97.5 a	100.0 a	95.0 a	100.0 a
Pulsfog	15.00[d]	2	–	300-500[e]	15.0 c	30.0 bc	45.0 ab	55.0 ab	57.5 a	77.5 a	100.0 a	97.5 a	97.5 a	95.0 a
Control					20.0 c	0.0 c	12.5 b	17.5 b	20.0 a	22.5 b	17.5 b	15.0 b	20.0 b	20.0 b

[a]Applied at 25 g ai/ha 11, 25, 39, 53, and 67 d after transplanting (DT) in all plots. [b]Hours after caging. [c]A special formulation for Electrodyn. [d]A commercial formulation of 5 EC. [e]300 liters water at 11-39 DT and 500 liters water at 53-67 DT.

Control and management of rice pests

Weeds

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HERBICIDE SCREENING

Agronomy Department

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; and in farmers' fields in Laguna, Batangas, and Nueva Ecija.

Echinochloa crus-galli ssp. *hispidula*, *E. glabrescens*, *Monochoria vaginalis*, and *Cyperus difformis* were common at most transplanted and broadcast seeded lowland sites. *E. colona*, *Eleusine indica*, *Digitaria ciliaris*, *D. setigera*, *Dactyloctenium aegyptium*, and *Rottboellia cochinchinensis* were dominant in the upland fields.

Irrigated transplanted rice. *Preliminary screening.* Butachlor and DOWCO 356-DOWCO 433 controlled *M. vaginalis* but not *Scirpus maritimus* (Table 1). DOWCO 356-DOWCO 433 applied 8 d after transplanting (DT) gave yields comparable to those of the butachlor and hand-weeded checks. SC 0735 and SC 0867 did not control weeds and were toxic to rice, giving low yields.

Advanced trials at IRRI and BPI. In the dry season (DS), all herbicides at the Visayas station, and all herbicides except pendimethalin at IRRI

Table 1. Effect of herbicides on weed control, crop tolerance, and yield of irrigated transplanted IR64.[a] IRRI, 1986 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	0 a	1 a	0	4.3 a
Butachlor	1.0	8	3 a	0 a	61 b	1	3.9 ab
DOWCO 356-DOWCO 433	0.45	8	1 a	0 a	65 b	1	3.5 ab
DOWCO 356-DOWCO 433	0.45	4	4 ab	1 ab	77 b	2	3.0 bc
SC 0867	0.035	8	29 c	1 ab	77 b	2	2.5 c
SC 0735	0.015	8	24 c	1 ab	95 b	1	2.5 c
SC 0735	0.025	8	10 bc	4 b	61 b	2	2.5 c
SC 0867	0.020	8	25 c	3 b	89 b	1	2.4 c
Untreated check	–	–	35 c	1 ab	100 b	0	1.6 d
SC 0867	0.050	4	19 c	3 b	132 b	3	1.6 d
SC 0735	0.035	4	15 bc	1 ab	119 b	4	1.4 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 2. Effect of granular herbicides applied before weed emergence (3-5 DT) on IR64 yield at 4 sites in the Philippines, 1986 DS.

Treatment[a]	Rate (kg ai/ha)	Yield[b] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Butachlor	1.0	5.7 a	5.7 a	4.2 abc	5.0 a
Hand-weeded check, 15 and 35 DT	–	5.7 a	5.4 a	4.8 a	4.3 ab
Piperophos – 2,4-D	0.3-0.2	5.2 abc	5.7 a	4.5 ab	4.7 a
Bensulfuron-methyl[c]	0.05	5.6 ab	5.3 a	4.1 abc	4.9 a
Quinclorac	0.3	5.7 a	5.6 a	4.3 abc	4.1 ab
Naproanilide – thiobencarb	1.0-0.7	5.7 a	5.2 a	3.7 bcd	4.2 ab
Pendimethalin	0.75	4.8 cd	5.8 a	3.9 abc	4.3 ab
2,4-D	0.8	5.2 abc	5.6 a	3.5 cd	4.5 a
Oxyfluorfen	0.1	5.0 bc	5.5 a	3.0 d	3.2 b
Untreated check	–	4.3 d	5.9 a	3.0 d	2.0 c
CV (%)		8	9	14	18

[a]A spaced dash (–) means the 2 herbicides were applied as a proprietary mixture. [b]Av of 4 replications/site. [c]Wettable powder.

gave significantly higher yields than the untreated checks (Table 2). At Maligaya, all treatments gave comparable yields. At the Bicol station, naproanilide - thiobencarb, 2,4-D, and oxyfluorfen did not differ in yield from the untreated control.

In the wet season (WS) at IRRI, all herbicide treatments yielded significantly higher than the untreated check but, except for butachlor, lower than the hand-weeded check (Table 3). The untreated check was markedly outyielded by only pendimethalin at Maligaya, and only bensulfuron -methyl at the Visayas station. At the Bicol station, yields were low because of tungro (RTV) infection. All herbicides gave significantly lower yields than hand weeding; naproanilide - thiobencarb and piperophos - 2,4-D yielded significantly more and oxyfluorfen less than the untreated check.

Irrigated wet seeded rice. *Preliminary screening.* Only DOWCO 356-DOWCO 433 applied at 9 d after seeding (DAS) was effective against *M. vaginalis* and *Echinochloa* spp. (Table 4). However, yields were generally low because of heavy *S.*

Table 3. Effect of granular herbicides applied before weed emergence (3-5 DT) on IR64 yield at 4 sites in the Philippines, 1986 WS.

Treatment	Rate (kg ai/ha)	Yield[a] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Hand weeded check[b]	–	4.1 a	3.4 b	1.7 a	3.6 abc
Bensulfuron-methyl[c]	0.05	2.7 b	3.9 ab	1.2 bc	3.8 a
Butachlor	1.0	3.2 ab	3.3 b	1.2 bc	3.7 ab
Pendimethalin	0.75	2.8 b	4.3 a	1.1 bc	3.2 abc
Piperophos – 2,4-D	0.3-0.2	2.7 b	3.7 ab	1.3 b	3.3 abc
Naproanilide – thiobencarb	1.0-0.7	3.0 b	3.7 ab	1.3 b	2.8 c
2,4-D	0.8	2.8 b	3.5 ab	1.2 bc	2.9 bc
Quinclorac	0.3	3.0 b	3.3 b	1.2 bc	2.8 c
Oxyfluorfen	0.1	2.7 b	3.5 ab	0.5 d	3.4 abc
Untreated check	–	1.6 c	3.3 b	0.9 c	2.9 bc
CV (%)		23	15	19	15

[a]Av of 4 replications/site. [b]At 15 and 35 d after transplanting. [c]Wettable powder.

Table 4. Effect of herbicides on weed control, crop tolerance, and yield of broadcast seeded irrigated IR64.[a] IRRI, 1986 WS.

Treatment	Application		Weed weight (g/m²)			Visual toxicity rating[c]	Yield (t/ha)
	Rate (kg ai/ha)	Time[b]	Broadleaf weeds	Grasses	Sedges		
SC 0867	0.050	1 DBS	29 bcd	28 c	52 ab	2	1.5 a
SC 0735	0.035	1 DBS	60 d	90 c	68 abc	2	1.4 ab
SC 0735	0.035	9 DAS	17 bc	79 c	31 a	1	1.2 abc
Butachlor	1.0	9 DAS	10 ab	6 ab	208 c	2	1.0 abcd
SC 0867	0.050	9 DAS	37 cd	137 c	25 a	3	0.8 abcde
Untreated check	–	–	27 bcd	98 c	53 ab	0	0.8 abcde
SC 0867	0.020	9 DAS	33 bcd	175 c	26 a	2	0.7 bcde
SC 0867	0.020	1 DBS	16 bc	33 c	65 abc	1	0.6 cde
DOWCO 356 - DOWCO 433	0.45	1 DBS	50 cd	72 c	114 bc	1	0.4 cde
DOWCO 356 - DOWCO 433	0.6	1 DBS	40 cd	20 bc	122 bc	1	0.3 de
DOWCO 356 - DOWCO 433	0.6	9 DAS	7 a	2 a	182 c	1	0.3 de
DOWCO 356 - DOWCO 433	0.45	9 DAS	16 bc	1 a	229 c	1	0.2 e

[a]Av of 3 replications. [b]DBS = days before seeding, DAS = days after seeding. [c]Rated 2 wk after herbicide application on a scale of 0-10: 0 = no toxicity, 10 = complete kill.

maritimus infestation and lodging at the spikelet filling stage. All herbicides were slightly toxic to rice.

Advanced trials at IRRI and BPI and in farmers' fields. All herbicides at the Bicol station and some at Maligaya gave significantly higher yields than the untreated checks in DS (Table 5). All treatments at IRRI except bensulfuron-methyl, and all at the Visayas station except butachlor + 2,4-D gave comparable yields.

In WS, few herbicide treatments at IRRI and none at the Bicol and Visayas stations differed in yield from the untreated checks (Table 6). At Maligaya, all but three herbicides gave significantly higher yields than the untreated check. Yields were low because of lodging at IRRI and RTV infection at the Bicol station.

Four herbicides were tested at different rates in farmers' fields in the turod (upper) portion of the landscape in Guimba, Nueva Ecija. The dominant weed species were *C. rotundus*, *Ischaemum rugosum*, and *Fimbristylis miliacea*. Butachlor controlled weeds poorly, and yields were thus significantly lower than those from the other herbicide treatments and not significantly different from the unweeded treatment. All the other herbicides performed well (Table 7).

Herbicide application method. In DS, applying herbicides into the water 3 d before seeding (DBS) affected weed control but not grain yield (Table 8).

Table 5. Effect of early postemergence (6-8 DAS) application of granular herbicides on yield of broadcast seeded flooded IR64 at 4 sites in the Philippines, 1986 DS.

Treatment[a]	Rate (kg ai/ha)	Yield[b] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Quinclorac	0.3	4.6 ab	5.2 a	4.8 ab	4.2 ab
Bensulfuron-methyl[c]	0.05	5.1 a	4.9 ab	4.2 bc	4.1 ab
Piperophos + 2,4-D	0.3-0.2	3.9 cd	4.7 abc	5.3 a	3.7 ab
Naproanilide + thiobencarb	1.0-0.7	4.2 bcd	5.0 ab	4.5 abc	3.8 ab
Thiobencarb + 2,4-D	1.0-0.5	4.1 bcd	5.2 a	4.1 bc	4.0 ab
Butachlor	1.0	4.3 bc	4.6 abc	4.2 bc	4.2 ab
Butachlor + 2,4-D	0.75 + 0.5	4.5 b	4.3 bc	3.8 c	4.5 a
Oxyfluorfen	0.1	4.5 b	4.2 bc	4.1 bc	3.8 ab
Pendimethalin	0.75	3.6 d	4.4 abc	4.1 bc	4.2 ab
Untreated check	–	4.0 bcd	3.9 c	1.5 d	3.1 b
CV (%)		9	11	12	20

[a]A plus (+) sign means the chemicals were applied separately. [b]Av of 4 replications/site. [c]Wettable powder.

Table 6. Effect of early postemergence (6-8 DAS) application of granular herbicides on yield of broadcast seeded flooded IR64 at 4 sites in the Philippines, 1986 WS.

Treatment	Rate (kg ai/ha)	Yield[a] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Thiobencarb + 2,4-D	1.0-0.5	1.9 ab	3.5 a	1.2 a	3.2 a
Bensulfuron-methyl[b]	0.05	2.5 a	2.9 ab	1.3 a	2.7 a
Piperophos + 2,4-D	0.3-0.2	1.9 ab	3.3 a	1.2 a	2.8 a
Butachlor	1.0	1.5 bcde	3.2 a	0.9 ab	3.0 a
Naproanilide + thiobencarb	1.0-0.7	1.5 bcde	3.3 a	1.2 a	2.4 a
Oxyfluorfen	0.1	0.7 ef	3.4 a	1.0 ab	3.1 a
Butachlor + 2,4-D	0.75 + 0.5	1.6 bcd	3.1 a	1.1 ab	2.3 a
Quinclorac	0.3	1.0 cdef	2.9 ab	1.3 a	2.5 a
Pendimethalin	0.75	0.5 f	2.9 ab	0.7 b	2.9 a
Untreated check	–	0.9 def	2.3 b	1.0 ab	2.2 a
CV (%)		39	13	26	22

[a]Av of 4 replications/site. [b]Wettable powder.

Butachlor, oxyfluorfen, and pendimethalin gave significantly lower weed weight than the untreated check. Conversely, incorporating herbicides into the soil affected grain yield but not weed control. Butachlor, naproanilide - thiobencarb, and oxyfluorfen yielded significantly higher than the untreated check. Neither application method influenced crop stand. However, water application resulted in slightly less weed weight but generally lower rice stand than soil incorporation.

In WS, butachlor at 1.0 kg ai/ha applied at 3 DBS had no effect on the stand count of broadcast seeded flooded rice, whether it was applied with a knapsack sprayer or poured directly into the water in the field as an undiluted solution or as a diluted (100 liters/ha) solution (Table 9). Weed densities and weed weights were lower in the butachlor-treated plots than in the untreated plots. No differences were observed among the different application methods.

In a subsequent trial, excellent weed control and high yields were obtained with butachlor and two other herbicides when they were applied undiluted into the water in the field (Table 10). This application technique was further tested with butachlor and pretilachlor + fenclorim in a farmer's field in Jaen, Nueva Ecija. Because of poor water control, butachlor significantly reduced crop stand, but the crop soon recovered such that at maturity its yield was not significantly different from that treated with pretilachlor + fenclorim. Both yielded significantly higher than the untreated check.

In Guimba, butachlor performed equally well in terms of weed con[illegible] and grain yield when the herbicide was appli[illegible] at 3 DBS into standing water, when the field was drained and flushed

Table 7. Yield of wet seeded rice as affected by weed control treatment. Guimba, Nueva Ecija, Philippines, 1986 WS.

Treatment	Rate (kg ai/ha)	Time of application	Grain yield (t/ha)
Pretilachlor + fenclorim	0.3	3 DAS	4.1 a
Bensulfuron-methyl	0.03	3 DAS	3.6 ab
Bensulfuron-methyl	0.04	3 DAS	3.5 ab
Propanil	3.0	15 DAS	3.5 ab
Pretilachlor + fenclorim	0.45	6 DAS	3.4 abc
Bensulfuron-methyl	0.05	6 DAS	3.2 bc
Butachlor	0.6	3 DBS	2.4 cd
Unweeded	--	--	2.5 cd
Butachlor	0.3	3 DBS	2.2 d

Table 9. Weed density, weed weight, tiller count, and grain yield of wet seeded IR58 as affected by method of butachlor application. IRRI, 1985 WS.

Treatment	Weed density (no./m²)	Weed weight (g/m²)	Tillers (no./m²)	Grain yield (t/ha)
Single nozzle	52 a	9.2 a	1062 a	3.3 a
Pouring concentrated solution	32 a	7.2 a	1057 a	3.4 a
Pouring diluted solution	50 a	7.7 a	1055 a	3.8 a
No weeding	484 b	199.4 b	495 b	1.0 b

Table 8. Effect of applying herbicide 3 DBS on weed control, crop stand, and yield of broadcast seeded IR64.[a] IRRI, 1986 DS.

Treatment	Rate (kg ai/ha)	Applied into water: Weed weight at 65 DAS (g/m²)	Applied into water: Seedlings (no.) at 26 DAS (no./m²)	Applied into water: Grain yield (t/ha)	Incorporated into soil: Weed weight at 65 DAS (g/m²)	Incorporated into soil: Seedlings (no.) at 26 DAS (no./m²)	Incorporated into soil: Grain yield (t/ha)
Butachlor	0.75	10 ab	179 a	4.4 a	18 a	216 a	4.6 a
Butachlor + 2,4-D	0.5 + 0.5	21 bc	179 a	4.4 a	32 a	212 a	4.4 ab
Naproanilide – thiobencarb	1.0-0.7	17 abc	199 a	4.5 a	21 a	220 a	4.6 a
Oxyfluorfen	0.1	7 ab	164 a	4.5 a	30 a	210 a	4.5 a
Pendimethalin	0.5	4 a	157 a	3.8 a	65 a	218 a	3.6 ab
Piperophos – 2,4-D	0.25-0.17	16 abc	235 a	4.3 a	25 a	204 a	4.0 ab
Thiobencarb – 2,4-D	0.75-0.375	18 abc	187 a	4.2 a	40 a	210 a	4.2 ab
Untreated check	--	30 c	207 a	4.2 a	44 a	206 a	3.5 b

[a] Av of 4 replications/application method.

Table 10. Plant height, weed weight, and yield of wet seeded IR64 as affected by different herbicides. IRRI, 1986 DS.

Treatment[a]	Plant height (cm)	Weed weight (g/m²)	Grain yield (t/ha)
Butachlor (0.75), 3 DBS	14.9 a	14.2 a	5.3 a
Pretilachlor + fenclorim (0.45), 3 DAS	14.8 a	27.1 a	4.8 a
Bensulfuron-methyl (0.04), 7 DAS	15.5 a	25.8 a	4.8 a
No weeding	15.1 a	344.3 b	1.8 b

[a]Figures in parentheses are application rates in kg ai/ha.

before seeding, when the field was saturated during herbicide application, and when the herbicide was incorporated immediately after application. The average yield in the herbicide-treated plots was 3.1 t/ha compared with 2.0 t/ha for the hand-weeded plots and no yield for the unweeded check. The low yield in the hand-weeded plots was caused by a delay in the first weeding until 25 DAS.

Herbicide combination and timing. In DS, bensulfuron-methyl alone and with butachlor or quinclorac, regardless of application time, and with thiobencarb applied at 12 DAS significantly reduced weed stand and increased grain yield (Table 11). Solo application of butachlor, thio-

Table 11. Effect of herbicide combination and application time on weed control, crop stand, and yield of broadcast seeded flooded IR64.[a] IRRI, 1986 DS.

Treatment[b]	Application		Rice count at 27 DAS (no./m²)	Weed count at 63 DAS (no./m²)	Yield (t/ha)
	Rate (kg ai/ha)	Time (DAS)			
Bensulfuron-methyl	0.04	6	227 a	7 a	5.5 ab
Butachlor	0.75	6	137 d	120 bc	4.2 c
Thiobencarb	2.0	6	119 d	228 d	1.8 d
Quinclorac	0.2	6	226 a	92 abc	5.1 abc
Bensulfuron-methyl + butachlor	0.02 + 0.5	6	157 cd	8 a	5.9 ab
Bensulfuron-methyl + butachlor	0.02 + 0.5	12	219 ab	2 a	6.2 a
Bensulfuron-methyl + thiobencarb	0.02 + 1.0	6	165 bcd	41 ab	5.3 abc
Bensulfuron-methyl + thiobencarb	0.02 + 1.0	12	228 a	0 a	5.8 ab
Bensulfuron-methyl + quinclorac	0.02 + 0.1	6	205 abc	6 a	5.6 ab
Bensulfuron-methyl + quinclorac	0.02 + 0.1	12	229 a	8 a	5.5 ab
Untreated check	–	–	244 a	162 cd	4.2 c

[a]Av of 4 replications. [b]+ = tank mixture.

Table 12. Effect of herbicide combinations on weed control, stand count, and yield of broadcast seeded irrigated IR64.[a] IRRI, 1986 DS.

Treatment	Application		Weed weight (g/m²)		Stand count (no./m²)	Yield (t/ha)
	Rate (kg ai/ha)	Time	Grasses	Sedges		
Butachlor + quinclorac	0.4 + 0.15	2 DBS	4 a	59 e	249 a	3.7 abc
Butachlor + quinclorac	0.4 + 0.15	6 DAS	2 a	26 cde	289 a	3.7 abc
Butachlor + bensulfuron-methyl	0.4 + 0.02	2 DBS	0 a	41 de	312 a	3.8 ab
Butachlor + bensulfuron-methyl	0.4 + 0.02	6 DAS	0 a	6 abc	243.a	4.2 a
Quinclorac + bensulfuron-methyl	0.1 + 0.02	2 DBS	0 a	26 cde	265 a	4.2 a
Quinclorac + bensulfuron-methyl	0.1 + 0.02	6 DAS	0 a	12 bcd	272 a	4.3 a
Quinclorac + bensulfuron-methyl	0.1 + 0.02	10 DAS	3 a	0 a	327 a	4.2 a
Quinclorac + bensulfuron-methyl	0.1 + 0.02	13 DAS	0 a	4 ab	320 a	4.0 a
Quinclorac + 2,4-D	0.1 + 0.4	10 DAS	9 ab	2 ab	304 a	4.2 a
Quinclorac + 2,4-D	0.1 + 0.4	13 DAS	0 a	29 cde	296 a	3.6 abc
Butachlor	0.75	2 DBS	1 a	51 de	256 a	2.9 bc
Untreated check	–	–	39 b	45 de	291 a	2.7 c

[a]Av of 3 replications.

bencarb, and quinclorac provided poor control of *S. maritimus*. Butachlor and thiobencarb, either alone or with bensulfuron-methyl, were highly toxic to rice when applied at 6 DAS. In another trial, all combinations were effective against the dominant *Echinochloa* spp., regardless of application time (Table 12). Bensulfuron-methyl with butachlor or quinclorac applied postseeding substantially reduced *S. maritimus* stand. Quinclorac + 2,4-D applied at 10 DAS also controlled the weed. All combinations with bensulfuron-methyl regardless of application time, and quinclorac + 2,4-D applied at 10 DAS gave significantly higher yields than the untreated check.

In WS, all treatments except butachlor alone significantly reduced weed weight (Table 13). Bensulfuron-methyl regardless of timing, pretilachlor applied at 3 DAS, and bensulfuron-methyl + pretilachlor or quinclorac yielded significantly higher than the untreated check.

Seeding method. A study at IRRI determined the effect of seeding method and herbicide treatment on stand establishment, weed growth, and rice yield. The seeding methods were a) broadcast seeding of flooded rice; b) modified broadcast seeding of flooded rice -- after seeding, the soil was allowed to dry for 6 d, residual herbicides were applied, and the plots were then irrigated; c) water seeding -- plots were flooded with 5-10 cm water until 7 DAS and then drained, the residual herbicides were applied, and 3 d later the plots were flooded to a depth of 3 cm; and d) modified water seeding -- at 2 DAS the plots were flooded to a depth of 5-10 cm; thereafter, the procedure was the same as for the water seeding treatment.

Rice stand was reduced by all water seeding methods and two herbicide treatments (butachlor and butachlor - 2,4-D); there was less weed growth in the broadcast seeded treatments than in the water seeding (Table 14). The best weed control

Table 13. Effect of herbicide combination and application time on weed control and yield of broadcast seeded flooded IR64.[a] IRRI, 1986 WS.

Treatment	Rate (kg ai/ha)	Time (DAS)	Weed weight (g/m^2)	Yield (t/ha)
Bensulfuron-methyl	0.04	3	19 ab	2.9 ab
Bensulfuron-methyl	0.04	6	3 a	3.5 a
Pretilachlor[b]	0.45	3	34 ab	2.8 ab
Pretilachlor[b]	0.45	6	32 ab	2.2 bcd
Butachlor	1.0	6	61 bc	2.2 bcd
Quinclorac	0.2	6	26 ab	1.3 d
Bensulfuron-methyl + pretilachlor[b]	0.02 + 0.225	6	5 a	3.3 a
Bensulfuron-methyl + butachlor	0.02 + 0.5	6	22 ab	2.6 abc
Bensulfuron-methyl + quinclorac	0.02 + 0.1	6	31 ab	3.3 a
Untreated check	–	–	77 c	1.6 cd

[a]Av of 4 replications. [b]With safener.

Table 14. Weed weight as affected by seeding method and weed control treatment. IRRI, 1986 DS.

Treatment[a]	Weed weight (g/m^2)				
	Wet seeded	Modified wet seeded	Water seeded	Modified water seeded	Mean
Bensulfuron-methyl (0.04)	28	16	30	44	30 a
Pretilachlor + fenclorim (0.45)	34	23	79	69	51 b
Butachlor (0.6)	55	81	138	228	126 c
Butachlor – 2,4-D (0.6 – 0.4)	107	70	327	374	220 d
2,4-D (0.8)	176	204	295	267	236 e
Untreated check	139	246	466	299	288 f
Mean[b]	90 a	107 a	223 b	214 b	

[a]Figures in parentheses are application rates in kg ai/ha. All herbicides were applied at 6-9 DAS, except 2,4-D (0.8) at 30 DAS. [b]In the row, means having a common letter are not significantly different at the 5% level by DMRT.

was obtained with bensulfuron-methyl. The broadcast seeded flooded treatments outyielded the water seeded treatments (Table 15). Across seeding methods, the best yields were obtained with bensulfuron-methyl, pretilachlor + fenclorim, and butachlor. However, butachlor is less useful because of initial crop damage and stand reduction.

Rainfed transplanted rice. In preliminary screening with rainfed transplanted rice, most treatments were effective against *Echinochloa* spp., *Leptochloa chinensis*, and *M. vaginalis*. Although ineffective against the sedges, the treatments gave significantly higher yields than the untreated control (Table 16). Butachlor, DOWCO 356 - DOWCO 433, and the hand-weeded check gave comparable yields. SC 0735 and SC 0867 were toxic to rice and gave low yields.

Rainfed broadcast seeded flooded rice. *Preliminary screening.* SC 0735 applied at 7 DAS was initially moderately toxic but effectively controlled sedges. Butachlor controlled grasses. Both gave significantly more yields than the untreated check (Table 17). All the other herbicides that were ineffective against one weed species or the other yielded the same as the untreated check.

Controlled-drop applicators. Three herbicides (bensulfuron-methyl, 2,4-D, and propanil) were each applied at half and at their recommended rates with the Birky, Micronherbi, and conventional knapsack sprayers on a 75% *S. maritimus*-infested field.

With the Birky and conventional sprayers, 2,4-D controlled the weed better than the two other herbicides, and better than propanil did with the Micronherbi (Table 18). Sprayer type did not

Table 15. Rice grain yield as affected by seeding method and weed control treatment. IRRI, 1986 DS.

Treatment[a]	Grain yield (t/ha)				
	Wet seeded	Modified wet seeded	Water seeded	Modified water seeded	Mean
Bensulfuron-methyl (0.04)	4.4	4.2	4.9	4.2	4.4 a
Pretilachlor + fenclorim (0.45)	4.1	4.2	4.9	4.5	4.4 a
Butachlor (0.6)	4.0	4.7	3.0	3.9	3.9 a
Butachlor – 2,4-D (0.6 – 0.4)	3.7	3.8	1.3	1.1	2.5 b
2,4-D (0.8)	1.5	2.4	2.3	1.0	1.8 c
Untreated check	1.8	2.1	1.0	0.8	1.4 c
Mean[b]	3.3 ab	3.6 a	2.9 bc	2.6 c	

[a]Figures in parenthoses are application rates in kg ai/ha. All herbicides were applied at 6-9 DAS, except 2,4-D (0.8) at 30 DAS. [b]In the row, means having a common letter are not significantly different at the 5% level by DMRT.

Table 16. Effect of herbicides on weed control, crop tolerance, and yield of rainfed transplanted IR64.[a] IRRI, 1986 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 ab	0 a	0 a	0	4.5 a
Butachlor	1.0	4	0 a	0 a	10 b	1	4.3 ab
DOWCO 356-DOWCO 433	0.6	4	2 bc	0 a	47 c	1	3.8 abc
DOWCO 356-DOWCO 433	0.45	8	1 ab	0 a	46 c	0	3.8 abc
SC 0867	0.020	8	15 e	6 ab	21 c	1	3.4 bc
SC 0735	0.035	8	4 bcd	0 a	34 c	2	3.4 bc
SC 0735	0.015	8	6 cde	0 a	26 c	2	3.0 cd
SC 0867	0.050	4	7 de	9 ab	43 c	4	2.2 de
SC 0735	0.025	4	16 e	16 b	64 c	5	1.8 e
Untreated check	–	–	22 e	58 b	39 c	0	1.6 e

[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 17. Effect of herbicides on weed control, crop tolerance, and yield of rainfed broadcast seeded flooded IR64.[a] IRRI, 1986 WS.

Treatment	Application		Weed weight (g/m²)		Visual toxicity rating[b]	Yield (t/ha)
	Rate (kg ai/ha)	Time	Grasses	Sedges		
SC 0735	0.025	7 DAS	70 cd	33 ab	4	3.7 a
Butachlor	1.0	7 DAS	9 b	132 cd	1	3.7 a
DOWCO 356-DOWCO 433	0.45	7 DAS	1 a	67 bcd	2	3.2 ab
SC 0867	0.020	7 DAS	94 cd	43 bcd	1	3.1 ab
SC 0867	0.035	7 DAS	95 cd	35 abc	2	3.0 ab
DOWCO 356-DOWCO 433	0.45	2 DBS	26 c	106 cd	2	2.9 ab
SC 0867	0.050	7 DAS	176 d	13 a	3	2.8 ab
SC 0867	0.020	2 DBS	93 cd	151 d	0	2.2 b
SC 0735	0.025	2 DBS	93 cd	71 bcd	0	2.2 b
SC 0867	0.050	2 DBS	126 cd	73 bcd	0	2.2 b
Untreated check	–	–	69 cd	117 cd	0	2.3 b

[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 18. Effect of sprayer type and herbicide on sedge population and grain yield of rainfed broadcast seeded flooded IR64.[a] IRRI, 1986 WS.

Herbicide	Sedges[b] (no./m²)			Grain yield (t/ha)			
	Micronherbi	Birky	Conventional	Micronherbi	Birky	Conventional	Mean
2,4-D IBE	62 a	21 a	69 a	2.56	2.60	2.34	2.50 a
Bensulfuron-methyl	102 ab	89 b	144 b	1.94	1.95	1.40	1.77 b
Propanil	151 b	146 b	142 b	0.93	1.20	1.33	1.16 c
Mean				1.81 a	1.92 a	1.92 a	1.81

[a]Av of 3 replications and 2 application rates. [b]Sampled at 53 DAS.

affect grain yield, but the kind of herbicide did. The 2,4-D plots yielded significantly higher than the bensulfuron-methyl plots, which yielded higher than the propanil plots.

Differences in weed control were observed only with 2,4-D (Fig. 1). Sedges were markedly less with the Birky than with the other sprayers.

Grain yield was not affected by application rate, although sedge population was generally lower at recommended rates.

Upland rice. *Preliminary screening.* All herbicide treatments for upland rice at first provided acceptable weed control. About a month later, however, *R. cochinchinensis* and *Calopogonium mucunoides* reinfested most treatments, resulting in yields not different from that of the untreated control (Table 19). Only DOWCO 356-DOWCO 433 and SC0735, although initially very toxic, gave significantly higher yields than the untreated check.

Advanced trial. Only oxyfluorfen and thiobencarb gave weed counts similar to that of the hand-weeded check (Table 20). No other herbicide treatment differed in weed density from the untreated check. Oxyfluorfen and propanil were moderately toxic to rice. No yield was obtained because typhoons hit the crop at the reproductive stage.

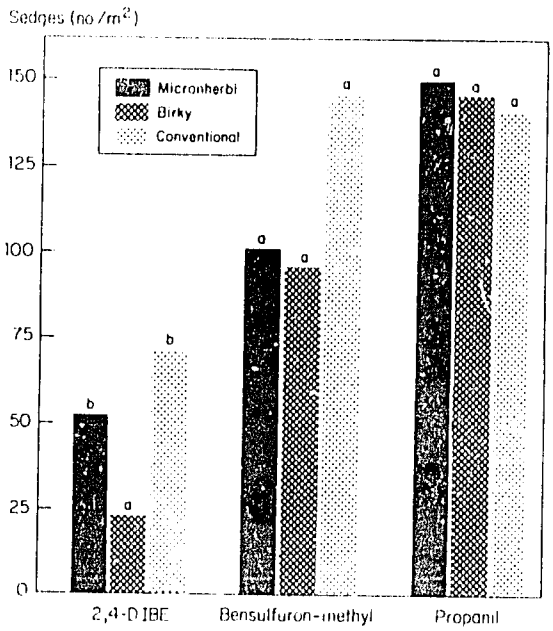
Application rate and timing of fluazifop-butyl. In the field, fluazifop-butyl was applied at 0.01, 0.05, 0.10, and 0.25 kg/ha, using the conventional hydraulic boom sprayer at 7, 14, 21, and 28 d after emergence (DE) of UPLRi-7.

The experimental area was heavily infested with the dominant weed *R. cochinchinensis*. At application times of 7-21 DE, fluazifop-butyl rates of 0.05 kg/ha and higher performed similarly in reducing the dry weight of grasses but performed better than 0.01 kg/ha (Table 21). At these times,

Table 19. Effect of liquid herbicides on weed control, crop tolerance, and yield of IR43 under upland conditions.[a] IRRI, 1986.

Treatment	Application		Weed weight (g/m²)			Visual toxicity rating[b]	Yield (t/ha)
	Rate (kg ai/ha)	Time (DAS)	Broadleaf weeds	Grasses	Sedges		
Hand-weeded check	Twice	15 + 30	2 a	18 a	2 a	0	2.8 a
DOWCO 356-DOWCO 433	0.6	4	102 bc	72 ab	8 a	0	1.2 b
SC 0735	0.015	4	71 bc	230 b	3 a	2	0.8 bc
SC 0735	0.035	4	190 c	90 b	2 a	3	0.7 bcd
DOWCO 356-DOWCO 433	0.45	4	66 b	118 b	3 a	0	0.7 bcd
SC 0867	0.050	4	78 bc	211 b	2 a	3	0.7 bcd
Butachlor	2.0	4	72 bc	195 b	5 a	1	0.6 bcd
SC 0867	0.035	4	112 bc	208 b	5 a	2	0.2 cd
Untreated check	–	–	155 bc	275 b	2 a	0	0.1 d

[a]Av of 3 replications. [b]Rated 2 wk after herbicide application on a scale of 0-10: 0 = no toxicity, 10 = complete kill.



1. Effect of sprayer type on the performance of herbicides in rainfed broadcast seeded flooded IR64, IRRI, 1986 WS. Within each herbicide, bars having a common letter are not significantly different at the 5% level by DMRT.

0.01 kg/ha performed better than the untreated check, but at 28 DE, 0.01 kg/ha was just comparable to the untreated check. Also, at 28 DE, the dry weight of grasses significantly decreased with increase in application rate.

Figure 2 shows that the dry weight of grasses at 0.01, 0.10, and 0.25 kg fluazifop-butyl/ha was not influenced by the time of application; at

Table 20. Effect of herbicides applied before weed emergence on weed control in upland IR36.[a] IRRI, 1986 WS.

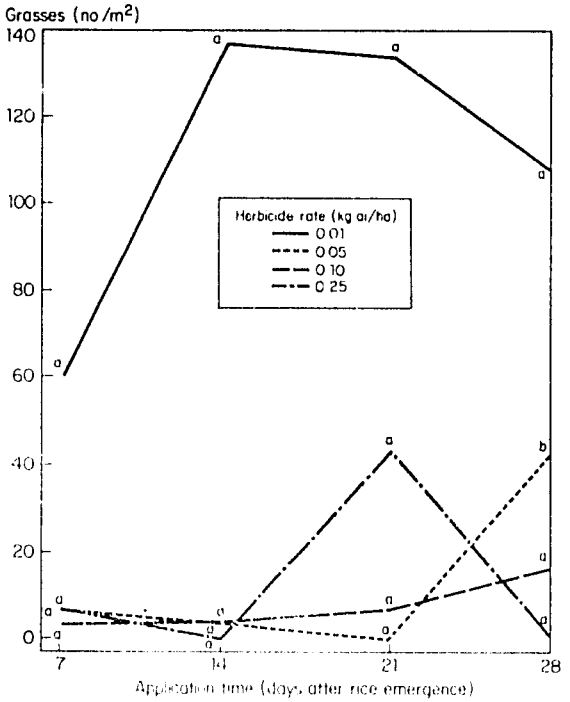
Treatment	Rate (kg ai/ha)	Crop injury rating[b]	Total weed count[c] (no./m²)
Hand-weeded at 18 and 37 DE	–	0	18 a
Oxyfluorfen	0.36	4	44 ab
Thiobencarb	3.0	0	55 ab
Pendimethalin	2.0	1	67 b
Butachlor	2.0	0	68 b
Propanil[d]	2.0	4	78 bc
Untreated check	–	0	78 bc
Dinitramine	1.5	0	84 bc
Oxadiazon	1.0	2	90 bc
Butralin	2.0	0	123 c

[a]Av of 4 replications. [b]Rating done 1 wk after herbicide application. [c]Sampled at 51 d after rice emergence (DE). [d]Applied at 10 DE.

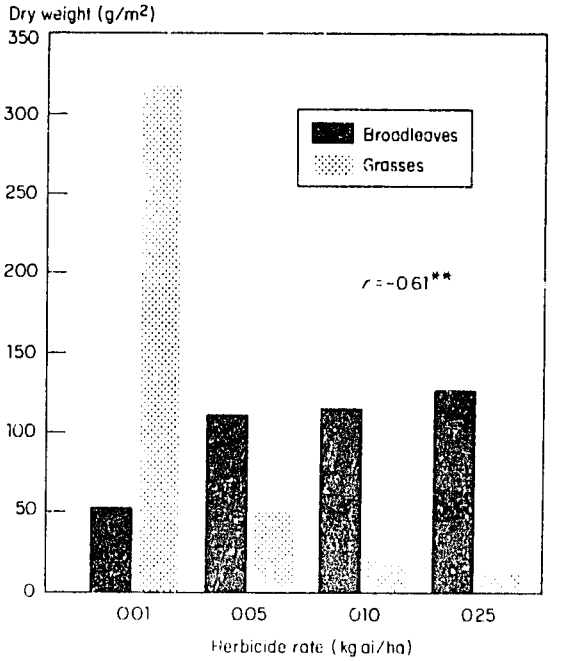
Table 21. Effect of fluazifop-butyl on control of grasses in upland UPLRi-7 as affected by application rate and time.[a] IRRI, 1986 WS.

Application rate (kg ai/ha)	Dry weight of grasses[b] (g/m²) with application at			
	7 DE	14 DE	21 DE	28 DE
0.01	353 b	147 b	291 b	475 d
0.05	15 a	1 a	0 a	178 c
0.10	5 a	2 a	4 a	49 b
0.25	8 a	1 a	19 a	0 a

[a]Av of 3 replications. [b]Sampled at 46 DE.



2. Effect of fluazifop-butyl on grass control in UPLRi-7 upland rice as affected by application rate and time, IRRI, 1986 WS. At each rate, means having a common letter are not significantly different at the 5% level by DMRT.



3. Effect of grass control with fluazifop-butyl on the dry weight of broadleaf weeds. IRRI, 1986 WS.

0.05 kg/ha, fluazifop-butyl was less effective at 28 DE than at the other application times. Thus the time of application of fluazifop-butyl is more critical when 0.05 kg/ha is used. The activity of fluazifop-butyl at 0.01 kg/ha may be low; rates such as 0.10 and 0.25 kg/ha may be high enough for application time to exert its effect.

The phytotoxicity of fluazifop-butyl increased with increase in application rate. Recovery was observed 2 wk after treatment. No grain yield was harvested because uncontrolled broadleaf weeds like *Ipomoea triloba* and *Amaranthus spinosus* took over in grass-controlled plots and smothered the rice crop. Figure 3 shows a significant correlation between the dry weights of grasses and broadleaves ($r = -0.61^{**}$).

Effect of sprayer type on performance of fluazifop-butyl. Fluazifop-butyl is a new post-emergence, selective, translocated grasskiller recommended for broadleaf crops. However, it may be selective to rice at certain rates and times of application.

In a greenhouse trial, the effect of application method using 3 rates of fluazifop-butyl (0.01, 0.05, and 0.10 kg ai/ha) was evaluated on UPLRi-5 and *R. cochinchinensis*. The herbicide was applied at 17 DE of both rice and *R. cochinchinensis*, using the Micronherbi, Birky, and conventional hydraulic knapsack sprayer calibrated to deliver 21, 57, and 250 liters/ha, respectively.

The type of sprayer did not affect the plant height of rice, but it affected that of *R. cochinchinensis* (Table 22). The weed plants treated with fluazifop-butyl in the Micronherbi and Birky were significantly shorter than those treated with the herbicide in the conventional sprayer. Shoot fresh weight and root dry weight of rice were lowest with the Micronherbi and highest with the conventional sprayer, but the latter values were similar to those with the Birky.

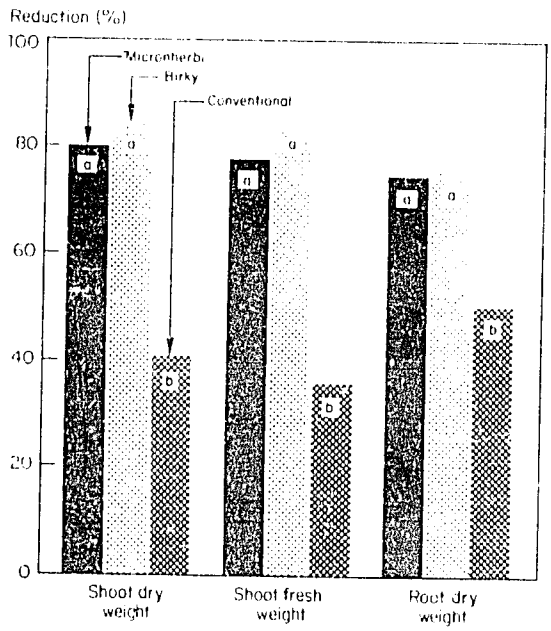
On the other hand, *R. cochinchinensis* shoot fresh weight and root dry weight were significantly lower with the Micronherbi and Birky than with the conventional sprayer.

Figure 4 shows that percentage reduction in shoot dry and fresh weights and root dry weight of *R. cochinchinensis* was higher when the Micron-

Table 22. Effect of sprayer type on the performance of fluazifop-butyl on UPLRi-5 and *Rottboellia cochinchinensis* grown under upland conditions in the greenhouse.[a] IRRI, 1986 WS.

Sprayer type	Rice[b]			*R. cochinchinensis*		
	Plant height (cm)	Shoot fresh weight (g)	Root dry weight (g)	Plant height (cm)	Shoot fresh weight (g)	Root dry weight (g)
Micronherbi	65.54 a	9.01 b	1.30 b	45 b	3.12 b	0.35 b
Birky	64.91 a	11.21 ab	1.48 ab	50 b	2.11 b	0.33 b
Conventional	64.83 a	12.77 a	2.10 a	74 a	8.95 a	0.68 a

[a]Av of 3 replications and 3 application rates. [b]Sampled at 48 d after weed and rice emergence or 30 d after fluazifop-butyl application. Fluazifop-butyl was sprayed on 17-d-old rice seedlings.



4. Effect of sprayer type on the effectiveness of fluazifop-butyl in controlling *Rottboellia cochinchinensis*, IRRI, 1986 WS. Within a parameter, treatments with a common letter are not significantly different at the 5% level by DMRT.

herbi and Birky were used. With 0.10 kg fluazifop-butyl/ha, the Micronherbi consistently gave the highest percentage reduction in shoot fresh weight and root dry weight of both weed and rice (Table 23). A *t* test indicated that *R. cochinchinensis* was more susceptible than rice to fluazifop-butyl.

EFFECT OF OVERFLOWING WATER ON HERBICIDE PERFORMANCE

Agronomy Department

Butachlor was applied as an emulsifiable concentrate at 1.0 kg ai/ha onto saturated soil at 4 DT. There was no loss in weed control or yield reduction when water was allowed to flow through the plots for 30 min at 2 h after the herbicide was applied (Table 24).

When the water flowed into an adjacent untreated plot of the same size as the treated plot, good weed control was obtained in both the treated and untreated plots, and yields were no lower than those in the treated plot where no flowing out had

Table 23. Percentage reduction in shoot fresh weight and root dry weight of UPLRi-5 and *R. cochinchinensis* as affected by fluazifop-butyl application rate and method.[a] IRRI, 1986 WS.

Application rate (kg ai/ha) and sprayer type	Reduction (%) in shoot fresh weight		Reduction (%) in root dry weight	
	Rice	*Rottboellia*	Rice	*Rottboellia*
0.01 Micronherbi	41 bc	61 abc	45 bc	64 abc
0.01 Birky	34 bc	73 ab	50 bc	67 abc
0.01 Conventional	33 bc	26 bc	30 ab	39 c
0.05 Micronherbi	35 bc	79 ab	33 ab	71 ab
0.05 Birky	37 bc	89 a	46 bc	78 ab
0.05 Conventional	31 b	68 ab	26 ab	60 abc
0.10 Micronherbi	59 c	93 a	75 c	89 a
0.10 Birky	24 ab	93 a	38 ab	83 ab
0.10 Conventional	3 a	13 c	10 a	54 bc
t-value	−5.3071**		−6.9961**	

[a]Av of 3 replications.

Table 24. Weed weight and grain yield in butachlor-treated and untreated plots as affected by flowing out of water and plot size. IRRI, 1986.

Treatment	Plot size (m^2)	Weed weight (g/m^2)	Grain yield (t/ha)
Butachlor, no overflow	15	16 a	5.1 a
Butachlor, overflow	15	12 a	4.8 a
Untreated receiver[a]	15	42 ab	4.6 a
Untreated receiver[a]	30	110 cd	3.8 b
Untreated receiver[a]	45	88 bc	2.9 c
Untreated, overflow	15	166 e	3.4 bc
Untreated receiver[b]	15	150 de	3.4 bc
Untreated, no overflow	15	118 cde	3.5 bc

[a]From butachlor-treated plot. [b]From untreated plot.

occurred. However, doubling or tripling the size of the untreated plot resulted in an increase in weed weight and a decrease in grain yield.

Weed control and yield in the plots to which no herbicide was applied were unaffected by the overflowing of water.

WEED CONTROL AND WATER MANAGEMENT PRACTICES FOR BROADCAST SEEDED FLOODED RICE

Agronomy Department

The performance of bensulfuron-methyl and butachlor + 2,4-D was evaluated under 3 water management practices: 1) broadcast seeding of pregerminated rice into 5 cm water (M1), 2) broadcast seeding of pregerminated rice onto mud without standing water and irrigation at 2 DAS (M2), and 3) broadcast seeding of pregerminated rice onto mud without standing water and irrigation at 4 DAS (M3).

Butachlor + 2,4-D applied at 3 DBS was toxic to rice seedlings under M1 and M2, but only slightly toxic under M3. Bensulfuron-methyl was slightly toxic to rice seedlings under any of the water management practices. In the untreated control, M1 and M2 slightly reduced crop stand.

Without herbicide treatment, IR58 and IR29723-143-3-2-1 yielded similarly under any water management practice (Table 25); IR64 yields significantly decreased under M1 because of the reduced crop stand. IR58 and IR64 yielded higher under M1 and M2 with bensulfuron-methyl; IR29723-143-3-2-1 gave similar yields under all water management practices.

Yield reduction due to herbicide toxicity was higher in IR58 than in IR64. Herbicide toxicity reduced the yield of IR29723-143-3-2-1 only under M1. Under M3, yields in plots with or without herbicide did not significantly differ because the weed population was not competitive enough to reduce yield.

Butachlor was not included in the WS trial. Four water management practices were evaluated using IR29723-143-3-2-1 and IR64 (damaged by rats). N was applied at 90 kg/ha following the recommended split application.

Under any water management practice, tillering ability and panicle production were consistently lower in the untreated than in the treated plots (Table 26). More broadleaf weeds grew in plots irrigated at 4 DAS to 10 cm deep than in plots irrigated to 5 cm deep. Similarly, there were more broadleaf weeds with seeding into water than with seeding onto mud and irrigating later.

Grain yield reduction due to weed control was higher when rice was broadcast seeded onto mud

Table 25. Grain yield of broadcast seeded flooded rice as affected by water management and weed control practices. IRRI, 1986 DS.

Treatment	Grain yield[a] (t/ha)								
	IR58			IR29723-143-3-2-1			IR64		
	M1	M2	M3	M1	M2	M3	M1	M2	M3
No weed control	4.2 a	4.2 a	4.2 a	5.6 a	6.1 a	5.3 a	4.6 b	5.0 ab	6.0 a
Bensulfuron-methyl	4.7 ab	5.6 a	4.0 b	5.9 a	6.3 a	5.8 a	6.8 ab	7.0 a	5.9 b
Butachlor + 2,4-D	1.3 b	1.2 b	4.6 a	4.1 b	5.6 b	5.9 a	2.6 b	3.2 b	6.4 a

[a]In a row within the same variety or line, means followed by a common letter are not significantly different at the 5% level by DMRT. M1 = broadcast seeding of pregerminated rice into 5 cm water, M2 = broadcast seeding of pregerminated rice onto mud and irrigation 2 DAS, M3 = broadcast seeding of pregerminated rice onto mud and irrigation 4 DAS. CV = 29% for variety, 17% for water management, and 22% for weed control.

Table 26. Agronomic characteristics and yield of broadcast seeded flooded IR29723-143-3-2-1 as affected by water management and weed control practices. IRRI, 1986 WS.

Water management and weed control practices	Seedlings (no./m²)	Tillers (no./seedling)	Panicles (no./m²)	Grain yield[a] (t/ha)
Irrigated to 5 cm, 4 DAS				
No weed control	141	2.3	327	3.4
Bensulfuron-methyl	135	3.3	355	4.8
Irrigated to 10 cm, 4 DAS				
No weed control	92	3.8	316	4.6
Bensulfuron-methyl	82	5.8	368	5.4
Seeding into 10-cm water, drained at maximum tillering				
No weed control	65	3.1	207	3.3
Bensulfuron-methyl	88	5.5	330	3.7
Seeding into 10-cm water, drained at 10 DAS for 5 d				
No weed control	119	2.9	393	3.2
Bensulfuron-methyl	97	4.6	352	3.4

[a]Av of 3 replications. To compare 2 water management means at the same or different weed control treatment, LSD (.05) = 2.5 t/ha. To compare weed control means at the same water management treatment, LSD (.05) = 2.6 t/ha. CV = 20% for water management and 23% for weed control.

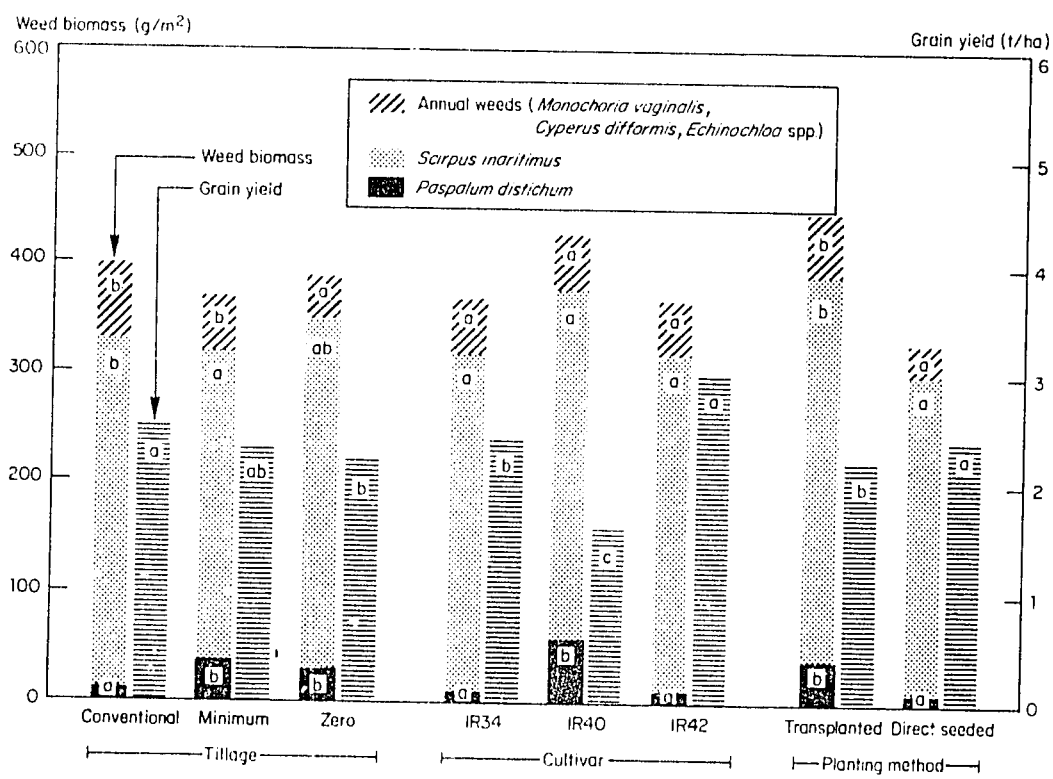
and irrigated at 4 DAS than when broadcast seeded into standing water. Irrigating the plots to 10 cm deep at 4 DAS produced higher yields than irrigating them to 5 cm deep.

With broadcast seeding into water, the time of draining did not significantly affect yields.

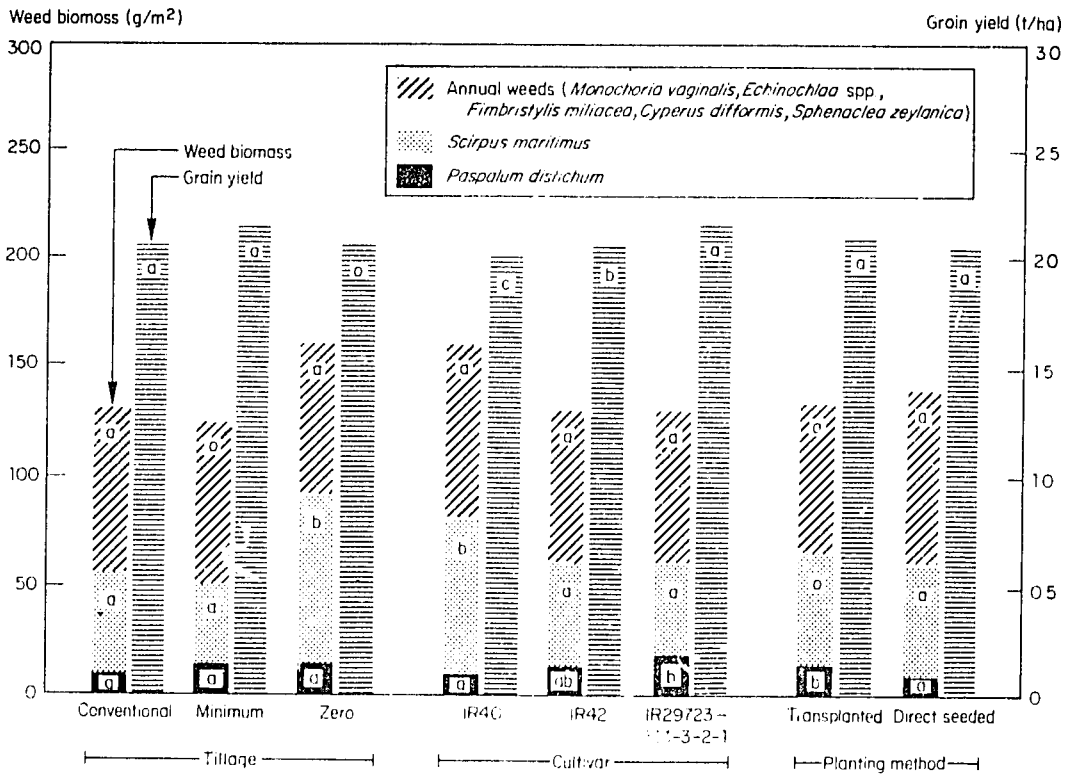
PERENNIAL WEEDS AND THEIR CONTROL

Agronomy Department

Irrigated rice. *Effect of tillage, cultivar, and planting method.* Research continued on the long-term effects of tillage level (conventional,



5. Weed biomass and grain yield in the 25th crop as affected by tillage, cultivar, and planting method, IRRI, 1986 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.



6. Weed biomass and grain yield in the 26th crop as affected by tillage, cultivar, and planting method, IRRI, 1986 WS. Within a parameter, and within a weed type or within grain yield, items with a common letter are not significantly different at the 5% level by DMRT.

minimum, and zero) and cultivar (IR34, IR40, and IR42) on weed shift. In DS (25th crop) and WS (26th crop), half of each cultivar treatment was transplanted and the other half direct seeded. IR34 was replaced with IR29723-143-3-2-1 in the 26th crop. Conventional tillage was one plowing and two harrowings, minimum tillage was one harrowing, and zero tillage was cutting and removing rice and weed debris.

In the 25th crop, conventional tillage gave substantially less *Paspalum distichum* but more *S. maritimus* than minimum tillage, and more annual weeds than zero tillage (Fig. 5). Grain yield decreased with each decrease in tillage intensity, but the difference was significant only between conventional and zero tillage. Yield was affected more by cultivar than by weed infestation. Significant yield differences were in the order IR42 > IR34 > IR40. The biomass of all weed types was significantly lower and grain yields higher with direct seeding.

In the 26th crop, *S. maritimus* biomass was significantly higher in the no-tillage than in the tilled plots (Fig. 6). The biomass of the other weeds and grain yield were, however, unaffected. Plots planted to IR40 had significantly less *P. distichum* but more *S. maritimus* than those planted to IR42 and IR29723-143-3-2-1. IR29723-143-3-2-1 yielded significantly higher than IR42, which yielded higher than IR40. Planting method did not influence weed control, except that of *P. distichum*, and grain yield.

Effect of cultivar, tillage, and herbicide. The study on the long-term effect of cultivar (IR36 and IR29723-143-3-2-1), tillage (one, two, and three harrowings), and herbicide (bensulfuron-methyl, propanil + 2,4-D, and untreated check) continued in DS (5th crop) and WS (6th crop). Each harrowing treatment was preceded by one plowing. Bensulfuron-methyl (0.05 kg ai/ha) was applied at 10 DAS and tank-mixed propanil + 2,4-D (1.5 + 0.5 kg ai/ha) was applied at 15 DAS.

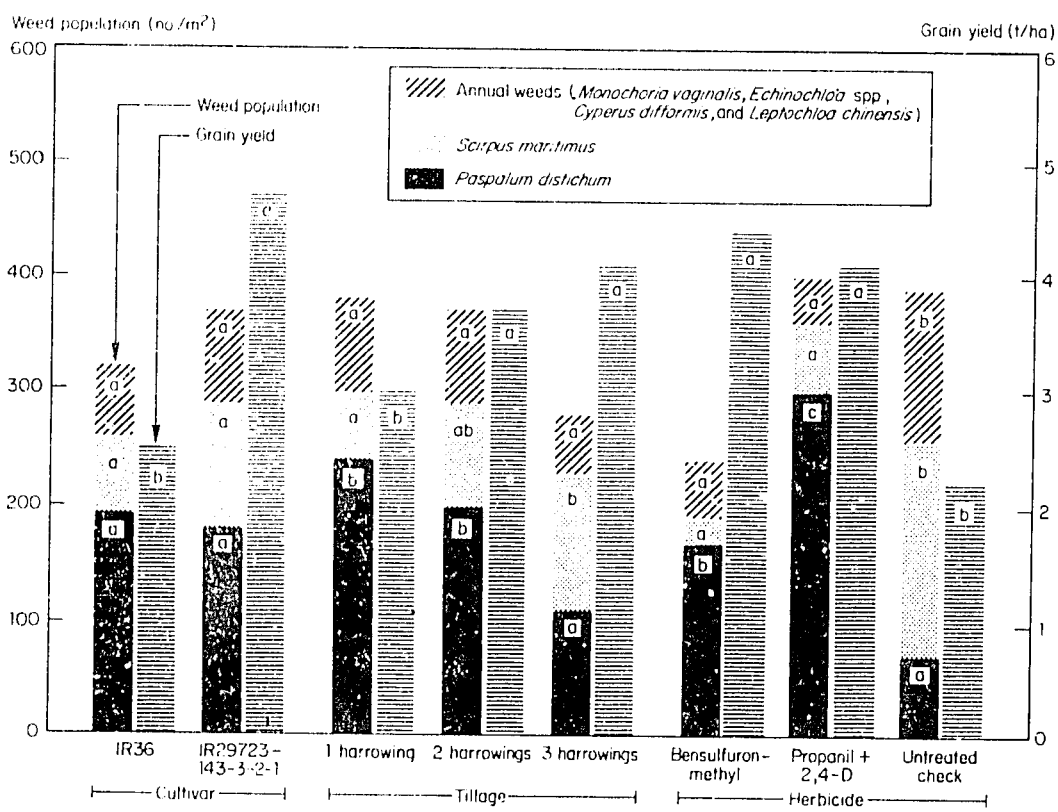
In the 5th crop, weed population was unaffected by cultivar type (Fig. 7); however, IR29723-143-3-2-1 yielded significantly higher than IR36. Three harrowings substantially reduced the *P. distichum* population but increased the *S. maritimus* stand relative to one harrowing. Two and three harrowings gave similar yields, which were significantly higher than that from one harrowing. The herbicides substantially controlled *S. maritimus* and the annual weeds, resulting in significant yield increases but high incidence of *P. distichum* over the untreated check.

In the 6th crop, cultivars again had no effect on the stand of any weed type, but IR29723-143-3-2-1 still outyielded IR36 (Fig. 8). *P. distichum* significantly decreased with each increase in tillage level. However, two and three harrowings led to high *S. maritimus* population. The annual weeds and grain yield were not affected by tillage intensity. The herbicides adequately reduced the stand of *S. maritimus* and gave significantly higher yields than the untreated check. However, the decrease in *S. maritimus* in the herbicide-treated plots was replaced by an increase in *P. distichum* population.

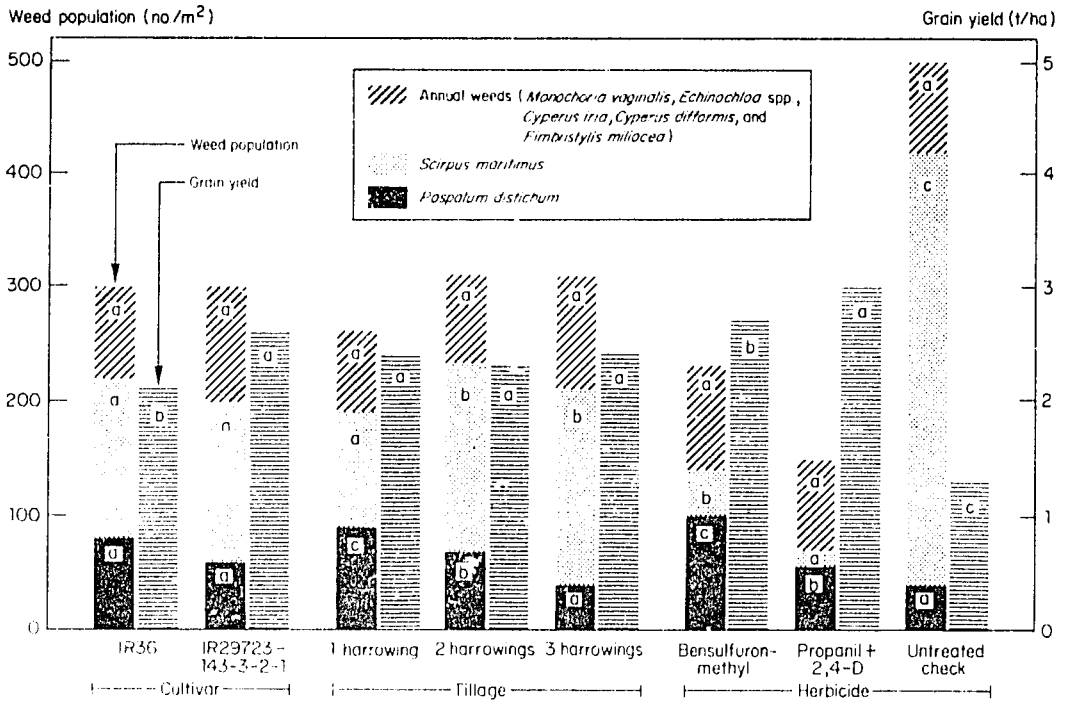
The significantly longer panicle and higher spikelet number of IR29723-143-3-2-1 may explain why its yield is higher than that of IR36 (Table 27).

Upland rice. A trial in DS examined the soil moisture-herbicide relationship in upland rice. The effect of water regime on preplant (glyphosate and SC 0224) and postemergence (bentazon and 2,4-D) herbicides against *Cyperus rotundus* in upland IR43 rice was tested, using water applied with a line source sprinkler (LSS). All plots were kept free of other weeds during the experiment.

The cumulative amounts of water applied from 4 to 120 DE to the plots nearest to or farthest from the LSS were 1,242, 1,004, 749, and 403 mm (M1 to M4). These amounts compared with 734 mm recorded by upland pan evaporation (UPE) during



7. Weed population and grain yield in the 5th crop as affected by cultivar, tillage, and herbicide, IRRI, 1986 DS. Within a parameter, and within a weed type or within grain yield, items with a common letter are not significantly different at the 5% level by DMRT.



8. Weed population and grain yield in the 6th crop as affected by cultivar, tillage, and herbicide, IRRI, 1986 WS. Within a parameter, and within a weed type or within grain yield, items with a common letter are not significantly different at the 5% level by DMRT.

Table 27. Yield components as affected by cultivar type.[a] IRRI, 1986 DS and WS.

Cultivar	5th crop (DS)		6th crop (WS)	
	Panicle length (cm)	Spikelets (no./panicle)	Panicle length (cm)	Spikelets (no./panicle)
IR36	19 b	68 b	21 b	91 b
IR29723-143-3-2-1	24 a	91 a	26 a	109 a

[a]Av of 3 replications, 3 tillage levels, and 3 herbicides.

the same period. Thus M1 and M2 were maintained above UPE, M3 at UPE, and M4 below UPE level at all stages of growth.

In M1 and M2, bentazon and 2,4-D were as effective as hand weeding in reducing the dry weight of *C. rotundus* (Table 28). As the moisture supply dropped to 749 mm, all herbicides were less effective than hand weeding. In M4, all herbicides were comparable; however, bentazon and 2,4-D

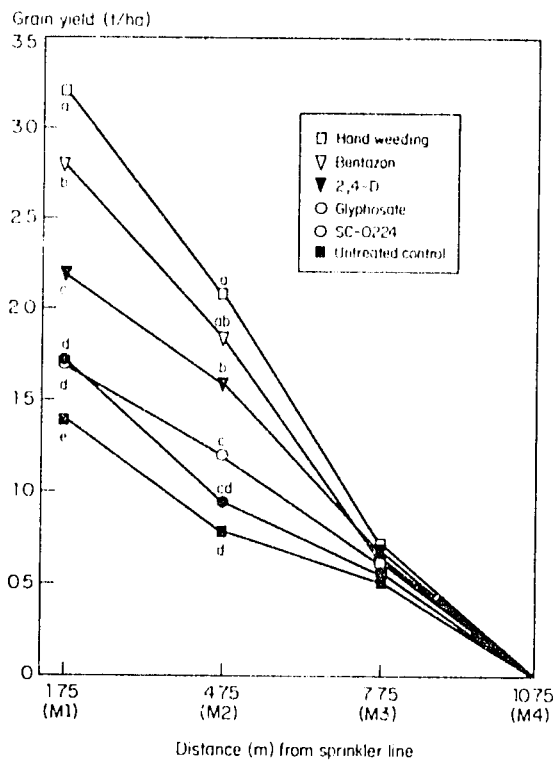
Table 28. Effect of herbicides on weed dry weight and rice panicles under 4 soil moisture regimes in upland IR43.[a] IRRI, 1986 DS.

Treatment	Application		Weed weight[b] (g/m²) at 35 DE				Panicles[c] (no./m²)		
	Rate (kg ai/ha)	Time	M1	M2	M3	M4	M1	M2	M3
Glyphosate	2.0	6 DBS	37 b	40 b	44 bc	32 bc	320 bc	258 b	206 a
SC 0224	2.0	6 DBS	53 bc	57 bc	52 c	29 bc	309 bc	243 b	195 ab
2,4-D (amine)	1.0	20 DE	15 a	15 a	26 b	22 ab	340 b	321 a	224 a
Bentazon	2.0	20 DE	11 a	13 a	26 b	24 ab	397 a	316 a	215 a
Hand weeding	–	10, 25, 40 DE	6 a	5 a	3 a	2 a	394 a	323 a	218 a
Untreated check	–	–	64 c	65 c	59 c	49 c	296 c	229 b	168 b

[a]Av of 4 replications. [b]*Cyperus rotundus*. [c]All treatments were comparable in M4.

maintained their superiority over the untreated control.

In M1, hand weeding gave the highest grain yield, followed by bentazon and 2,4-D in decreasing order (Fig. 9). In M2, bentazon and hand weeding gave comparable yields. Hand weeding, bentazon, and 2,4-D produced higher panicle numbers in M1 and M2. All the treatments gave similar yields when soil moisture was maintained at the M2 level.



9. Effect of herbicide on IR43 yield under 4 soil moisture regimes, IRRI, 1986 DS. Within a given distance, values with a common letter are not significantly different at the 5% level by DMRT.

COMPETITIVE ABILITY OF AN F_1 RICE HYBRID

Agronomy Department

In a trial conducted in 1986 DS, an F_1 rice hybrid (IR21845-90-3A/IR54) was as competitive against weeds as one of its parents (IR21845-90-3B) and more competitive than the other parent (IR54) and IR64. Weeds caused a significant reduction in plant height in IR64, but not in the other cultivars. The leaf area index (LAI) of the hybrid was not affected by weed competition, but that of the other cultivars was significantly reduced.

With all cultivars, weeds caused a significant yield reduction (Table 29). The hybrid had the highest yields and the least yield loss due to weeds.

When the same trial was conducted in 1986 WS, the hybrid and its parents performed poorly, probably because of lodging. In the treatment that was hand weeded at 21 DT, the hybrid yielded 2.2 t/ha, whereas IR64 yielded 3.3 t/ha.

COMPETITION BETWEEN TRANSPLANTED RICE AND *ISCHAEMUM RUGOSUM*

Agronomy Department

Ischaemum rugosum, an annual grass weed, is becoming increasingly important as a weed of rice grown in rainfed fields in some countries in South and Southeast Asia. A trial in 1985 WS and DS determined the effect of weed density on the growth of transplanted rice (TPR).

Rice plants were significantly taller than the weeds at 30 DT at all weed densities in both seasons (Fig. 10, 11). In WS, when there were 5 and 10 *I. rugosum* plants/m^2, the crop and the weed did not significantly differ in plant height at 45 DT (Fig. 10). But at the other weed densities, *I. rugosum* was significantly taller than the rice plant.

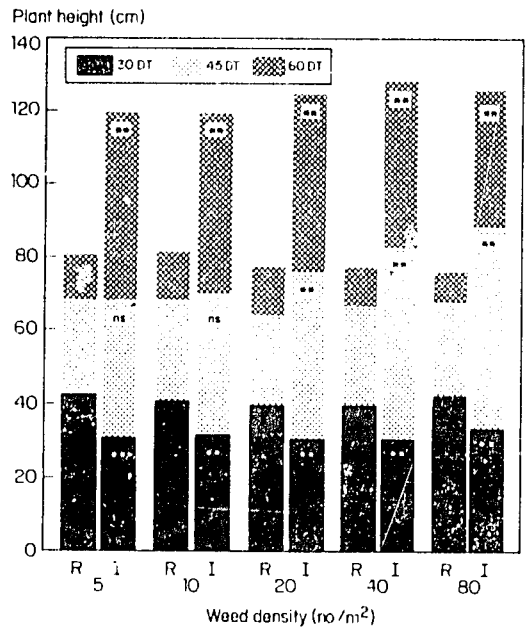
Table 29. Grain yield of rice cultivars as affected by method of weed control. IRRI, 1986 DS.

Treatment	Grain yield (t/ha)			
	IR64	IR54	IR21845-90-3B	IR21845-90-3A/IR54
Hand-weeded, 21 DT	4.6 a	5.2 a	5.5 a	5.9 ab
Hand-weeded, 15 + 35 DT	4.5 a	4.7 ab	5.2 ab	6.6 a
Butachlor (1.0 kg ai/ha), 3 DT	4.6 a	3.7 bc	4.7 ab	5.1 bc
Unweeded	1.8 b	2.6 c	3.8 b	4.3 c
Yield loss due to weeds (%)[a]	61	50	31	27

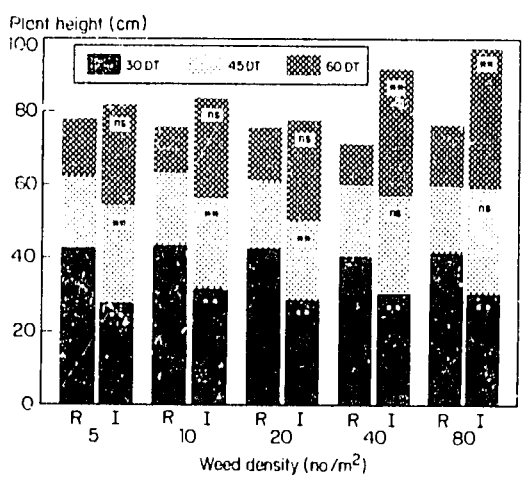
[a]Compared to the treatment that was hand weeded at 21 d after transplanting (DT).

At 60 DT, *I. rugosum* was taller than rice at all plant densities.

During DS, with densities of 5, 10, and 20 *I. rugosum* plants/m^2, the rice plants were significantly taller than the weeds up to 45 DT (Fig. 11). At 60 DT, the heights of the weed and the crop were not significantly different at those densities. With 40 and 80 *I. rugosum* plants/m^2, no significant difference was observed between the height of the crop and that of the weed at 45 DT, but by 60 DT the weed was taller.



10. Effect of *Ischaemum rugosum* density on the height of rice (R) and weed (I), IRRI, 1985 WS. DT = days after transplanting.



11. Effect of *I. rugosum* density on the height of rice (R) and weed (I), IRRI, 1985 DS. DT = days after transplanting.

The difference in response between WS and DS was due to the more intense competition for light that occurred in WS.

Weed competition reduced the number of tillers per hill and rice grain yield in both WS and DS. In WS the number of tillers/hill was significantly reduced by competition with 10 *I. rugosum* plants/m^2, while yield was reduced by 5 *I. rugosum* plants/m^2 (Table 30). In DS, however, 20 plants/m^2 were needed to cause reduction in both tiller number and yield. In both seasons, grain yield was negatively correlated with weed density.

WEED-INSECT INTERACTIONS

Agronomy and Entomology Departments

Transplanted rice. Four trials in different areas of the Philippines at different times evaluated the effects of weed control treatment and insect control method on weeds and insects in TPR. All trials had two cultivars (one moderately resistant to insects, the other susceptible), different levels of weed control, and three insect control levels (economic threshold, vegetative phase insect protection, and no insect control).

In Victoria, Laguna, the insect population was so low that no significant differences occurred within each weeding treatment as a result of the insect control treatments applied to both cultivars. Differences in yield were observed in response to the weed control treatments.

Table 30. Effect of *Ischaemum rugosum* density on the number of tillers per hill and the grain yield of IR58, IRRI, 1985 DS and WS.

Weed density (no./m^2)	Wet season		Dry season	
	Tillers (no./hill)	Grain yield (t/ha)	Tillers (no./hill)	Grain yield (t/ha)
0	17.7 a	3.9 a	17.2 a	4.0 a
5	15.8 ab	3.3 b	16.9 a	4.0 a
10	13.9 bc	2.7 c	16.5 a	3.9 a
20	12.3 bcd	2.2 c	14.6 b	2.9 b
40	11.1 cd	1.1 d	14.6 b	2.7 b
80	10.1 d	0.7 d	14.1 b	2.3 c

In two trials conducted at IRRI, the two cultivars did not significantly differ in insect damage, weed weight, or yield. Insect pressure was so low that yields did not differ significantly among insect control treatments within each weed control method. In one trial, with all insect control methods, the yields of plots that were weeded (either by hand or with herbicides) were significantly higher than those from unweeded plots. The plots that were kept weed free yielded significantly higher than those that were not weeded. In the other trial, plots that were kept weed-free by hand or hand weeded only once yielded significantly higher than unweeded plots. With herbicides, yields were significantly higher than in unweeded plots when vegetative insect protection was used, but not when there was no insect control or when the economic threshold level was used.

In the fourth trial conducted in Jaen, Nueva Ecija, in 1986 DS, the weed population was low and deadheart infestation occurred late, so vegetative insecticide application did not affect stem borer infestation. As a result, yields were not significantly different, irrespective of the cultivar grown or the weed control or insect control method used.

Effect of planting method. In another experiment, weed (herbicide and no weed control) and insect control methods were evaluated across four methods of planting in Jaen: broadcast seeding of flooded rice, modified broadcast seeding of flooded rice, water seeding, and transplanting. The planting method had no effect on weed weight. When transplanting was used, the plots treated with herbicide with complete insect protection had significantly lower weed weights than the plots with no weed control, whether or not insecticide was applied. With the other planting methods, weed weights were not affected by weed control method or insecticide treatment. However, weed weights were consistently higher when insecticides were applied (average 172 g/m^2 vs 121 g/m^2), indicating that the insecticides were controlling insects that were attacking the weeds.

There were no differences among planting methods and among weed control and insect control methods with respect to damage by whorl maggot, caseworm, semilooper, and green hairy caterpillar. Whitehead percentage was greater in TPR than in the other planting methods when herbicide was applied, whether insecticide was applied or not. However, this was not reflected in the yields. Averaged across all planting methods, yields were significantly higher when herbicides were applied than when there was no weed control. Yields were not affected by the level of insect protection. In a broadcast seeded flooded trial also conducted in Jaen, results were similar when yields were averaged across 7 seeding rates ranging from 100 to 400 kg/ha.

CULTURAL CONTROL OF *CYPERUS ROTUNDUS*

Agronomy Department

The effect of plowing depth (10, 20, and 30 cm) and rototillage interval (0, 7, and 14 d) on *C. rotundus* control in upland rice was examined in DS. Rototillage was done three times.

Plowing depth had no effect on weed control and grain yield. Rototillage at intervals beyond 0 d resulted in significant reductions in weed and tuber counts and weed dry weight, and an increase in grain yield. The 7- and 14-d intervals gave comparable weed control and grain yield (Table 31).

Table 31. Effect of plowing depth and rototillage interval on *Cyperus rotundus* control and yield of upland IR43.[a] IRRI, 1986 DS.

Treatment	Weed count (no./m^2) 30 DE	Weed dry weight (g/m^2) 30 DE	Live tuber count (no./m^2) in 0-30 cm At seeding	Live tuber count (no./m^2) in 0-30 cm At harvest	Grain yield (t/ha)
Plowing depth					
10 cm	99 a	128 a	398 a	970 a	1.2 a
20 cm	86 a	81 a	336 a	804 a	1.4 a
30 cm	91 a	129 a	387 a	787 a	1.4 a
Rototillage interval					
0 d	137 b	152 b	519 b	1261 b	0.9 b
7 d	71 a	92 a	325 a	743 a	1.5 a
14 d	69 a	92 a	279 a	558 a	1.6 a

[a]Av of 4 replications.

INTEGRATED WEED MANAGEMENT

Agronomy Department

Broadcast seeded flooded rice. Three rice cultivars (IR64, IR29723-143-3-2-1, Binato) were broadcast seeded in the field at 100 and 200 kg/ha. N as urea at 100 kg N/ha was applied either 1/3 basal incorporated, 1/3 applied at 30 DAS, and 1/3 applied before panicle initiation or 2/3 topdressed at 15 DAS and 1/3 before panicle initiation. Two weeding regimes butachlor (1.5 kg/ha) applied at 3 DBS followed by 2,4-D (0.8 kg/ha) applied at 20 DAS, and an untreated check were also evaluated.

Table 32. Effect of cultivar and weed control on plant height, tiller count, and total weed weight of irrigated broadcast seeded flooded rice.[a] IRRI, 1986 DS.

Treatment	Plant height (cm)	Tillers (no./m²)	Total weed weight (g/m²)
Variety[b]			
IR64	77 c	505 a	215 ab
IR29723-143-3-2-1	96 b	495 a	253 b
Binato	124 a	405 a	165 a
Weed control[c]			
Butachlor fb 2,4-D	99 a	498 a	162 a
Unweeded check	98 a	439 b	260 b

[a]Sampled at 74 DAS. [b]Av of 4 replications, 2 seeding rates, 2 N management levels, and 2 weeding regimes. [c]Av of 4 replications, 3 cultivars, 2 seeding rates, and 2 N management levels. fb = followed by.

Table 33. Effect of seeding rate and N management on tiller count and plant height of 3 irrigated broadcast seeded flooded rices.[a] IRRI, 1986 DS.

Treatment	Tillers (no./m²)	Plant height (cm)
Seeding rate[b] (kg/ha)		
100	423 b	99 a
200	514 a	98 a
N management[c]		
1/3 BI, 1/3 at 30 DAS, 1/3 BPI	473 a	100 a
2/3 at 15 DAS, 1/3 BPI	464 a	97 b

[a]Sampled at 74 DAS. [b]Av of 4 replications, 3 cultivars, 2 N management levels, and 2 weeding regimes. [c]Av of 4 replications, 3 cultivars, 2 seeding rates, and 2 weeding regimes. BI = basal incorporated, BPI = before panicle initiation.

Binato plants were tallest, followed by IR29723-143-3-2-1 (Table 32); IR64 was the shortest. Tiller number was similar for all cultivars, while total weed weight was lowest in Binato plots and highest in IR29723-143-3-2-1 plots. Butachlor-treated plots had more tillers and lower weed weights than the untreated check. Plant height of each cultivar was the same in butachlor and untreated plots.

There were more tillers at seeding rate 200 kg/ha than at 100 kg/ha, but plant height was similar at both seeding rates (Table 33). Tiller number was not affected by the type of N management. Plants were taller when N was applied in three splits.

At seeding rate 100 kg/ha, weed weight was lower when N was applied in 2 splits than in 3 (Table 34). Doubling the seeding rate also reduced weed weights and at the same time masked the effect of N management level.

In butachlor-treated plots, IR64 yielded higher than IR29723-143-3-2-1 and Binato when N was applied in three splits (Table 35). In unweeded plots, IR29723-143-3-2-1 gave the highest yield; yields of IR64 and Binato were similar. When N was applied in two splits, IR64 and IR29723-143-3-2-1 had similar yields, which were higher than that of Binato.

Among the three cultivars, only IR64 was affected by the type of N management. In butachlor-treated plots, IR64 yielded higher when N was applied in three splits. But when no weed control was applied, IR64 with two splits yielded more than when N was applied in three splits. This indicates that the efficiency of a three-split application of N can be fully realized if there is effective

Table 34. Effect of seeding rate and N management on the growth of weeds in irrigated broadcast seeded flooded rices.[a] IRRI, 1986 DS.

Seeding rate (kg/ha)	Total weed weight (g/m²)		
	1/3 N BI, 1/3 at 30 DAS, 1/3 BPI	2/3 N at 15 DAS, 1/3 BPI	Difference
100	285	225	60**
200	171	163	8ns
Difference	114**	62*	

[a]Av of 4 replications, 3 cultivars, and 2 weeding regimes. Sampled at 74 DAS.

weed control, particularly with N-responsive cultivars such as IR64.

Except for Binato, which was not affected by weed control, grain yields of the cultivars were higher in butachlor-treated plots than in the untreated plots.

Rainfed transplanted rice. Three rice cultivars (IR64, IR29723-143-3-2-1, and Binato), 2 N management levels (researcher's split or 1/3 basal incorporated without standing water, 1/3 applied at 20-30 DT, and 1/3 applied at 5-7 d before panicle initiation; farmer's practice or 1/2 applied at 15-20 DT, and 1/2 at early booting), and 3 weeding regimes (butachlor, hand-weeded at 15 and 30 DT, and untreated check) were evaluated in rainfed fields.

The hand-weeded check gave the highest tiller count and LAI and the lowest weed weight. Butachlor was comparable with the untreated check (Table 36) because it failed to control the dominant weed, *S. maritimus*, in the experimental area.

Considering N management, IR29723-143-3-2-1 had the highest tiller count, and Binato the lowest (Table 37). IR64 and IR29723-143-3-2-1 had comparable LAI, which was higher than that of Binato. Total weed weight was lower in IR29723-143-3-2-1 and Binato plots.

Table 35. Effect of cultivar, N management, and weed control on the grain yield of 3 irrigated broadcast seeded flooded rices.[a] IRRI, 1986 DS.

Cultivar	Grain yield (t/ha)		
	1/3 BI, 1/3 at 30 DAS, 1/3 BPI	2/3 at 15 DAS, 1/3 BPI	Difference
	Butachlor		
IR64	4.38 a	3.46 a	0.92**
IR29723-143-3-2-1	3.36 b	3.19 a	0.17ns
Binato	1.72 c	1.81 b	-0.09ns
	Unweeded		
IR64	1.65 b	2.47 a	-0.82**
IR29723-143-3-2-1	2.39 a	2.60 a	-0.21ns
Binato	1.30 b	1.52 b	-0.22ns
	Difference		
IR64	2.73**	0.99**	
IR29723-143-3-2-1	0.97**	0.59*	
Binato	0.42ns	0.29ns	

[a]Av of 4 replications.

Table 36. Tiller number, leaf area index, and grain yield of rainfed transplanted rices and total weed weight as affected by cultivar and weed control regime.[a] IRRI, 1986 WS.

Weed control	Tillers[b] (no./m²)				Leaf area index[b]				Total weed weight[b] (g/m²)				Grain yield[c] (t/ha)			
	IR64	IR29723-143-3-2-1	Binato	Mean	IR64	IR29723-143-3-2-1	Binato	Mean	IR64	IR29723-143-3-2-1	Binato	Mean	IR64	IR29723-143-3-2-1	Binato	Mean
Butachlor	168	211	110	163 b	1.58	2.07	1.25	1.64 b	315	245	263	275 b	0.92 b	2.20 b	1.26 a	1.46
Hand-weeded twice	368	381	256	336 a	3.09	2.98	2.53	2.87 a	8	5	5	6 a	2.83 a	4.30 a	1.19 a	2.78
Untreated check	176	193	105	158 b	1.86	1.98	1.23	1.69 b	300	282	226	269 b	0.77 b	2.08 b	1.33 a	1.40
Mean	237 B	262 A	158 C	219	2.18 A	2.35 A	1.67 B	2.07	208 B	178 A	165 A	183	1.51	2.86	1.26	1.88

[a]Av of 4 replications and 2 N management levels. Values in a column followed by a common lowercase letter, and values in a row within a parameter (e.g., tiller count) followed by a common capital letter are not significantly different at the 5% level by DMRT. [b]Sampled about 65 days after transplanting. [c]LSD (0.05) between 2 cultivar means at each weed control = 0.44. Interaction between cultivar and weed control regime is significant at the 1% level by DMRT (*F*-value = 25.84**).

Tiller count and LAI were higher, and total weed count was lower with the researchers' split, indicating that this is a more efficient method of N application than the farmer's practice.

A correlation analysis indicated that, as tiller count and LAI increased, total weed count and total weed weight decreased.

N management did not affect the grain yield of the three rices, but weed control did. For IR64 and IR29723-143-3-2-1, two hand weedings gave the highest yields, while butachlor plots gave yields similar to that of the unweeded check. Binato yields were not affected by weed control.

IR29723-143-3-2-1 consistently gave the highest yields among the cultivars, regardless of weed control. However, IR64 yield was similar to Binato's when butachlor was applied. When plots were hand weeded twice, IR64 gave higher yields than Binato. When there was no weed control, Binato yielded higher than IR64, indicating that IR64 is more susceptible to weed pressure than Binato.

Upland rice at IRRI and in Batangas. A field experiment at IRRI evaluated the effect of cultivar (IR43, UPLRi-5, and Kinandang Patong), seeding method (lithao and inverted-T seeder), and weed control (hand weeded at 15 and 35 DE, butachlor [2.5 kg/ha] followed by 2,4-D [0.8 kg/ha], and untreated check) on the growth of rice and weeds in upland fields.

Seeding method had no effect on the growth of rice and weeds. Tiller count and LAI were highest, and total weed weight was lowest with the hand-weeded check for all cultivars (Table 38). Among the cultivars, IR43 was the most susceptible to weed pressure, with about 81% reduction in tiller count and 83% reduction in LAI. UPLRi-5 was less susceptible than IR43, with 35% reduction in tiller count and 49% in LAI. Kinandang Patong was the least susceptible with only 27% reduction in tiller count and 33% in LAI.

When weed control was applied, IR43 had more tillers than either UPLRi-5 or Kinandang Patong. With no weed control, UPLRi-5 and Kinandang Patong had more tillers than IR43. This further indicates that the susceptible IR43 requires an effective weed control to exert its full potential. The same trend was observed in LAI.

Cultivar significantly affected total weed weight, which was lowest in the hand-weeded plots and highest in the untreated check. Total weed weight was highest in IR43 plots.

A correlation analysis indicated that total weed weight decreased with increase in tiller count and LAI.

Typhoons occurred during the reproductive stage of Kinandang Patong, and the plants lodged and produced no yield. Because of insufficient degrees of freedom, it was not statistically possible to analyze the grain yield data.

In Batangas, weed pressure was extremely high, resulting in zero yield from the unweeded plots (Table 39). Although all weeding regimes substantially reduced weed weight and increased grain yield, only properly timed hand weedings led to high yields. Plots hand weeded earlier than 30 DE gave low yields. The yield discrepancy between IR43 and UPLRi-5 could be due to the difference in height, because both cultivars produced similar panicle numbers. IR43, a short cultivar, yielded significantly lower than UPLRi-5. Most IR43 plots were covered with weeds at flowering.

Effect of azolla. *Flooding.* The effect of flooding to a depth of 15 cm for varying periods at 1 DT and

Table 37. Tiller number and leaf area index of rainfed transplanted rices and total weed count as affected by cultivar and N management.[a] IRRI, 1986 WS.

N management	Tillers (no./m²)				Leaf area index				Total weed count (no./m²)			
	IR64	IR29723-143-3-2-1	Binato	Mean	IR64	IR29723-143-3-2-1	Binato	Mean	IR64	IR29723-143-3-2-1	Binato	Mean
Researcher's split	262	291	158	234	2.58	2.70	1.76	2.35	216	210	201	209
Farmer's practice	222	232	158	204	1.78	2.00	1.58	1.78	264	241	224	243
Difference	30	59	0	30*	0.80	0.70	0.18	0.56**	−48	−31	−23	−34*

[a]Av of 4 replications and 3 weeding regimes. Sampled about 65 d after transplanting.

Table 38. Tiller count and leaf area index of 3 rices grown in upland fields and total weed weight as affected by cultivar and weed control.[a] IRRI, 1986 WS.

Weed control[b]	Tillers[c] (no./m²)				Leaf area index[c]				Total weed weight[d] (g/m²)			
	IR43	UPLRi-5	Kinandang Patong	Mean	IR43	UPLRi-5	Kinandang Patong	Mean	IR43	UPLRi-5	Kinandang Patong	Mean
Hand weeded twice	418 a	241 a	256 a	305	3.19 a	2.55 a	1.98 a	2.57	26	6	5	12 a
Pendimethalin	300 b	208 ab	212 ab	240	2.18 b	2.15 a	1.91 a	2.08	62	38	16	38 b
fb 2,4-D												
Untreated check	81 c	157 b	188 b	142	0.54 c	1.29 b	1.32 b	1.05	224	150	131	168 c
Mean									104 b	65 a	50 a	73
Two cultivar means at each weed control (LSD = 0.05)				60				0.60				

[a] Av of 4 replications and 2 seeding methods. [b] Hand weeding was done at 15 and 35 DE. Pendimethalin at 2.0 kg/ha was applied preemergence. fb = followed by. 2,4-D at 0.8 kg/ha was applied at 20 DE. [c] Sampled at 78 DE. [d] Sampled at 60 DE.

azolla inoculation on the growth of rice was studied in a greenhouse trial. When azolla was inoculated, flooding reduced plant height, tiller number, number of productive tillers, dry matter, and yield. These characters were not affected by flooding when azolla was absent. When flooding occurred for at least 8 h, grain yield was significantly lower when azolla was inoculated than when treatments had no azolla (Table 40). Shorter flooding durations had no effect on grain yield.

Amount of inoculum. In another greenhouse trial, it was observed that light transmission ratio and O_2 content of the water — factors that favor weed seed germination and growth — and pH of the water decreased as the amount of inoculated azolla increased (Table 41). This is a possible explanation of how azolla suppresses weeds.

DIFFERENTIAL WEED-SUPPRESSING ABILITY OF RAINFED LOWLAND RICE

Multiple Cropping Department

The weed-suppressing ability of 12 rice cultivars of varying plant stature was evaluated under rainfed and flush-irrigated conditions at 2 weed management levels during 1985 WS at Solana, Cagayan, Philippines.

In the rainfed trial, rainfall was inadequate to maintain shallow flooding during most of the vegetative period of the experiment (Fig. 12). Soil moisture tension reached 47 cb for a brief period at the panicle initiation stage of the short-duration cultivars and increased again shortly after flowering of the late-maturing cultivar Wagwag Fino. *Scirpus supinus* L. and *Paspalum distichum* L. were the most important weed species (Table 42). Sedges dominated the weed complex in terms of dry weight at harvest in the irrigated experiment (Table 43). Grasses dominated the weed complex at the rainfed site.

At 50 DT, differences in plant height among cultivars were not significantly correlated with differences in weed weight (Table 44); however, tiller number was negatively correlated with weed weight. At harvest, weed weights were negatively correlated with plant height and days to flowering in both environments (Table 44).

For the short cultivars as a group, most of the accumulated weed weight at harvest occurred after

Table 39. Effect of weeding regime on weed control and yield of upland rice in Batangas, Philippines, 1986 WS.[a]

Treatment[b]	Time[c]	Weed weight at 52 DE (g/m^2)	Yield (t/ha)
Butachlor	PE	313 c	0.8 e
Butachlor fb IRC	PE fb 25 DE	260 bc	1.0 e
Butachlor fb HW	PE fb 30 DE	25 a	2.7 c
HW fb IRC	10 fb 25 DE	277 bc	1.3 e
HW fb IRC	20 fb 25 DE	148 ab	1.9 d
IRC fb HW	10 fb 30 DE	35 a	3.3 b
IRC fb HW	25 fb 35 DE	22 a	3.0 bc
2 HW	20 & 35 DE	25 a	3.5 ab
3 HW	10, 30, & 40 DE	6 a	3.9 a
Unweeded check	–	546 d	0 f

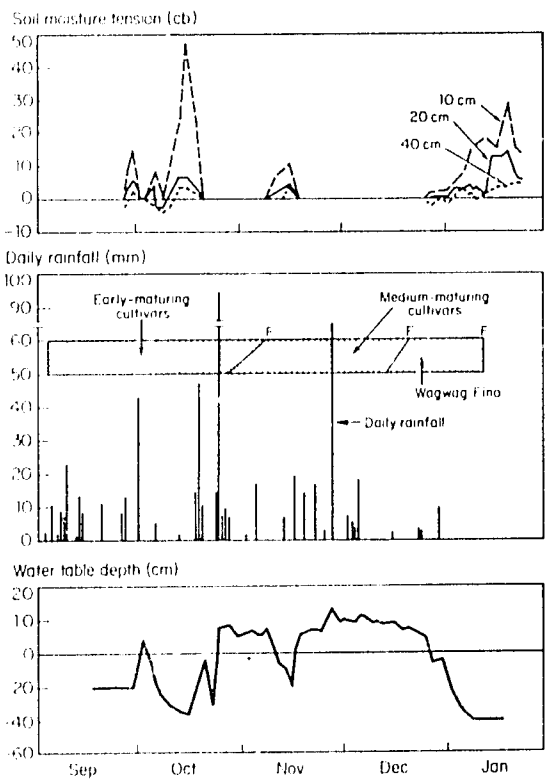
[a]Av of 3 replications and 2 cultivars (IR43 and UPLRI-5). [b]Butachlor was applied at 2.0 kg ai/ha. IRC = interrow cultivation, fb = followed by, HW = hand weeding. [c]PE = preemergence, DE = days after emergence.

Table 40. Grain yield as affected by flooding duration and azolla. IRRI, 1985.

Flooding duration (h)	Grain yield (g/pot)		
	No azolla	With azolla	Difference
0	64 a	70 a	-6^{ns}
1	54 a	59 ab	5^{ns}
2	60 a	66 a	-6^{ns}
4	61 a	61 ab	0^{ns}
8	64 a	40 bc	24*
24	60 a	32 c	28*
48	62 a	19 c	43**

Table 41. Effect of azolla cover on light transmission ratio (LTR), O_2 content of water, and water pH at 5 d after inoculation. IRRI, 1986.

Azolla rate (g/m^2)	LTR (%)	O_2 content of water (ppm)	Water pH
0	54.1 a	9.9 a	9.5 a
100	28.3 b	9.2 a	9.5 a
200	13.3 c	8.4 ab	9.3 a
300	13.7 c	6.6 bc	9.1 ab
400	11.8 c	6.1 c	8.5 c
500	12.4 c	5.4 c	8.6 bc



12. Soil moisture tension at 10, 20, and 40 cm; daily rainfall; and water table depth (40 cm), Bangag, Solana, Cagayan, Philippines, 1985-86. F = flowering period of the preceding cultivar group.

50 DT (Fig. 13). Only a small increase in weed weight was observed during this period with the intermediate and tall cultivars. About one-half of the plant height of the tall cultivars occurred after 50 DT, while the short cultivars had nearly reached their mature height by this time (Fig. 13).

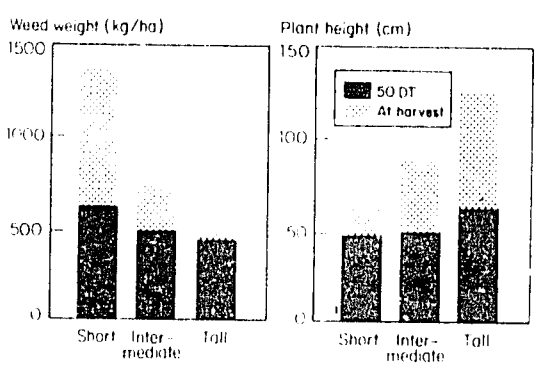
Wagwag Fino and BR539-119-1-1-2 suppressed weed growth most successfully under rainfed conditions (Fig. 14). The differences in weed weight at this stage were negatively correlated with plant height in both rainfed and flush-irrigated environments (Fig. 14, 15). IR60 and IR36 had two to

Table 42. Dominant weed species growing in association with transplanted rice (mean of 9 samples) at harvest in the unweeded treatment. Solana, Cagayan, Philippines, 1985-86 WS.

Rank	Weed species	Total dry matter (%)
	Rainfed conditions	
1	*Paspalum distichum* L.	18.5
2	*Echinochloa colona* (L.) Link	15.3
3	*Fimbristylis miliacea* (L.) Vahl	13.3
4	*Cynodon dactylon* (L.) Pers.	13.0
5	*Cyperus iria* L.	7.7
6	*Cyperus difformis* L.	5.9
7	*Ischaemum rugosum* Salisb.	5.8
8	*Eclipta alba* (L.) Hassk.	4.9
	Flush-irrigated conditions	
1	*Scirpus supinus* L. var. *lateriflorus* (Gmel.) T. Koyama	39.9
2	*Cynodon dactylon* (L.) Pers.	9.3
3	*Eclipta alba* (L.) Hassk.	8.8
4	*Ludwigia perennis* L.	8.3
5	*Cyperus difformis* L.	7.8
6	*Echinochloa colona* (L.) Link	6.2
7	*Paspalum distichum* L.	5.7

Table 43. Dry weight at harvest, by vegetative class, of weeds growing in association with rice (mean of 9 samples) in the unweeded treatment. Solana, Cagayan, Philippines, 1985-86 WS.

Weed classification	Dry weight (%)	
	Flush-irrigated	Rainfed
Broadleaves	26	10
Sedges	52	34
Grasses	22	56

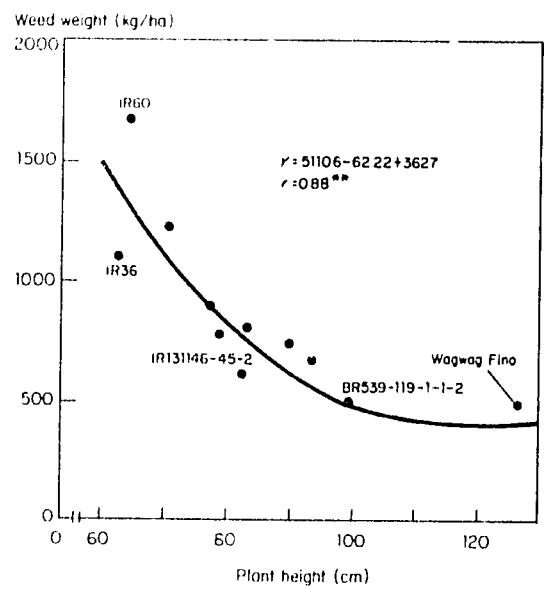


13. Weed weight and plant height of different cultivars at 50 d after transplanting (DT) and at harvest in the rainfed environment. Solana, Cagayan, Philippines, 1985.

Table 44. Correlation coefficients (*r*) between weed weight and plant traits at 50 DT and at harvest in 2 hydrological environments. Solana, Cagayan, Philippines, 1985-86 WS.

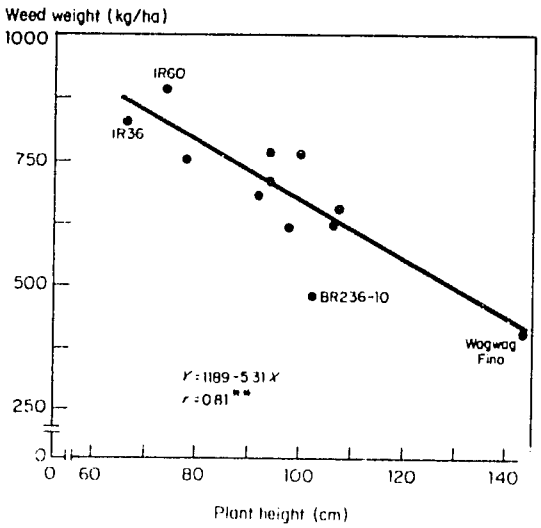
Plant trait	Correlation	
	Weed weight at 50 DT	Weed weight at harvest
	Rainfed environment	
Plant height	-0.27^{ns}	-0.88^{**}
Tiller number or panicle number[a]	-0.81^{**}	–
Days to flowering	–	-0.80^{**}
Total dry matter	-0.01^{ns}	-0.79^{**}
Grain yield	-0.63^{**}	-0.85^{**}
	Irrigated environment	
Plant height	-0.45^{ns}	-0.81^{**}
Tiller number or panicle number[a]	-0.21^{ns}	–
Days to flowering	–	-0.69^{*}
Total dry matter	-0.75^{**}	-0.72^{*}
Grain yield	-0.46^{ns}	-0.56^{ns}

[a]Tiller number per m^2 was correlated with weed weight at 50 d after transplanting (DT); panicle number at maturity was correlated with weed weight at harvest.

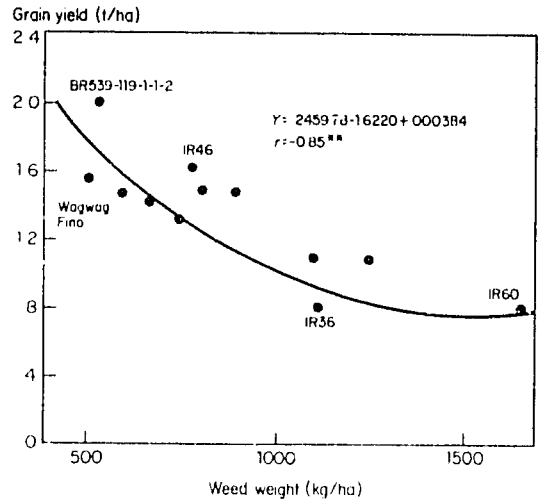


14. Effect of plant height on weed weight at harvest in the rainfed environment. Solana, Cagayan, Philippines, 1985.

three times as much weed weight at harvest as the above cultivars. The results suggest that the weed-suppressing ability of the taller cultivars was most clearly expressed during the period after 50 DT.



15. Effect of plant height on weed weight at harvest under flush-irrigated conditions. Solana, Cagayan, Philippines, 1985.



16. Effect of weed weight on grain yield in the rainfed environment. Solana, Cagayan, Philippines, 1985.

Grain yields were strongly and negatively related to weed weights at harvest under rainfed conditions (Fig. 16). The correlation in the irrigated environment was also negative but not statistically significant. This was apparently due to the smaller differences in weed weight among cultivars observed with irrigation (Fig. 14). Among the cultivars tested, the intermediate improved BR539-119-1-1-2 and IR46, and the tall traditional Wagwag Fino had the highest grain yields under rainfed conditions.

In drought- and submergence-prone rice-growing areas, the high production risks lead to less farmers' investment in hand weeding. Currently grown cultivars are tall and competitive with weeds.

Plant stature, days to flowering, and tillering potential were shown to be important traits in evaluating the weed-suppressing ability of rice.

Irrigation water management

Water Management, Agricultural Economics, and Soils Departments

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WATER HARVESTING AND CONSERVATION TO INCREASE RAINFED RICELAND PRODUCTIVITY

Water Management Department

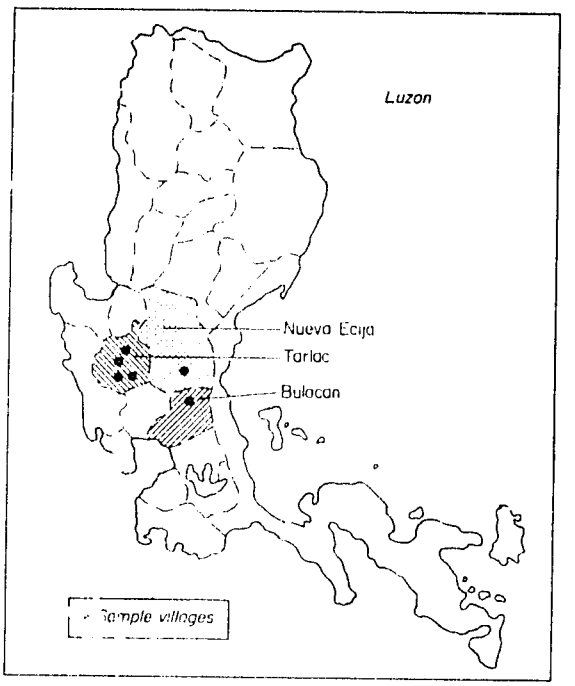
In most of monsoonal Asia, the wet season (WS) rainfall is significantly more than necessary for a rice crop, and the unused rainwater is lost as runoff. Rice yields and production could be increased in rainfed areas if the excess WS rainfall could be stored on the farm for timely use.

In three provinces — Tarlac, Bulacan, and Nueva Ecija — in Central Luzon, Philippines, where the dry season (DS) rainfall is inadequate for crop production, a technique for water harvesting and conservation on the farm using small dug-out reservoirs has been used for several years. These farm reservoirs (FR) store rainwater for supplemental irrigation of WS rice grown on the entire farm, for DS rice on part of the farm, and for fish culture.

From December 1985 to April 1986, a field survey of 68 pairs of FR users and adjacent nonusers (purely rainfed farmers) assessed the technical and management features of the FR technology, its use, and its economic impact. The study was designed to elicit research needs to make the technology more adoptable. Forty-eight pairs in the sample were located in 4 villages of Tarlac, 13 pairs in Nueva Ecija, and 7 pairs in Bulacan. The sample sites were in gently rolling topography, mostly with clay and clay-loam soils. The long-term average annual rainfall is 2,130 mm at the Bulacan site but lower in Tarlac and Nueva Ecija (Fig. 1). During November-April, monthly total rainfall is less than 100 mm. May is the transition month from DS to WS, and October the transition from WS to DS.

Technical features of farm reservoirs. A FR is a dug-out pond with well-defined embankments. Many are rectangular, but the majority have no regular geometric shape. The average size was about 1,500 m^2, but the range was from <500 to >2,500 m^2. The average depth was 2.6 m, but the range was 0.6-8.0 m (Table 1).

An average FR user owned 1.7 reservoirs, occupying 7.5% of the farm area. The nonusers' farm size averaged 2.1 ha compared with the 3.3 ha average for FR users.



1. Locations of the rainfed research sites in Central Luzon, Philippines.

Most FRs were constructed at the top or middle of the farm toposequence (Table 1) to allow harvesting of runoff from the upper microcatchment (part of which may be outside the farm boundary) and gravity flow of the stored water to the farm. Design, construction, and size of FR seem to be arbitrary. Regression analysis of DS service area and FR area, and depth or volume of stored water at the beginning of DS showed no significant relationships. The size seems to have been affected by the amount of cash the farmer had.

Almost all FRs were built by contractors with bulldozers. Usually, no water control facilities or hydraulic structures were provided. Embankments were made mostly of poorly compacted earth and had steep slopes, resulting in excessive erosion after a heavy rain or typhoon, inefficient water storage, and shortened life. Farmers were aware of these problems and recognized the need for improvement in design and construction.

Siltation is the most troublesome problem. Siltation takes place more in early WS when the catchment soil is bare and erosion high. Desilting,

Table 1. Farm reservoir (FR) characteristics by location, Central Luzon, Philippines, January 1986.

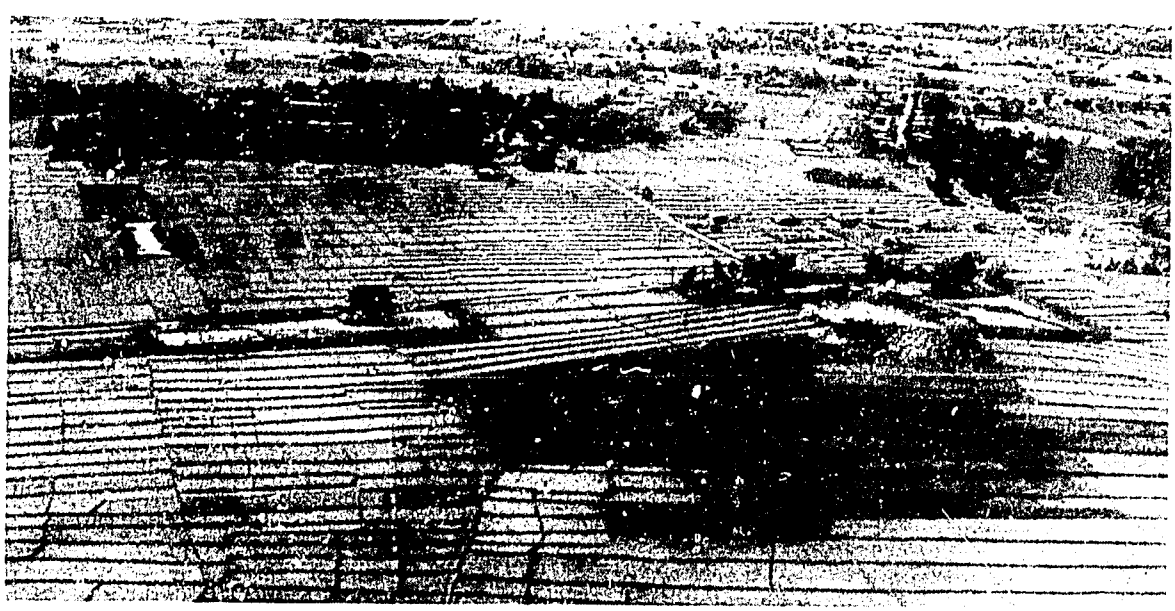
Location	Av age (yr)	Av FR per farmer (no.)	Location in farm landscape[a]	Av area (m^2)	Av depth (m)	DS planting 1985 Area (ha)	DS planting 1985 Farmers (no.) with crop	DS planting 1986 Area (ha)	DS planting 1986 Farmers (no.) with crop
Tarlac									
Santa Ines	11	1.2	T, M	2520	2.1	1.54	12	0.88	10
Padapada	8	1.2	T, M	1945	2.4	0.96	12	0.78	12
Tibag	18	2.2	T	1432	2.1	0.85	9	0.52	10
Tibagan	11	2.4	T	469	2.7	0.90	9	0.88	8
Nueva Ecija									
Mahipon	18	2.1	T	1669	3.7	1.90	9	1.4	10
Bulacan									
San Miguel	15	1.1	T, M	492	2.8	1.73	3	0.75	2
All sites	13.5	1.7	T, M	1490	2.6	1.30	54	0.90	52

[a]T = top, M = middle.

which requires a bulldozer, is needed every third year to avoid major loss of storage capacity, but most farmers neglected this maintenance work because of the high cost of hiring a bulldozer ($20/h). Desilting by carabao and harrow has limited effectiveness. Farmers plant trees on the embankments as windbreaks to reduce evaporation and prevent collapse.

Farm reservoir use, irrigation, and cropping practices. Rainwater harvesting and storage start immediately at the onset of WS in May to supplement rainfall for land preparation for rice throughout the farm. At this time the farmer also starts seeding fish fingerlings in the reservoir.

The DS area to be planted to rice is determined by the amount of stored water at the end of the WS harvest. On the average, FR users grew DS rice on about one-third of their farms (Fig. 2). Early establishment of the DS crop is critically important, as water loss by evaporation is high during



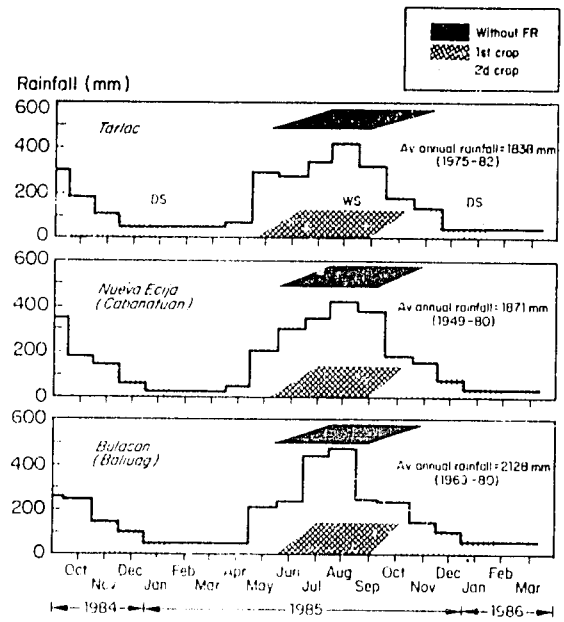
2. Several farm reservoirs in Tarlac, Philippines, showing limited rice area in foreground. 1986 DS.

DS, and most reservoirs dry up between January and March (Table 2).

Water is released from the FR by siphon tubes, pump, or spillway. Lower plots, which hold water more efficiently, are usually used for DS rice. Reservoir water is conveyed to the cropped area in small ditches, and field-to-field flow distributes the water within the area. The most common irrigation practice is maintaining standing water in the fields, but only soil saturation is allowed when available water storage is considered inadequate. Some farmers save water by applying it to alternate fields in the toposequence and allowing the lower fields to use the seepage water from the upper ones.

Almost all FR users adopted a rice - rice cropping pattern, whereas nonusers followed a rice - fallow pattern during 1985-86 (Fig. 3). During these 2 yr, 76% of FR users planted rice in both DSs; the rest had either one DS rice crop or none for lack of water in their reservoirs. About 70% of the FR users also grew fish.

In 1985 WS, the FR users and nonusers did not significantly differ in their use of fertilizer and in the amount of money spent per hectare on fertilizer and pesticide.



3. Rainfall pattern at the 3 agromet stations near the study sites in 3 Philippine provinces, and cropping patterns and calendars used by farmers with and without farm reservoirs, 1984-85.

Table 2. Farm reservoir management aspects in 6 rainfed villages, Central Luzon, Philippines, 1986 DS.

Parameter	Frequency of farmers	
	no.	%
Start of water collection		
Early WS	50	96
Late WS	2	4
Method of water release from FR		
Pumping	17	33
Siphoning	30	57
Spillway cut	5	10
Frequency of irrigation		
Once/2 wk	9	18
1/wk	26	51
2/wk	13	25
3/wk	3	6
Field water distribution		
Field-to-field	52	100
Month pond dried up		
Nov-Dec	4	9
Jan	10	24
Feb	8	19
Mar	10	24
Apr	10	24

Benefits from farm reservoir technology. An average FR user produced 0.3 t rice/ha more than the average 2.5 t/ha yield of nonusers in 1985 WS. Since the input use levels of both groups were about the same, the higher yield can be attributed to the effects of supplemental irrigation practiced by FR users. FR users obtained average yields of 2.3 t/ha in 1985 DS and 2.7 t/ha in 1986 DS. There was no crop grown in DS on the pure rainfed farms.

Each farmer's income from farming was computed in terms of gross margin, which was obtained by subtracting the total variable cost of production from the total value of the output. Data on all variable costs except labor costs at current prices were gathered through interviews. Labor use data were adapted from earlier IRRI work for the same geographical region. Total variable cost did not differ significantly between FR users and nonusers in WS. Total variable costs for DS were higher, mainly because a higher percentage of farmers used fertilizer in DS than in WS (Table 3).

Table 3. Comparative costs and returns from rice and fish for FR users and nonusers in 6 rainfed villages, Central Luzon, Philippines, 1985 and 1986.[a]

Parameter	1985			1986[b]		
	FR users	Nonusers	Difference	FR users	Nonusers	Difference
		Wet season				
Mean farm size (ha)	3.3	2.1	1.2	3.3	2.1	1.2
Area planted (%)	100.0	100.0	0.0	100.0	100.0	0.0
Yield (t/ha)	2.8	2.5	0.3	2.8	2.5	0.3
Value of output ($/ha)	385	344	41	420	376	44
Total variable cost[c] ($/ha)	274	272	2	278	277	1
Gross margin ($/ha)	111	72	39	142	99	43
		Dry season				
Area planted (%)	39.0	0	39.0	27.0	0	27.0
Yield (t/ha)	2.3	0	2.3	2.7	0	2.7
Value of output ($/ha)	392	0	392	502	0	502
Total variable cost[c] ($/ha)	283	0	283	309	0	309
Gross margin ($/ha)	109	0	109	193	0	193
		Crop year				
Annual yield (t/ha)	5.1	2.5	2.6	5.5	2.5	3.0
Annual gross margin						
Rice ($/ha)	220	72	148	335	99	236
Fish[d] ($/farm)	92	0	92	92	0	92

[a]Assumed conversion rate: $1 = ₱20.00. [b]Yield and input use for 1986 WS were assumed the same as in 1985 WS. [c]Includes cost of labor, seeds, fertilizer, and pesticide. [d]Income from fish culture was assumed the same for both crop years.

The gross margin from rice culture attributable to FR use in 1985 was $39/ha in WS and $109/ha in DS, giving an annual total of $148/ha for the double-cropped area. After accounting for $33 as the value of the output forgone in WS for the fraction (7.5%) of the farm used for FR construction, an average FR user received a gross margin of $236 through rice culture in 1986, which is attributable to the use of the technology. In addition, he received $92 from fish culture in the FR (Table 3).

At constant 1984 prices, the cost of FR construction per farm is $178. The service area cost, $59/ha, is only a fraction of the construction cost of other types of water resources development schemes in Central Luzon (Table 4).

Using an annual interest rate of 18%, a 15-yr lifespan for a reservoir, and a regular 3-yr cycle of maintenance costing $99, the benefit-to-cost ratio of a FR project at constant 1984 prices is 5.1 and the internal rate of return is 182% (Table 4). In addition to the attractiveness of the investment, the FR technology has a number of unique advantages: 1) It is owned and operated by individual farmers; hence, complex organizational problems inherent in conventional irrigation development are avoided. 2) The investment can be made in phases, i.e., instead of constructing a large reservoir, a farmer has the choice of constructing two or three small ones in a preferred time sequence.

Table 4. Investment costs, benefit-to-cost ratios (B:C), and internal rates of return for irrigation systems and farm reservoirs. Central Luzon, Philippines (at 1984 constant prices).[a]

Types of irrigation system	Investment cost of service area ($/ha)	B:C[b]	Internal rate of return (%)
Gravity (run-of-the-river)	469	2.1	73.6
Surface pumps	444	1.6	34.9
Large	536	1.8	48.3
Medium	306	1.0	18.0
Small	555	1.8	55.3
Deepwell pumps	1527	0.5	4.9
Farm reservoirs	59	5.1	182.0

[a]Assumed exchange rate: $1 = ₱20. [b]Interest rate used for calculation of B:C is 13%. Life of structures assumed: 60 yr for dams, 30 yr for canals, and 15 yr for pumps.

Important research issues. The FR technology looks highly attractive for wider adoption in rainfed areas. However, several problems related to its long-term viability and suitability for adoption need systematic research — 1) identification and analysis of critical landscape, soil, and hydrologic conditions that are prerequisites to profitable use of the technology in rainfed rice areas; 2) evaluation of the scope of using small-scale, economic pumping devices for lifting water from the reservoirs constructed in flat topographic rainfed rice areas that do not have the natural slope advantage for gravity flow of water from reservoir to farm; 3) development of efficient but simple reservoir design standards and management guidelines for constructing, operating, and maintaining the facilities, including managing the siltation problem; 4) assessment of water loss through evaporation, seepage, percolation, and evaluation of cost-effective methods of reducing these losses; and 5) development of practically suitable techniques for DS growing of crops that require low water but have high value.

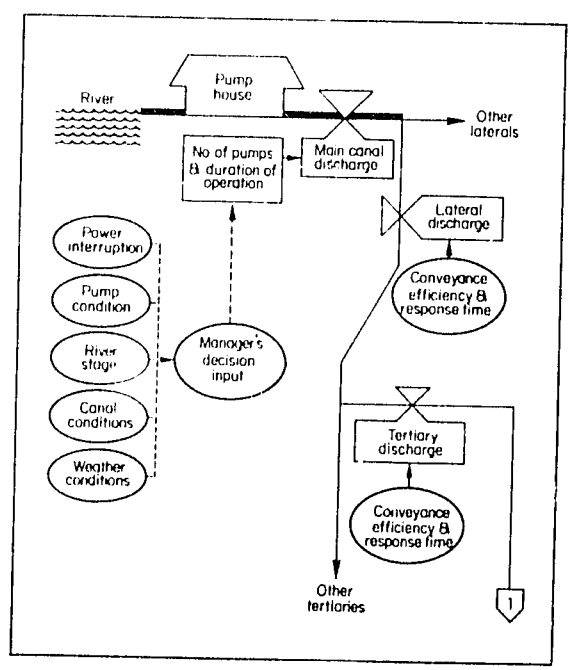
A SIMULATION MODEL FOR MULTIPUMP RICE IRRIGATION SYSTEMS OPERATION

Water Management Department

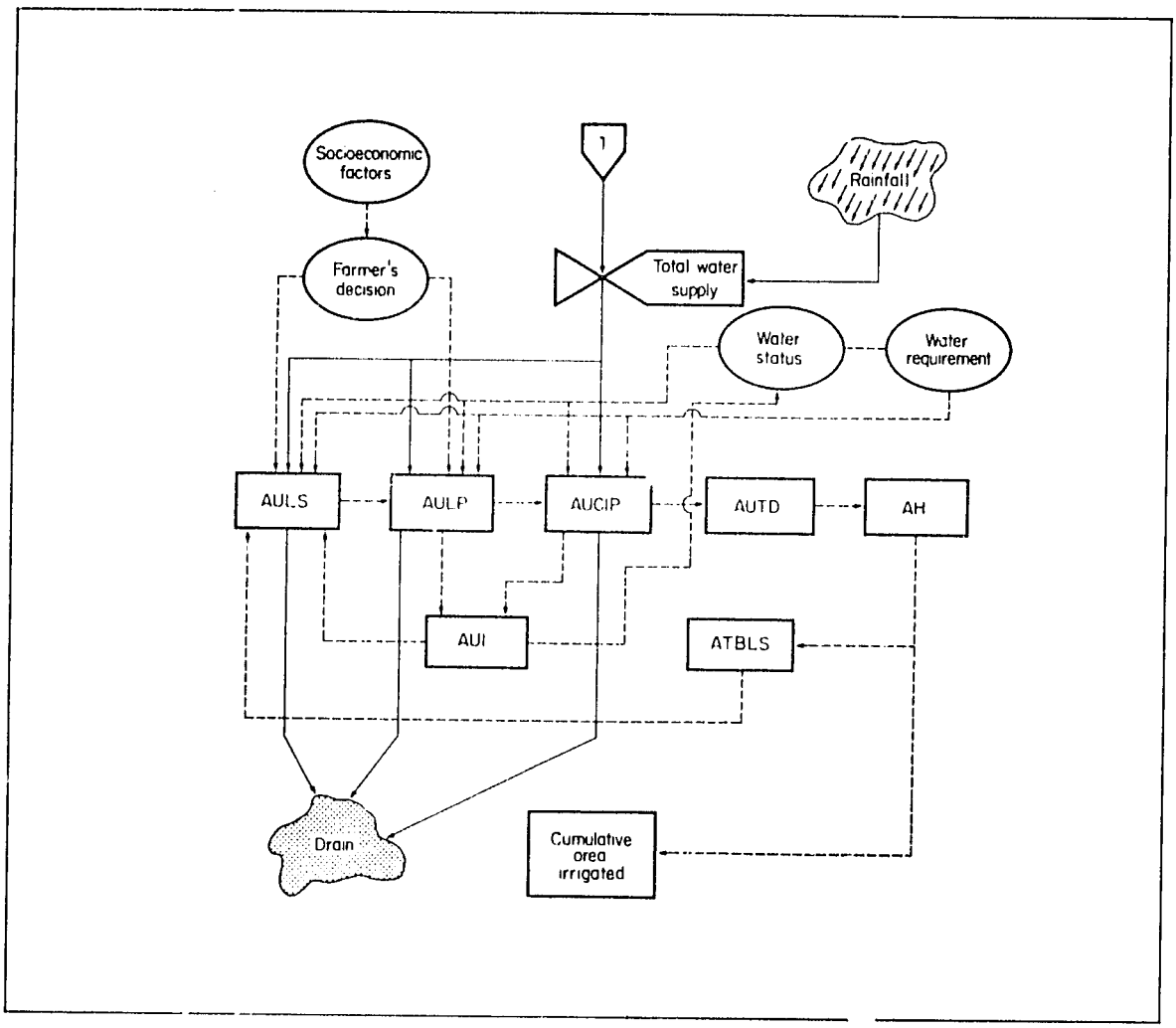
To be economically viable, pump-based irrigation systems must operate at high efficiency because of their high investment and operating costs. A primary objective of such a system operation should be to maximize the use of rainfall so as to minimize the need for pumping and to use water with minimum wastage. When multiple pumps are used for an irrigation system, the operational alternatives for optimizing their use are greater. The optimization task becomes more complex when local technical and socioeconomic constraints must be considered.

Simulation models are an effective tool for studying an irrigation system's behavior and for optimizing its operation to achieve a chosen goal, without affecting the normal operation of the system or its users. A microcomputer-based simulation model called PUMPMOD was developed for simulating the operation of multipump irrigation systems supporting rice production. The model uses data generated through 4 yr (1981-85) of collaborative research with the Philippine National Irrigation Administration in its Libmanan-Cabusao Pump Irrigation System (LCPIS) located in Camarines Sur Province. LCPIS has 4 electrically driven turbine pumps, each with a discharge capacity of 1,500 liters per second (lps) and a total service area of about 3,300 ha.

PUMPMOD is designed to capture the dynamic changes in the hydrologic and agronomic status of the service area as land soaking, land preparation, transplanting, and crop irrigation activities for rice culture are supported by irrigation water or rainfall. The conceptual framework or relational diagram of PUMPMOD is shown in Figures 4 and 5. Figure 4 shows the different factors affecting daily pump operation at the system level. The amount of irrigation water delivered to the system's service area in a day depends on the number of pumps operated; the duration of operation of each pump; the carrying capacity of the canal network; hydraulic response time (the time required for developing a working hydraulic head to deliver water to various parts of the service area for different numbers of pumps operated simultaneously); and the water distribution scheme used



4. PUMPMOD relational diagram, system level. IRRI, 1986.



5. PUMPMOD relational diagram, service area level. IRRI, 1986.

for the various service areas within the system. The number of pumps to be operated simultaneously and the duration of their operation on a particular day are decision inputs of the system manager, which can be determined using the available information on electric power supply schedules and limitations, condition of the pumps, water stage at source, canal conditions, and rainfall.

Figure 5 shows the service area level relations. The total water supply, which consists of irrigation supply and rainfall, is distributed to the area during the different phases of farming activities, taking into account the water requirements for each of these activities and the prevailing farm water status.

The principal output of PUMPMOD is the extent of the serviceable area that could be irrigated, prepared, and grown to rice, based on the amount of water delivered to the service area.

The model works on a daily basis for each of two seasons, WS and DS, lasting 190 d, thus allowing an overlap between the seasons within the service area. WS starts on 1 May and DS on 1 Nov. At the field level, 100 mm water is considered necessary to soak the land for the start of plowing each season. A water delivery rate of 13 mm/d or 1.5 lps/ha for 30 d is considered necessary to complete land preparation and transplanting with 15-d-old seedlings. The daily field water requirement for evapotranspiration plus seepage and percolation is taken

at 8 mm. It is assumed that the rice variety grown has a 110-d maturity period.

In the management of field water, the height of the spillway maintained by farmers is assumed to be 75 mm. Therefore, any water supplies from rainfall, pump source, or both beyond the 75-mm height are considered drained out of the system. Canal water conveyance efficiency is taken to be 85%. These values are mostly the average values of the parameters, which were determined by field investigations during 1981-85. These inputs to the model can be changed to suit existing local conditions.

The model is designed to operate under specific given constraints, which in the case of LCPIS are as follows: 1) only three pumps could operate simultaneously because the main canal could not accommodate simultaneous discharge from more than three. 2) Electric power supply for pump operation is available for only 17 h/d, from midnight to 5 pm. 3) The maximum daily rate of land preparation when water supply is not limiting is 2.5% of the potential service area. The first two are technical constraints of the system, whereas the third is a socioeconomic constraint of the farming community determined by such factors as draft power and labor availability, and access to credit.

The computer program for PUMPMOD is written in CBASIC and requires at least 1024 K of memory on a TRS-80 Model-16B under a CP/M-68K operating system. It has two major flow paths. The first path uses actual data and is required for validation of the model. The other path uses generated data useful for prediction and optimization purposes. Probability distributions of rainfall and of electric power supply interruptions and the water stage at the source are required for generation of water inflow data needed for prediction and optimization purposes.

Functional relationships. Functional relationships between the main canal flow rate and water delivery rates in each of the four major lateral canals (laterals B, C, D, and MC tail) were established through regression, using the field data gathered during 1981-85. These regression equations were used:

$$QB(d) = -117.13 + 0.71\ QT(d) - 0.[illegible]\ QMCT(d) - 0.6[illegible]\ QC(d)$$
$$(r^2 = 0.79; \quad n = 233)$$

$$QC(d) = 254.02 + 0.57\ QT(d) - 0.51\ QB(d)$$
$$(r^2 = 0.74; \quad n = 233)$$

$$QMCT(d) = -96.32 + 0.60\ QT(d) - 0.53\ QC(d) - 0.61\ QB(d)$$
$$(r^2 = 0.60; \quad n = 233)$$

$$QD(d) = QT(d) - QB(d) - QMCT(d) - QC(d)$$

In the above equations, $QT(d)$ is the total main canal discharge, and $QB(d)$, $QC(d)$, $QD(d)$, and $QMCT(d)$ are discharges in laterals B, C, D, and MC tail, respectively, for day d. All discharges are in lps. Solution of the above simultaneous equations led to the following equations, which were applied through each season:

$$QMCT(d) = -126.0 + 0.19\ QT(d)$$
$$QB(d) = -427.2 + 0.50\ QT(d) - 0.90\ QMCT(d)$$
$$QC(d) = 254.0 + 0.57\ QT(d) - 0.51\ QB(d)$$
$$QD(d) = QT(d) - QB(d) - QC(d) - QMCT(d)$$

Because each lateral canal in LCPIS has a specific schedule for delivering its water to identified sections of its total service area for each day of the week (Annual report for 1982), the total volume of water a section receives in a given day is expressed as:

$$V(s,d) = 3.6\ RTC(s,d) \times SC(s,d) \times PH(d) \times Q(l,d) + 10\ RN(d) \times AS(s)$$

where

$V(s,d)$ = volume of water received (in section s during day d), in m^3,
$RTC(s,d)$ = reduction factor due to hydraulic response time,
$SC(s,d)$ = irrigation schedule determinant,
$PH(d)$ = pump-hours spent,
$Q(l,d)$ = canal flow in lateral l, in lps,
$RN(d)$ = rainfall, in mm, and
$AS(s)$ = service area, in ha.

The reduction factor due to hydraulic response time (RTC) for a section is computed from the following equation:

$$RTC(s,d) = EC(s)[PH(d)/NP(d) - RT(s,d)]/[PH(d)/NP(d)]$$

where

$EC(s)$ = conveyance efficiency of the canal in fractions, and
$RT(s,d) = NDH(s,d) - HRTe(s,d)$, in h.

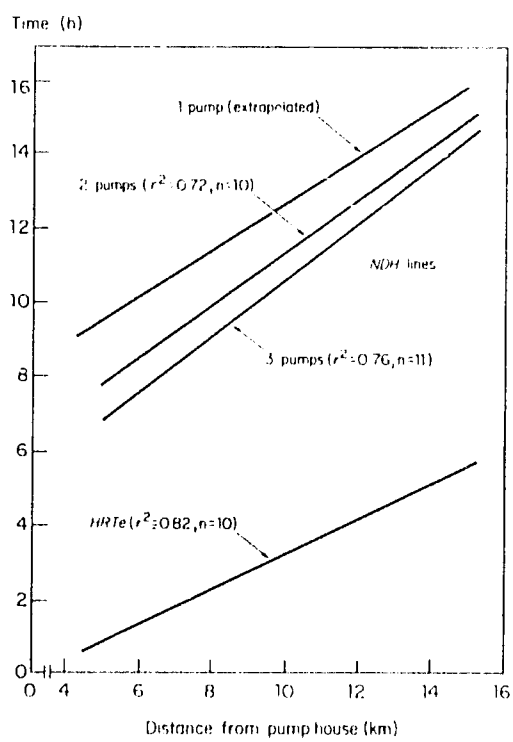
NDH is the period between start of pump operation and buildup of a working head at the section's

delivery point. The term *HRTe* denotes the time taken for the working head to start receding, counting from the time pump operation has been suspended. The *NDH* and *HRTe* relationships for different numbers of pumps operating simultaneously are shown in Figure 6.

The irrigation schedule (*SC*) determinant is a factor that assumes a value of either 0 or 1, depending on whether a section is scheduled for receiving irrigation flow or not on a particular day of the week. It may have a value between 0 and 1 if two or more sections are scheduled to receive water simultaneously. In such a case, the *SC* value to be used for a section is a fraction proportional to its area.

Response computation. PUMPMOD captures the dynamic changes in the area under different stages of farming activities within the irrigation system. These changes are computed by a response computation subroutine in which the potential area that could be landsoaked (*PAL*) on a day is determined using the residual volume of water after subtracting from the total volume available for the day the requirements of those areas that are under land preparation [*AULP*(*s,d*)] and crop irrigation [*AUCIP*(*s,d*)]. *AULP*(*s,d*) and *AUCIP*(*s,d*) together comprise the area under irrigation *AUI*(*s,d*).

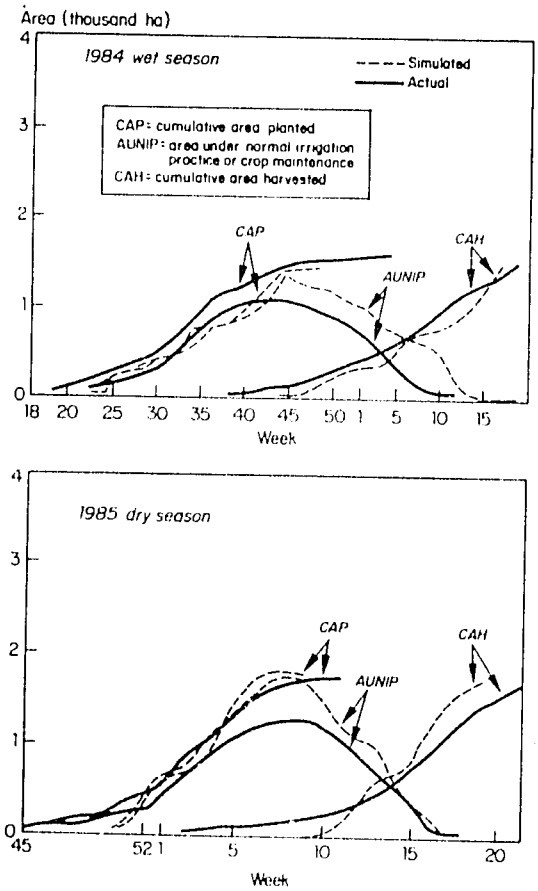
If *PAL* is negative on a particular day, it means that water stress occurred and hence no area is landsoaked on that day. The area to be landsoaked [*ATBLS*(*s,d*)] is the area remaining after *AUI*(*s,d*) is subtracted from the section's total service area *AS*(*s*). The area not landsoaked within 70 d after the start of the season is considered to remain fallow for the season. The area landsoaked during the previous day goes to the land preparation stage that is completed, and transplanting is accomplished in 30 d. When the water supply is limited, *AUCIP* is given priority, and *AULP* might be reduced accordingly. A field is drained of water 80 d after transplanting and then harvested after another 15 d.



6. Relationship between distance of service area and time required to develop a sufficient working head in a canal for field water delivery with different number of pumps operating simultaneously (*NDH* lines). The *HRTe* line shows the relationship between the distance of the service area from the pumps and the elapsed time from the stoppage of pumping operations to the time when the water head starts to recede. IRRI, 1986.

Evaluation of the model and various uses. PUMPMOD was applied to LCPIS using actual data on pump operation, lateral canal flows, and water distribution schedules adopted during six seasons starting in 1982 WS. Model outputs characterizing the irrigation system response to water supply during each season closely matched actual field observations of area under the different hydrologic and agronomic statuses, as exemplified in Figure 7. The minor differences between simulated and actual figures may be attributed to the following: 1) The model assumes that all rice varieties grown have the same 110-d maturity period, while the actual period may vary between 90 and 130 d. 2) Some farmers started farming activities either earlier or later than the seasonal schedule used in the model.

PUMPMOD can be used for various investigative purposes. It can assess relationships of irrigated area to such variables as maximum sustainable rate of land preparation, farm-plot spillway management practices to store more water on-farm, and the degree of water stress allowed within the system. Likewise, the model can assess the effects of alternative designs of water allocation



7. Actual and PUMPMOD-simulated progress of farm activities for the Libmanan-Cabusao Pump Irrigation System, Philippines, 1984 WS and 1985 DS.

in the canal network to maximize irrigation benefits. PUMPMOD can also be used to investigate the impact of removing the identified technical and socioeconomic constraints that have been considered in the model.

WATER STRESS EFFECTS ON INPUT USE AND CROP YIELD IN IRRIGATED AND RAINFED FARMS, LCPIS

Agricultural Economics and Water Management Departments

The rice crop is affected by environmental, institutional, economic, physical, and social factors and by the farmer's managed inputs. However, the interaction of these factors must not be overlooked because of its additional impact on the overall productivity of the crop. A study that emphasized the effect of water availability on input use and yield was conducted in LCPIS in collaboration with the Philippine National Irrigation Administration (NIA). Its aim was to determine factors that affect water availability and input use and their effects on yield. Simultaneous equation systems for irrigated and rainfed farms were developed to describe the input use and yield relationships.

Methodology. LCPIS has been operating since 1981 WS, with irrigation, drainage, and flood protection facilities serving about 2,100 farmers in its 3,500-ha service area. Field data were analyzed for six seasons — from 1981 WS to 1984 DS. There were 201 sample farmers for irrigated farms: 89 for WS, and 112 for DS. There were only 53 farmers from rainfed farms: 31 for WS, and 22 for DS. Each simultaneous equation system was composed of stress days, input use, and yield equations. As the equations were overidentified, the three-stage least squares (3SLS) method was used for their solution instead of the two-stage least squares (2SLS) method for more efficient estimates. The equations for the irrigated farms follow.

Stress days equation:

Stress days = f(adarnfl, elev, T_1, T_2, T_3, season, area, latdist, slatdist, todist, tenure, μ_1)

Input use equation:

Input (nitrogen) use = f(stress, Ca, yrexp, pelay, oc, season, npv, tenure, μ_2)

Yield equation:

Yield = f(stress, nitrogen, pest, herb, phlabor, T_1, T_2, T_3, season, μ_3)

where,

stress days = number of days in excess of 3 for which the field was continually without water with a depth of 30 cm or more belowground,
nitrogen = N use at farm level in kg/ha,
yield = rice yield at farm level in t/ha,
adarnfl = average daily rainfall in mm,
elev = elevation of farm in m above sea level,
area = area planted in ha,
latdist = distance of farm from lateral in m,
slatdist = distance of farm from sublateral in m,
todist = distance of farm from turnout in m,
season = season dummy, 1 = dry season, 0 = otherwise,
T_1 = typhoon dummy, 1 = typhoon at early stage, 0 = no typhoon,
T_2 = typhoon dummy, 1 = typhoon at vegetative phase, 0 = no typhoon,
T_3 = typhoon dummy, 1 = typhoon at reproductive phase, 0 = no typhoon,

tenure = tenure dummy, 1 = owners and amortizing owners, 0 = share-tenants, mortgage owners, leaseholders,
ca = credit availability of farmer in $/ha,
yrexp = experience in farming in years,
pclay = percent clay in soil,
oc = percent organic C,
npv = N price variation, which is the difference in mean N price and actual N price, divided by mean N price,
pest = pesticide expenditures in $/ha,
herb = herbicide expenditures in $/ha,
phlabor = preharvest labor in d/ha, and
μ_1, μ_2, μ_3 = random errors.

Structural equations in the rainfed farms were the same as in the irrigated farms except that in the stress model, the distance variables (latdist, slatdist, and todist) and tenure were not included.

Results and discussion. In WS, in 2 of 3 yr, yields on irrigated farms were significantly higher than on rainfed farms (Table 5). On the average, yields on rainfed farms were lower by 0.81 t/ha than on irrigated farms. In DS, the same trend occurred. On the average, the yield difference between the 2 kinds of farms was 1.48 t/ha. The wider differences in yield between irrigated and rainfed farms during this season could be attributed to the occurrence of drought and the unpredictability of rainfall, which make water availability on farms a major problem.

On the average, the stress difference between irrigated and rainfed farms was 2 stress days in WS and 6.2 stress days in DS.

The mean amounts of N applied in WS varied between irrigated and rainfed farms. On the average, irrigated farms received twice as much N as rainfed farms. In DS, average fertilizer use did not vary significantly.

On the average, the amounts spent for herbicides and pesticides on irrigated and rainfed farms were the same. Rainfed rice farmers spent more on herbicides in WS than in DS.

In the stress days model for irrigated farms, only the average daily rainfall and distance from turnout were significant; for rainfed farms, average daily rainfall, typhoon at early stage, and season dummies were significant.

Results of the N model show that on irrigated farms, stress, credit availability, organic C, N price variation, season, and tenure were significant. However, in the rainfed model, only three variables were significant: N price variation, season, and tenure dummies.

In the yield equation for the irrigated farms, stress, N use, and pesticide and herbicide expenditures were significant (Table 6). A 1% increase in stress would bring about a 0.36% decrease in yield, keeping all other variables equal, while a 1% increase in N use, pesticide expenditure, and herbicide expenditure would increase yield by 0.06%, 0.63%, and 0.03%, respectively. This means that each stress day accounted for a yield reduction of 175 kg/ha, and each kg increase in N use increased rice yield by 40 kg. Compared to the irrigated model, stress was the only variable significant in the rainfed model. A 1% increase in stress days decreased yield by 1.03%, all else being equal. The R^2 in the final yield equation was lower in the

Table 5. Average yield, fertilizer use, and chemical expenditure in LCPIS, Philippines, 1981 WS-1984 DS.[a]

Year	Yield (t/ha)		N (kg/ha)		Stress (d)		Pest[b] ($/ha)		Herb[b] ($/ha)	
	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
					Wet season					
1981	3.23	2.03*	9.82	3.56	0	0	6.91	4.76	2.03	1.51
1982	2.79	1.92+	37.29	32.20	0.36	1.43**	7.66	9.38	4.08	5.12
1983	2.19	1.70	34.31	10.15*	3.27	8.56	9.62	9.13	4.09	5.26
Average	2.70	1.89*	30.07	15.76	1.13	3.13	8.07	8.11	3.63	4.50
					Dry season					
1982	3.32	1.80*	23.08	21.93	1.19	3	5.71	5.43	3.06	2.05**
1983	2.70	0.53+	30.56	21.99	2.49	13*	7.72	9.86	4.14	2.07**
1984	2.66	1.84**	20.55	17.05	1.72	7.44*	9.63	8.82	4.71	4.30
Average	2.89	1.41	25.23	19.95	1.84	8	7.60	8.15	3.95	2.98

[a]Significance at the 10% (+), 5% (*), and 1% (**) levels. [b]Exchange rate $1 = ₱20.00

Table 6. Regression coefficients of the rice yield model, LCPIS, Philippines, 1981-84. Dependent variable = rice yield.[a]

Variable	Irrigated	Rainfed
Intercept	-1.59**	-9.14
	(0.34)	(4.22)
Stress	-0.36**	-1.03**
	(0.06)	(0.37)
Nitrogen	0.06*	-0.06
	(0.03)	(0.17)
Pest[b]	0.63**	0.23
	(0.06)	(0.20)
Herb[c]	0.03*	-0.19
	(0.02)	(0.15)
Phlabor[d]	-0.12	1.00
	(0.07)	(1.17)
T_1	-0.17	-0.20
	(0.18)	(1.86)
T_2	-0.27	0.84
	(0.20)	(1.48)
T_3	-0.32	-2.51
	(0.23)	(2.21)
Season	0.17	1.44
	(0.19)	(2.02)
R^2	0.4961	0.3113

[a]Figures in parentheses are standard errors. [b]Pesticide, [c]Herbicide, [d]Preharvest labor.

rainfed model. From the model, it is evident that the impact of stress on yield was more greatly felt in rainfed than irrigated areas, since a 1% increase in stress days decreased yield by 1.03% on rainfed farms as against 0.36% on irrigated farms.

The calculated economic efficiency indices (EIs) for labor and fertilizer are given in Table 7. The following are the criteria for interpreting EI: input level is optimal if EI = 1; input level is less than the optimal if EI > 1; input level is more than optimal if Ei < 1.

Labor and fertilizer were used below the optimal level, implying an underutilization of resources on both irrigated and rainfed farms. Fertilizer use never reached the recommended rate of 60 kg N/ha. This behavior, which is unusual on irrigated farms but justifiable for rainfed farms, may have been due to the high prices of the input and the lack of credit. With this situation, credit schemes must be made more readily available so that farmers can easily procure the needed inputs. If the current level of fertilizer use is increased to the recommended level, an additional yield of 0.17 t/ha will be achieved. Labor may be underutilized in agriculture if scarcity arises due to seasonality, and if family labor, which is a substitute for hired labor, cannot meet specific labor requirements.

EFFECT OF WATER REGIME ON RICE YIELD

Soils Department

To determine the effects of water regime on rice yield, a greenhouse study used different drying periods at varying growth stages on different soils. In a randomized complete block design, 18 water regimes were tested on Maahas clay (53% clay, pH 6.4, 2.0% organic C, 0.17 N_t) and Luisiana clay (6.3% clay, pH 4.7, 2.2% organic C, 0.24 N_t). Fertilization was 100-25-75 mg NPK/kg soil.

Soil drying up to field capacity for 2 wk at maximum tillering and panicle initiation caused the highest yield reductions on Maahas clay (Table 8). Extending the drying period to 4 wk depressed yields further.

However, drying periods on Luisiana clay resulted in yield increases (Fig. 8). The same trends were found with saturated water regimes and when drainage effects were investigated (Tables 9, 10).

Table 7. Economic efficiency indices (EI) of inputs in LCPIS, Philippines, 1981-84.

Input	Index	
	Irrigated	Rainfed
Labor	8.32	3.79
Fertilizer	2.31	3.14

$$EI = \frac{MVP_{x_i}}{P_{x_i}}$$

$$MVP_{x_i} = MPP_{x_i} \cdot P_Y$$

$$= \left(\eta \times \frac{\bar{Y}}{\bar{x}_i}\right) \cdot P_Y$$

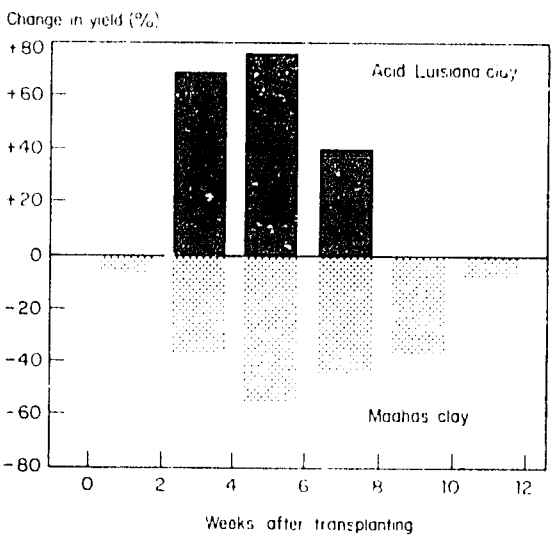
where:

MVP_{x_i} = marginal value product of input x_i,
MPP_{x_i} = marginal physical product of input x_i,
P_{x_i} = price of input x_i,
P_Y = price of output Y,
η = output elasticity, and
$\bar{Y}$, $\bar{x}_i$ = geometric means of yield and input x_i.

Table 8. Effect of 2-wk or 4-wk soil drying on IR54 grain yield.[a] IRRI, 1986.

Drying period imposed at given WT[b]	Grain yield (%)		
	Maahas clay		Luisiana clay
	2 wk	4 wk	2 wk
0	– 7.5ns	–60.5**	
2	–35.6**	–70.3**	+67.0**
4	–56.1**	–75.9**	+77.3**
6	–43.0**	–60.5**	+41.9**
8	–36.2**	–31.7**	
10	– 7.3ns		

[a]** = significantly different at the 1% level from the continuously submerged treatment. [b]WT = wk after transplanting.



8. Effect of 2-wk soil drying on changes in yield of IR54. IRRI, 1986.

In highly fertile soils, submergence always results in highest yields. Drying such soils to field capacity reduces grain yield, mainly because of reduced N supply (denitrification after resubmergence) and lowered P and K availability.

On the other hand, in moderate to low fertility soils having latent or obvious nutrient disorders such as Fe or Mn toxicity, and P, Zn, or S deficiency, yield increases can be achieved through drying soils to field capacity or increasing percolation rates.

Another greenhouse experiment separated the adverse effects of the aerobic soil environment from the effect of moisture stress. The unfavorable chemical environment of aerobic soils reduced the yield by 17-74%, depending on soil properties, the largest decrease being in the high pH soil. Flooding depressed grain yield in strongly acidic soils (Table 11).

Table 10. Effect of drainage on IR54 grain yield. IRRI, 1986.

Drainage	Rice grain yield[a]			
	Maahas clay		Luisiana clay	
	g/pot	%	g/pot	%
None	92.1	100	29.1	100.0
5 mm/d	82.9	90.0 ns	38.0	130.0**
10 mm/d	78.3	85.0 ns	42.5	146.0**
LSD (0.05)	19.0			
(0.01)			8.4	

[a]% grain yield in relation to no-drainage treatment. ** = significantly different at the 1% level from the no-drainage treatment, ns = nonsignificant.

Table 9. Effect of standing water on rice grain yield. IRRI, 1986.

Standing water	Rice grain yield[a]					
	Maahas clay		Luisiana clay			
			No straw		0.25% straw	
	g/pot	%	g/pot	%	g/pot	%
5 cm	92.1	100.0	29.1	100.0	40.2	100.0
None	74.3	80.7ns	39.3	135.0**	47.9	119.1**
LSD (0.05)	19.0					
(0.01)			8.4		8.4	

[a]% yield in relation to treatment with 5 cm standing water. ** = significantly different at the 1% level from treatment with continuous submergence and no drainage.

Table 11. Grain yield of IR43 on 6 soils under 3 water regimes. IRRI greenhouse, 1986 WS.

Soil	pH	Texture	Grain yield[a] (g/pot)		
			Field capacity	Wet	Flooded
Pila	7.6	Loam	12.7 C d	29.2 B d	112.4 A a
IRRI farm (F)	6.6	Silty clay	25.6 C bc	45.8 B bc	106.7 A a
IRRI farm (UK)	6.6	Clay loam	29.0 C b	54.2 B b	65.5 A c
Rotonda	6.1	Loam	41.3 C a	75.1 B a	93.1 A b
Luisiana	4.5	Clay	23.1 B bc	40.2 A c	33.2 A d
Burabod	3.8	Sandy loam	18.7 C cd	66.7 A a	30.7 B d

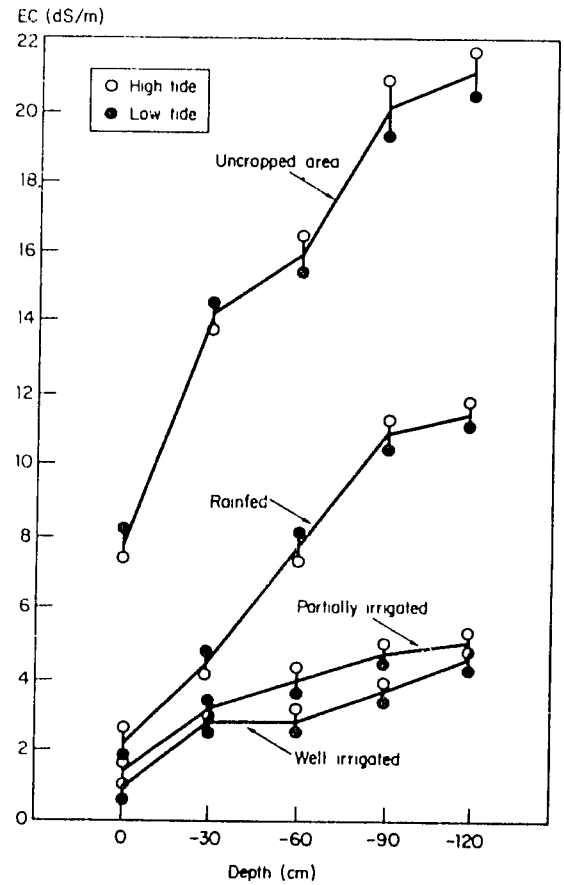
[a]Treatment means having a common capital letter in a row and a common small letter in a column are not significantly different at the 5% level by DMRT.

ALLEVIATING SALINITY PROBLEMS AND IMPROVING FARMER INCOME

Water Management Department

Rice production in the coastal areas of the Bicol River basin is hampered by shortage of water during DS, excess water during WS, and intrusion of seawater all year round. In 1984, a joint study was initiated with NIA in the Inarihan River Irrigation System (IRIS), Camarines Sur Province. A diversion dam on the Inarihan River supplies water to IRIS for a potential service area of about 1,400 ha for 1,100 farm families. Because of flat slopes (0-3%), low elevations (mostly 0.5-1.3 m above mean sea level), and proximity to the sea, the area is affected by seawater and tidal fluctuations. About 30-40% of IRIS area is affected by high salinity. The research objectives were to 1) assess the potential for improving efficiency in water use and equality in water allocation-distribution, and increasing rice yields; 2) develop and implement a practical system of efficient and equitable water allocation and distribution, and evaluate its impact on rice production and farmer income; and 3) analyze the dynamic effect of irrigation water on the salt-affected land and its relationship to productivity.

The soils are in general clayey, with clay content ranging between 49 and 53% and relatively high N content (about 0.35% total N). The electrical conductivity (EC) of the saturated extract varied widely. About 1/3 of the service area is saline, with EC of about 10 dS/m. The remaining (nonsaline) area has an average EC of 1.4 dS/m. Available Zn is very low, averaging about 0.1 ppm in the saline and 0.2 ppm in the nonsaline soil. The Zn deficiency is perhaps associated with poor drainage and waterlogged conditions in WS, suggesting benefits from good drainage. On the other hand,



9. Average seasonal EC values of water samples at various depths. Inarihan River Irrigation System, Camarines Sur, Philippines, 1986 WS.

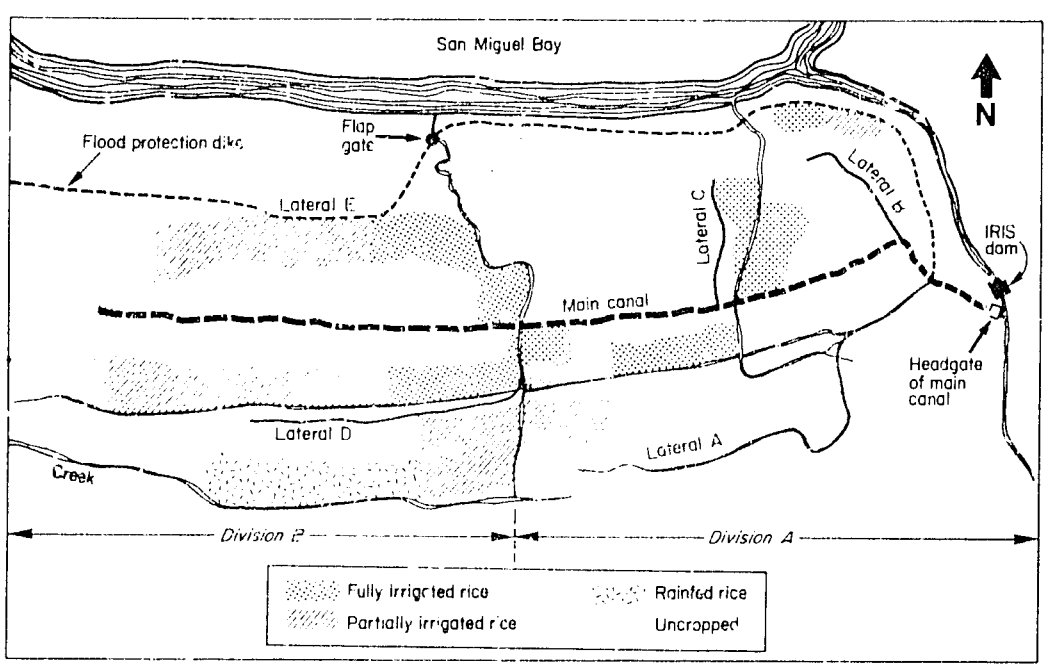
the high EC and the low average sodium absorption ratio (<2.2) in the saline soils indicate that sufficient quantity of good quality irrigation water must be applied to improve rice productivity

In 1986 WS, 30 sample ricefields were monitored for subsurface water quality and water table fluctuations. Of these, 14 were well irrigated, 8 partially irrigated, and 3 rainfed. The remaining five fields were in the neighboring uncropped area, which is closer to the sea. Water samples for EC measurement were taken at 0, 30, 60, 90, and 120 cm below ground level. The average EC values of the water samples, collected by piezometer, are shown in Figure 9. In all cases, salinity increased with depth below the surface. In the uncropped area not reached by irrigation water, the EC increased from about 7 dS/m at the surface to about 21 dS/m at 120-cm depth. In the rainfed areas, EC in the first 30 cm below the surface exceeded the 4 dS/m limit considered suitable for rice production. The partially irrigated areas were marginally within the desired limit, and the irrigated fields were slightly better.

The water samples from the irrigation canal had an EC of 0.15-0.31 dS/m, indicating its high suitability for diluting the soil salinity to improve land productivity. The variations in EC during high and low tide periods were negligible.

The IRIS service area is divided into two major divisions. Division A, which is adjacent to the main source of irrigation water, consists of 647 ha of ricelands, or 47% of the total service area. Division B (743 ha) lies on the far side of the main canal (Fig. 10). To analyze irrigation water supply and use aspects, a database was created with information on field water status, farming operations, production inputs, yields (crop-cuts), and soil physicochemical properties from 84 sample fields forming a grid network covering both divisions. Irrigation flows were measured at the headgate of the main canal, and each lateral canal and the area served with irrigation water were regularly monitored.

The irrigation water delivery rates to the system started with a low 300 lps flow at the start of WS but increased to a maximum of about 1,200 lps during both WS and DS. The division-wise seasonal average delivery rates are overly skewed in favor of Division A, which has a smaller service area but consumed over 3 times more water in DS



10. Service area of the Inarihan River Irrigation System, showing rice areas affected by salt water intrusion under different water regimes.

and 1.2-2.4 times more in WS (Table 12). Division B farmers, despite a bigger service area, received only 24-30% of the total water supply.

The inequitable allocation-distribution of irrigation water in the two divisions created a similar effect on the area that could be planted to rice. In DS, Division B used irrigation water more efficiently than Division A. Division B had about 75-100 ha less area planted and significantly lower yields. Because Division B areas had less irrigation water, they suffered more severe salinity problems. Thus, yields averaged 1.3 t/ha lower than those of Division A.

In WS, more farms in Division B were transplanted late because of lower water delivery rates. Fields harvested after the second week of October were affected by typhoons and produced about 1 t/ha lower yield than those harvested by the second week of October. October is one of the most typhoon-prone months in Bicol, and farmers can reduce the risk of typhoon damage by establishing their crops early to be able to harvest by late September or early October (Annual report for 1985).

A farm management survey, conducted once for every season and covering 43 sample farms in Division A and 41 in Division B, provided the data for input-output analyses. Higher rates of water supply encouraged Division A farmers to use more fertilizer than Division B farmers, whose farms suffered water shortage in DS. On the average, about 85%, 24%, and 23% of the farmers in Division A used N, P, and K, respectively, compared with 75%, 7%, and 5% in Division B during the 4 seasons of 1984-86. Division A farmers spent $10/ha on insecticides and $7/ha on herbicides during each season, compared with $9/ha and $6/ha by Division B farmers.

The saline farms in Division B produced the same WS yield as those in Division A, but their average yield was 1.0 t/ha less in DS, mostly because of less irrigation water supply to those farms (Table 13). The nonsaline farms in Division A produced significantly higher yields in both WS and DS. Many Division B farms, which were late in establishing WS rice, suffered crop damage from the October typhoons. The early-planted farms, located more in Division A, were harvested before the typhoons. As on the saline farms, the average nonsaline farm of Division B was hit by water shortage in DS and produced a lower yield (2.6 t/ha).

To estimate the return or gross margin per hectare from rice production, the total variable costs composed of cash and noncash costs were deducted from the total value of the output. Division A farms, mostly because of their higher yields, obtained much higher gross margin per hectare from both saline and nonsaline farms during both seasons (Table 13). But typhoon damage in WS on saline farms reduced the gross margin difference between Divisions A and B. On the average, annual gross margin per hectare was higher by about $147 in the nonsaline areas and $103 in the saline areas, indicating the significant potential for increasing the income of disad-

Table 12. Average canal water delivery rates, area planted, and yield obtained in 2 divisions of IRIS, Camarines Sur, Philippines, 1985-86.

Season	Division A			Division B			Difference in yield between Divisions A and B
	Delivery rate (lps)	Area planted (ha)	Yield (t/ha)	Delivery rate (lps)	Area planted (ha)	Yield (t/ha)	
1985 WS	376.4	528.6	3.2	157.2	469.9	2.4	0.8**
1986 WS	399.5	537.6	3.3	335.1	449.2	2.1	1.2**
Mean	388.0	533.1	3.2	246.1	459.5	2.2	1.0**
1985 DS	529.7	485.8	4.6	162.3	427.7	2.7	1.9**
1986 DS	475.9	547.3	4.1	157.1	406.2	2.5	1.6**
Mean	502.8	516.5	4.3	159.7	416.9	2.6	1.8**

Table 13. Comparative gross margin per hectare, saline and nonsaline farms by division.[a] IRIS, Camarines Sur, Philippines, crop years 1984-86.

Item	Saline farms			Nonsaline farms		
	Division A	Division B	Difference	Division A	Division B	Difference
			Wet season			
Yield (t/ha)	2.1	2.1	0	3.2	1.9	1.3**
Value of output ($/ha)	248	245	3	397	228	169 **
Total variable cost ($/ha)	232	236	−4	289	203	86 **
Gross margin ($/ha)	16	9	7	108	25	83 **
			Dry season			
Yield (t/ha)	3.3	2.3	1.0*	3.6	2.6	1.0**
Value of output ($/ha)	463	312	151 **	493	365	128 **
Total variable cost ($/ha)	287	232	55 *	301	237	64 **
Gross margin ($/ha)	176	80	96 *	192	128	64 **
			Crop year			
Annual yield (t/ha)	5.4	4.4	1.0+	6.8	4.5	2.3*
Annual gross margin ($/ha)	192	88	103 +	300	153	147 *

[a]Assumed exchange rate: $1 = ₱20.00. ** = significant at the 1% level, * = 5% level, + = 10% level.

vantaged farmers by establishing an equitable water allocation-distribution method in the irrigation system.

FARMER ORGANIZATION MODEL: A CASE STUDY

Water Management Department

The importance of organized farmers' efforts in attaining equity in water allocation and distribution, maintaining irrigation facilities, and enhancing the overall performance of irrigation systems is well recognized. In recent years, the concept assumed critical importance in the Philippines because the government stopped subsidizing the operation and maintenance of irrigation systems.

NIA recently took some significant initiatives in selected national irrigation systems for consolidating the lateral or sublateral canal-based farmer irrigators associations (FIAs) into bigger system-based (federated) farmer associations. A federated association can provide a common ground for discussing problems of the FIAs and promote coordination among them in formulating guidelines, policies, and rules regarding water allocation, distribution, and use within the whole system or its major part being served by the association. The federated association is expected to provide a stronger voice for the FIAs in communication and negotiations with NIA management.

In cooperation with NIA, a study in 1985 assessed the organizational characteristics and capabilities of a federated association, the Father Farmer Federated Irrigators' Association (FFFIA), in the Pampanga River Irrigation System (PRIS) in Central Luzon and determined the factors that affected FFFIA's success or failure in attaining its goals. Data were gathered through participant observation and formal interviews with sample farmer respondents during 1985 DS.

FFFIA was composed of 5 FIAs, all organized between 1981 and 1985 and sharing water from lateral canal F of PRIS. Each had entered into a contract with NIA for irrigation service fee (ISF) collection, and one also had a maintenance contract with NIA. The service area of these FIAs ranged between 225 and 716 ha in 1985 DS.

Water distribution. While the main lateral F canal experienced continuous water delivery, a rotation method of water distribution was implemented among the sublaterals serving the FIAs. Survey results indicate that in 1985 DS, more farmers were satisfied with the water flow during land preparation than during the rest of the season, perhaps because of a greater rate of water delivery early in the season. Among those who were satisfied with the water flow during the vegetative

and reproductive phases, 46% had farms near the main lateral F canal, which is the source of water. The difference in the mean distance of farms from the turnout on the lateral F canal for the satisfied and the dissatisfied groups of farmers was significant at the 1% level for both the vegetative and reproductive phases of the crop as well as for the entire cropping season. For the vegetative phase, for example, the mean distance of farms was 1.7 km for farmers who were satisfied with the water supply and 2.8 km in the case of dissatisfied farmers.

Farmer participation in association activities. Farmer participation in FIA-organized field activities in 1985 DS mainly comprised efforts to get their share of water from the upstream section of the canal during their scheduled days. This became a necessity during most of the season because of nonobservance of the water delivery schedule by most farmers and the decreasing volume of water available during the critical stage of crop growth. On the average, the farmer himself or his family in each FIA spent about 12 d in irrigating the farm in 1985 DS.

Irrigation service fee payment. Under an ISF collection contract with NIA, each FIA was entitled to receive an incentive payment if it succeeded in achieving its target collection. One FIA was also under the maintenance contract with NIA, which obligates the association to maintain about 3.5 km of canal for a fee paid by NIA, which is 2,285 kg of rough rice/yr or its cash equivalent. However, only the Murcon FIA has in the recent past successfully availed of the incentive payment — in 1982 DS, it collected 90% of its ISF. ISF collection decreased for all FIAs from 1981 to 1984 WS, but a small increase was achieved during 1985 DS by all the FIAs except Murcon, in which about 147 ha of planted area suffered crop damage because of water stress. ISF collection in 1985 DS averaged 62% and ranged between 54 and 73%.

Farmers who paid their ISF regularly had a higher average rice yield (3.9 t/ha) than the 3.3 t/ha of those who did not. However, the expressed satisfaction or dissatisfaction over water flow was unrelated to what farmers did in terms of ISF payment.

FFFIA performance and factors affecting performance. The five FIAs that comprise FFFIA have the same organizational setup and follow similar policies and guidelines with respect to water distribution, maintenance activities, and ISF collection. Although federated, they worked independently. Their age, location with respect to the lateral F headgate (main water source), and amount of water supply available in DS differ.

Since its inception in 1984, FFFIA has developed policies and procedures on how to carry out its functions. Monthly meetings with the FIA representatives are held to discuss major problems concerning water. If the solution requires consultation with NIA management, the FFFIA president arranges a dialogue between them and FFFIA members. FFFIA is the direct link of the FIAs to NIA management. Other major problems of FIAs that need immediate action are brought to the attention of the FFFIA president. To distribute the available water to the five FIAs equitably, water distribution schedules were developed and implemented for lateral F during 1985 DS.

The members did not strictly observe the preceding policies, rules, and schedules during 1985 DS. In some cases, FIA presidents brought their problems directly to the NIA zone engineer or other officials rather than to FFFIA as the policy required. The nonfulfillment of some commitments made by NIA staff to FFFIA regarding repair of structures, schedule of field inspections, etc., resulted in the loss of interest of the member FIAs and the FFFIA president. Monthly meetings were not held during the season. The FIAs lacked understanding of their specific roles and obligations to FFFIA and the rationale for organizing the federation. At the same time, a wide gap existed between the expectations of FFFIA and NIA's capacity to fulfill them. To gain immediate farmer support and cooperation, NIA personnel tried to meet the demands of FIAs on an ad hoc basis, beyond their normal capacity. On the other hand, FFFIA was somewhat unrealistic in its demands on NIA without much to show in terms of fulfilling its own obligations and commitments.

BANGLADESH COLLABORATIVE RESEARCH

Water Management Department

Collaborative research with the Bangladesh Rice Research Institute (BRRI) and the Bangladesh

Water Development Board (BWDB) aims to develop methodologies for increasing irrigation effectiveness and crop production in two irrigation systems — the Ganges-Kabodak (G-K) irrigation system (Phase I) and the North Bangladesh tubewell irrigation system. Field research is conducted by a multidisciplinary team of BRRI scientists and BWDB professionals. IRRI provides technical support in research planning, data collection and analysis, reporting, and training.

In the G-K irrigation system, both irrigation coverage and modern variety use increased in aman during 1982-85 in the study area. The greatest benefits were achieved by tailend farmers, whose average aman yield increased by about 1 t/ha. Progress in aus was constrained by lack of suitable varieties and water supply uncertainties.

A pump operation schedule of 1 Feb-31 Oct is recommended as optimum for growing two rice crops.

For areas that cannot be served by irrigation in aus, a green manure crop (sesbania) was grown using rainfall prior to irrigated aman rice, producing 6.4 t/ha with 50% of the recommended chemical N — significantly higher than farmers' average yield.

The results of recent research in the G-K irrigation system are reported in greater detail in the section on Cooperative Country Projects.

COLLABORATIVE RESEARCH IN TAMIL NADU, INDIA

Agricultural Economics Department

A collaborative study with Tamil Nadu Agricultural University, completed in 1986, used 4-yr tank irrigation data from Tamil Nadu State to analyze the impact of varying water supplies on rice yield. Both simultaneous equations and simulation models were used. The simultaneous equations model captured the direct and indirect effects of water shortages on rice yield, while the simulation model estimated rice yield losses due to water shortages via stress days. The results of the simultaneous equations model were used to analyze the rice yield gap, and the results of the simulation model were used to evaluate tank rehabilitation strategies. Detailed results of this research are reported in the section on Cooperative Country Projects.

Soil and crop management

Soil characterization

Multiple Cropping, Agronomy, and Soils Departments

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PHYSICAL CHARACTERISTICS OF RAINFED LOWLAND SOIL IN RESPONSE TO DROUGHT **292**

GEOGRAPHIC DATABASE OF SOIL FERTILITY CONSTRAINTS ON ASIAN RICELANDS IN FIVE CULTURAL REGIMES

Multiple Cropping Department

We integrated rice hectarage statistics, geographic location of rice-growing areas, and soil parameters of 14 countries in South (SA) and Southeast (SEA) Asia and assembled these into a computer-stored rice geographic database. Following a systematic cartographic data extraction and encoding procedure, five lowland rice culture types were classified — shallow rainfed (SRL) (water depth 0-30 cm), medium deepwater and deepwater (MDW) (water depth 30-100 cm), very deepwater (VDW), irrigated wet season (IWS), and irrigated dry season (IDS) — representing a total rice cropped area of 76 million ha.

The major types of soil fertility constraints were identified by interpreting the FAO soil mapping units for SA and SEA, and using modifiers from the Fertility Capability Classification (FCC) System. Each soil unit or subunit was assigned corresponding soil condition modifiers that indi-

Table 1. Major soil constraint classes identified from the South and Southeast Asian lowland rice regional database with 1 million ha or more of rice area at the regional level.

Soil constraint class[a]	Indicative soil conditions	Important FAO soil units involved	FCC modifiers
Alkaline	pH >7.3; calcareous (free $CaCO_3$ within 50 cm of surface)	Calcic or calcaric subunits of Cambisols, Gleysols, Fluvisols, Xerosols	b
Acid sulfate	pH < 3.5 after drying; jarosite mottles within 60 cm of surface	Thionic Fluvisols	c
Saline	> 4 dS/m electrical conductivity of saturated extract at 25 °C within 1 m of surface	Saline phase of subunits of Cambisols, Gleysols, Fluvisols, Histosols, Solonchaks, etc.	s
Low CEC, moderately acid + low nutrient reserves			
Low CEC	CEC of 4-10 meq/100 g soil	Dystric subunits of Cambisols, Fluvisols	e
Low CEC, moderately acid	Low CEC + pH 5-6	Ferralic Cambisols, ferric Luvisols, humic Gleysols	eh
Low CEC, low nutrient reserve	< 10% weatherable minerals in silt and sand fractions; exchangeable K < 2% of sum of bases if bases < 10 meq/100 g soil	Dystric Gleysols, Regosols, Podzols, cambic Arenosols	ek
Low CEC, moderately acid + low nutrient reserves	< 10% weatherable minerals in silt fractions; exchangeable K < 2% of sum of bases if bases < 10% meq/100 g soil	Dystric Nitosols, albic Arenosols	ehk
Very acid, high P fixation by Al or Fe	pH < 5.0 in 1:1 H_2O within 50 cm; > 60% Al saturation of CEC; red soils (hues of 7.5 or redder)	All subunits of Acrisols	alek
Organic		Histosols	o
P-fixing by allophane		Vitric, mollic, and humic Andosols	x
Sodic		Natric phase of gleyic Solonchaks	n
No major constraint		Eutric subunits of Gleysols, Cambisols, Fluvisols, Luvisols, chromic Andosols	f[b]
Shallow soils		Lithic subunits and complexes	l[b]

[a]CEC = cation exchange capacity. [b]Introduced modifiers for purposes of this study.

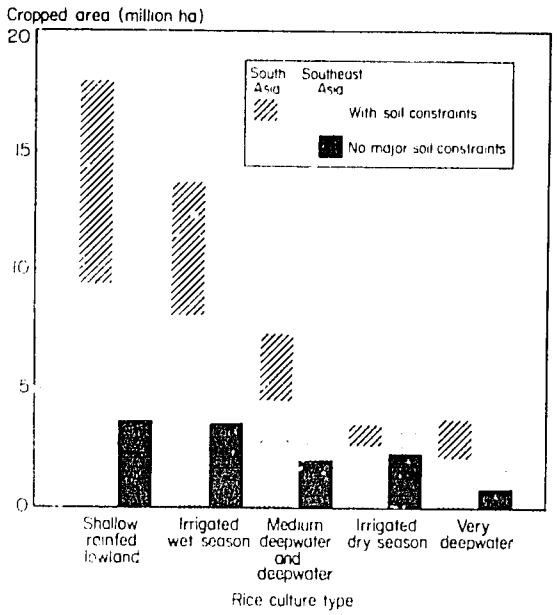
cate a specific type of constraint or a complex of edaphic problems. Rice cropped area statistics and spatial distribution were obtained from the text and maps of Huke's rice culture types for SA and SEA.

Eleven major types or complexes of soil fertility constraints were identified using the pedological characteristics of FAO units and FCC modifiers. In some cases, the transformation from the FAO soil unit to FCC class was straightforward, particularly with regard to the classical soil problems such as salinity, alkalinity, sodicity, organic soils, and acid sulfate soils. The soil units associated with these problems were identified either as discrete mapping units, associated soil units, inclusions, or phases, and they have an equivalent individual FCC unit. The other constraints, however, were grouped as complexes of interrelated conditions and deficiencies, e.g., the complex aiek composed of soils having several specific adverse character modifiers (Table 1).

Of the 76 million ha of lowland rice cropped area in SA and SEA, 37 million ha (49%) were classified as having soil-related constraints. Ranked on an area basis, the most important constraints were complexes of low cation exchange capacity (CEC), low native nutrient reserves, and moderate to severe acidity (eh, ehk, and ek) = 13.6 million ha (29% of 37 million ha); potentially very acid, high P fixation by Fe or Al (aiek) = 10.4 million ha (28%); alkaline or calcareous (b) = 5.5 million ha (15%); saline (S) = 3.4 million ha (9%); and acid sulfate (c) = 2.3 million ha (6%).

In SA, the amount of fertile rice cropped area was observed to exceed that which has various soil constraints (Fig. 1). In SEA, however, the areas affected by adverse soil fertility conditions clearly dominate those with no major fertility constraints, particularly in SRL (56%), IWS (52%), and VDW (52%) rice areas. The proportion of rice cropped area having major soil fertility constraints varies between the two regions because of basic geological, pedological, and climatic differences.

The proportion of ricelands covered by adverse rice-growing soils varies widely across country and rice culture type (Table 2). The priorities in tailoring adaptable rice technologies for these areas must consider such important variations.



1. Comparative distribution of lowland rice cropped areas with and without major soil constraints in 5 rice culture types in South and Southeast Asia, 1986.

The various soil constraint classes differed in their importance among the rice culture types (Fig. 2). The number of specific soil constraints varied from 10 for SRL to 7 for VDW. Although most of the classes were observed in all of the rice culture types, two or three classes were clearly dominant. The complex of high P fixation, low CEC, and low nutrient reserves (aiek, e, eh, ehk) is dominant in SRL, MDW, and IDS; alkaline soils in IWS and VDW; saline soils in SRL and IWS; and acid sulfate soils in VDW (Fig. 2).

The breakdown by country shows interesting and useful comparisons at a more detailed level. These data, which are based on the correlation of soil constraints with actual rice-growing areas, can be usefully related to the data previously reported for the total estimated land area of various problem soils in the Asian countries (Annual report for 1985).

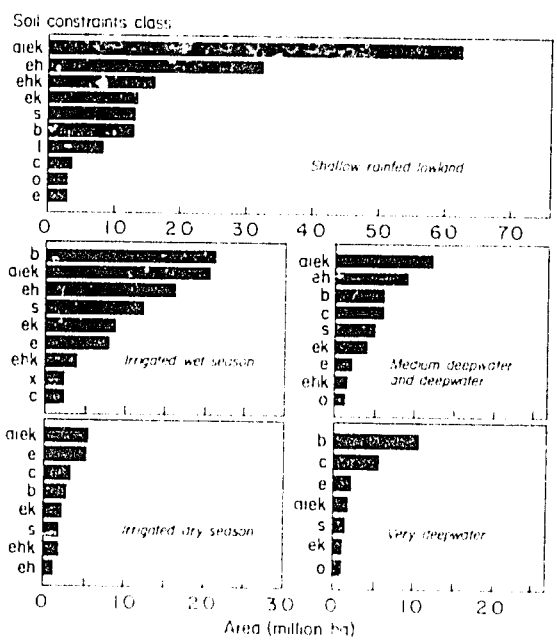
SULFUR STATUS OF SOME PHILIPPINE RICE SOILS

Agronomy Department

Philippine soil profile samples from 19 provinces on Luzon, 3 in the Visayas, and 1 on Mindanao,

Table 2. Percent distribution of fertile (no major constraint) and adverse soil conditions in 5 culture types for the countries of South and Southeast Asia

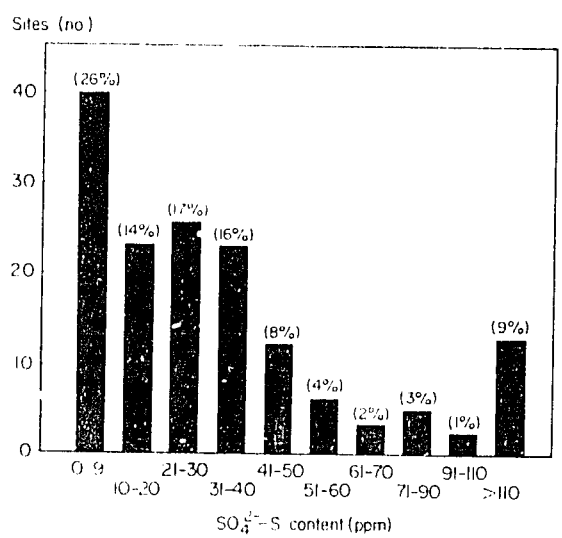
Country	Distribution (%)									
	Shallow rainfed lowland (<30 cm)		Irrigated wet season		Medium deepwater and deepwater (30-100 cm)		Irrigated dry season		Very deepwater (>100 cm)	
	Fertile	Adverse	Fertile	Adverse	Fertile	Adverse	Fertile	Adverse	Fertile	Adverse
South Asia										
Bangladesh	67	33	61	39	64	36	74	26	52	48
Bhutan	0	100	–	–	8	92	–	–	–	–
India	48	52	63	37	54	46	74	26	61	39
Nepal	42	58	80	20	100	0	–	–	100	0
Pakistan	–	–	17	83	–	–	–	–	–	–
Sri Lanka	23	77	70	30	0	100	72	28	–	–
Southeast Asia										
Burma	70	30	53	44	82	18	84	16	93	7
Cambodia	58	42	60	40	65	35	–	–	74	26
Indonesia	42	58	50	50	32	68	52	48	3	97
Laos	5	95	0	100	–	–	0	100	–	–
Malaysia	2	98	1	99	0	100	6	94	–	–
Philippines	70	30	80	20	94	6	92	8	–	–
Thailand	5	95	18	82	16	84	12	88	11	89
Vietnam	14	86	46	54	45	55	67	33	64	36



2. Relative distribution of rice cropped area under various types of soil fertility constraints in the 5 lowland rice culture types for South and Southeast Asia, 1986. aiek = potentially very acid, high P fixation, b = alkaline (calcareous), potentially Zn deficient, e = acid sulfate, e = low CEC, eh = low CEC, moderate to severe acidity, ek = low CEC, low native nutrient reserves, ehk = low CEC, moderate to severe acidity, low nutrient reserves, o = organic soil, s = saline, x = allophane soils, high P fixation, l = shallow soils (added only for sorting purposes).

taken from 20-cm depth intervals, were analyzed for total S, SO_4^{2-}-S, and other soil properties to identify potential S-deficient rice areas.

Among the 153 sites sampled, surface soils of 40 sites contained less than 10 ppm SO_4^{2-}-S — the critical level for rice (Fig. 3). More sites contained



3. Frequency distribution of 153 rice-growing sites in the Philippines based on SO_4^{2-}-S content in the surface soil (0-20 cm depth), 1986.

low SO_4^{2-}-S at lower soil depths, associated with decreasing organic matter. However, at eight sites, S content increased with depth, which may have been associated with S-containing parent material.

Surface soils with very low S content were found in Cagayan, Isabela, and Tarlac Provinces on Luzon and in Iloilo and Aklan on Panay Island. Once Philippine farmers cease to apply S-containing fertilizers such as $(NH_4)_2SO_4$ and intensify rice monoculture, S deficiency may become widespread.

Surface soils of sites with very low S contents had pH 5.1-7.4, 0.3-1.7% organic C, CEC 5.4-57.1 meq/100 g, 0-1.8 mg available Zn/kg, and 7-69% clay (Table 3).

MINERAL SOLUBILITY RELATIONSHIPS IN A CONTINUOUSLY FLOODED DEFICIENT SOIL

Soils Department

To better understand the mineral phases that may be important in the control of Zn in soil solutions of Zn-deficient soils, a laboratory experiment was conducted using a San Pablo clay soil (Tropaquent) from the IRRI Zn screening site in Bay, Laguna. This soil is noncalcareous with pH 7.3, 3.6% organic C, 0.34% N, CEC 50 meq/100 g, 80 mg total Zn/kg, and 0.4 mg available Zn/kg. Samples of saturated soil were placed in 3-liter pots and maintained in a continually wet condition at 25 ± 2 °C. Treatments, all based on a kilogram of soil, were control, 300 mg P as KH_2PO_4, 500 mg S as K_2SO_4, 5 g freshly precipitated $Fe(OH)_3$, 1.5 g freshly precipitated FeS, 10 g hydrated silica, and 50 g freshly divided $CaCO_3$ (calcite). They were repeated with and without 40 mg Zn as $ZnSO_4$. Samples for solution analysis were obtained at 7, 23, 42, 71, and 87 d after treatment.

The $Fe(OH)_3$, FeS, silica, and calcite treatments had little or no effect on Zn and most other soil solution components. The calculated mineral solubility saturation indices, log IAP/K_{sp} (IAP = ion activity product), for day 42 (Table 4), however, show that the silica treatment raised the silica concentration to equilibrium with amorphous silica, and adding PO_4^{3-} increased oversaturation with respect to vivianite and hydroxyapatite. The undersaturation with respect to calcite in the $CaCO_3$ treatment may reflect a small (0.1 unit) underestimation of pH.

The addition of SO_4^{2-} was accompanied by a significant addition of K^+, which resulted in the displacement of Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}, and Na^+ in the exchange complex, increasing the solution concentrations of these ions. Ca^{2+} and Mg^{2+} accounted for most of the increase. The displacement of Ca^{2+} resulted in an oversaturation with respect to calcite and the very slow precipitation of calcite. After 42 d, the SO_4^{2-} treatment still had Ca^{2+} equal to 3 times that of the other treatments. The concentration of Fe^{2+} decreased much more rapidly, and by day 71 was the same as the other treatments. Because no fresh organic matter was added, SO_4^{2-} reduction to S^{2-} was very slow, with about half of the added SO_4^{2-} reduced by day 42. There was no measurable additional accumulation of S^{2-} in the SO_4^{2-} treatment. The high degree of oversaturation with respect to precipitation of PO_4^{3-}, S^{2-}, and some of the CO_3^{2-} minerals (Table 4) appears to be maintained indefinitely. Lack of crystallinity of the mineral phases may contribute to the oversaturation with respect to crystalline solids, but blockage of crystal growth sites by

Table 3. Range of soil pH, organic C content, CEC, available Zn, and clay content of surface soils with very low to very high S content. 1986.

Item	Very low S	Low S	Medium S	High S	Very high S
pH	5.1-7.4	5.1-7.5	4.2-7.5	5.4-6.4	5.3-7.7
Organic C (%)	0.3-1.7	0.3-1.9	0.4-3.1	1.0-1.6	0.7-6.7
CEC (meq/100 g)	5.4-57	4.2-65.2	4.2-63.1	21.2-42.3	18.0-54.5
Available Zn (mg/kg)	0-1.8	0-1.8	0-2.6	0.17-1.8	0.03-0.67
Clay (%)	7-69	3-69	8-66	21-64	3-66

Table 4. Saturation indices (log IAP/K_{sp}) of CO_3^{2-}, PO_4^{3-}, and S^{2-} mineral phases and amorphous silica in a continuously flooded Zn-deficient soil 42 d after treatment, 1986.

Treatment	Solution pH	Saturation index							
		Calcite $CaCO_3$	Siderite $FeCO_3$	Rhodochrocite $MnCO_3$	Vivianite $Fe_3(PO_4)_2 \cdot 8H_2O$	Hydroxyapatite $Ca_5OH(PO_4)_3$	Troilite FeS	Wurtzite ZnS	Amorphous silica $SiO_2 \cdot nH_2O$
Control	6.87	-0.20	1.0	0.4	2.6	4.04	1.2	4.2	-0.14
PO_4^{3-}	6.86	-0.13	0.7	0.4	4.0	7.98	0.8	3.6	-0.04
PO_4^{3-} + Zn	6.80	-0.33	0.4	0.2	3.7	7.78	0.3	3.5	-0.02
SO_4^{2-}	6.84	0.13	1.1	0.7	2.3	4.87	1.3	4.3	-0.18
SO_4^{2-} + Zn	6.84	0.10	1.0	0.6	2.1	4.79	1.0	4.0	-0.19
$Fe(OH)_3$	7.13	-0.06	1.2	0.4	2.4	3.79	1.4	4.5	-0.25
$Fe(OH)_3$ + Zn	7.12	-0.06	1.2	0.6	1.8	3.70	1.1	4.5	-0.29
FeS	6.95	-0.21	0.9	0.4	2.4	4.20	1.2	4.4	-0.20
FeS + Zn	7.01	-0.09	1.0	0.4	2.7	4.51	1.1	4.4	-0.22
Silica	6.87	-0.20	1.0	0.4	2.8	4.38	1.1	4.3	-0.03
Silica + Zn	6.99	-0.06	1.2	0.6	3.2	4.89	1.2	4.5	-0.03
$CaCO_3$	6.86	-0.17	1.0	0.4	2.3	3.90	1.1	4.1	-0.17
$CaCO_3$ + Zn	6.78	-0.22	1.0	0.4	2.4	3.43	0.9	4.2	-0.18

organic and other anions may also contribute to the oversaturation. The high oversaturation with respect to ZnS (wurtzite) may reflect difficulty in forming a separate phase in a system low in total Zn.

Thus silica, $CaCO_3$, FeS, and $Fe(OH)_3$ have little direct effect on soil solution Zn and most other soil solution ions. In continually flooded neutral and alkaline soils, Zn is likely controlled by the formation of a S^{2-} phase, possibly a mixed phase with Fe^{2+}.

PHOSPHORUS SORPTION ISOTHERMS OF ACID AND ACID SULFATE SOILS

Soils Department

Acid sulfate soils are P deficient, and added phosphates do not always give a positive response. A study was undertaken to relate soil characteristics and oxidation-reduction state to differences in P sorption patterns.

The P sorption of surface soils (0-20 cm) collected from various provinces of the Mekong Delta, Vietnam, were studied under oxidized and reduced conditions. The soils were characterized for properties associated with P (Table 5).

P sorption isotherms grouped according to soil classification (Fig. 4-7) indicate that, up to 500 μg P/g soil, Freundlich equation was followed. All soils adsorbed P strongly, and sorption was considerably affected by oxidized and reduced soil conditions. In all soils, except soil no. 9, more P was sorbed under oxidized than under reduced conditions.

All soils under both treatments showed an abrupt increase in P sorption after solution P reached values ranging from 0.06 to 1.9 μg/ml, perhaps because of the precipitation of vivianite and amorphous aluminum phosphate and the adsorption of P by clay minerals.

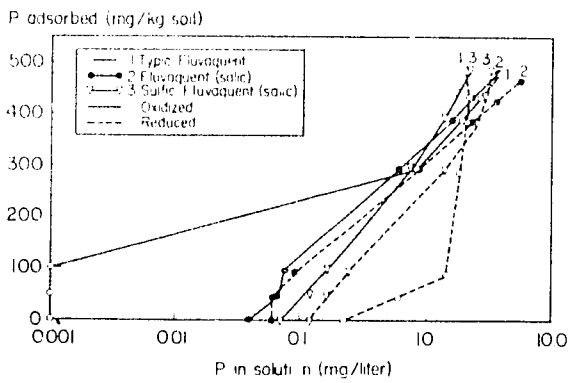
PHYSICAL CHARACTERISTICS OF RAINFED LOWLAND SOIL IN RESPONSE TO DROUGHT

Agronomy Department

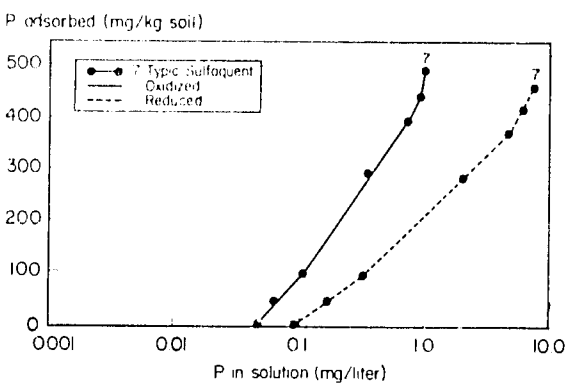
A previous experiment on water deficit in rainfed lowland rice suggested that the effects of soil moisture depletion continue long after the soil has been reflooded. To determine the changes a puddled soil undergoes during drought, the physical properties — specifically penetration resistance, bulk density, and moisture content — of a rainfed lowland soil were characterized at 10-cm layers to a depth of 40 cm. Penetration resistance of the soil profile was measured for continuously flooded plots, and for stressed plots after 28 d without irrigation (stressed) and at 2, 5, and 10 d after reflooding. Bulk density and gravimetric

Table 5. Some characteristics of soils (0-20 cm) from the Mekong Delta, Vietnam.

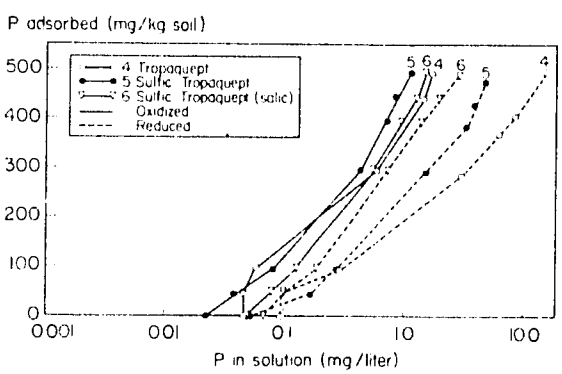
Classification	pH		Organic C (%)	Available P (mg/kg)		Active Fe (%)	Active Mn (%)	Exchangeable acidity (meq/100 g)
	H_2O (1:1)	H_2O_2		Olsen	Bray No. 2			
1. Typic Fluvaquent	4.51	3.68	1.26	9	17	1.53	0.017	1.58
2. Fluvaquent (salic)	4.55	2.94	1.26	3	11	2.25	0.014	1.85
3. Sulfic Fluvaquent (salic)	3.76	2.16	3.86	17	34	2.65	0.005	3.07
4. Tropaquept	4.40	2.58	2.59	2	16	0.49	0.008	4.06
5. Sulfic Tropaquept	4.14	2.71	3.95	6	15	0.88	0.023	2.53
6. Sulfic Tropaquept (salic)	3.63	1.74	4.48	3	12	0.42	0.008	11.28
7. Typic Sulfaquent	3.64	2.14	3.07	6	19	1.40	0.004	9.38
8. Sulfaquept (humic)	3.49	1.86	5.98	5	13	0.53	0.001	16.34
9. Sulfaquept (pale humic)	3.48	1.91	7.03	14	109	0.30	0.011	18.13
10. Typic Sulfaquept (salic)	3.70	1.74	3.65	5	12	0.43	0.010	9.66



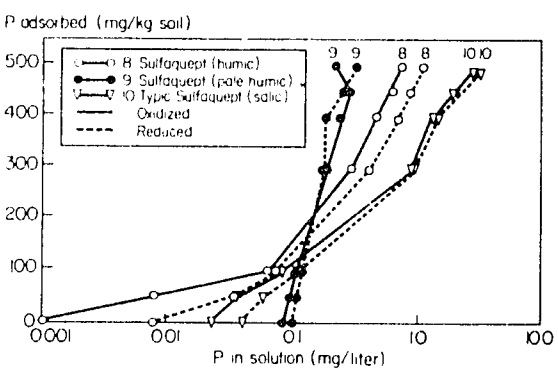
4. P sorption under oxidized and reduced conditions in Fluvaquents.



6. P sorption under oxidized and reduced conditions in a typic Sulfaquent.



5. P sorption under oxidized and reduced conditions in Tropaquepts.



7. P sorption under oxidized and reduced conditions in Sulfaquepts.

moisture content were measured from undisturbed core samples from the continuously flooded, stressed, and 10-d reflooded stressed plots. Results are given in Table 6.

Penetration resistance significantly increased during water deficit as compared with continuously flooded and reflooded plots. Up to 10 d after reflooding, the penetration resistance of the top

Table 6. Changes in penetration resistance, moisture content, and bulk density of a rainfed lowland soil as affected by drought stress.[a] IRRI, 1986.

Depth (cm)	Treatment					Significance level of DMRT
	Continuously flooded	Stressed	Reflooded for 2 d	Reflooded for 5 d	Reflooded for 10 d	
			Penetration resistance (MPa)			
0-10	0.16 b	3.05 a	0.25 b	0.25 b	0.24 b	**
10-20	0.43 c	>7.00 a	0.62 b	0.51 bc	0.39 c	**
20-30	0.78 b	>7.00 a	0.86 b	0.88 b	0.79 b	**
30-40	1.01 b	>7.00 a	0.89 b	0.98 b	0.84 b	**
			Moisture content (%)			
0-10	67 a	37 c	–	–	56 b	**
10-20	58 a	43 b	–	–	56 a	**
20-30	56	48	–	–	58	ns
30-40	62 a	53 b	–	–	60 a	*
			Bulk density (g/cm^3)			
0-10	0.97 b	1.24 a	–	–	0.98 b	**
10-20	1.03 b	1.22 a	–	–	1.03 b	**
20-30	1.10	1.13	–	–	1.01	ns
30-40	0.99 b	1.13 a	–	–	0.96 b	**

[a]Within a row, means followed by a common letter are not significantly different by DMRT at the following levels: ** = significant at the 1% level, * = significant at the 5% level, ns = not significant.

10-cm depth in stressed plots was still higher than that in continuously flooded plots, although not significantly different. For the 10-40 cm depths, penetration resistance returned to the initial levels by 10 d after reflooding. The measured penetration resistance for 0-10 cm in the stressed plots probably did not reflect the actual penetration resistance. Rather it was the penetration force registered when the soil cracked and crumbled from tensile failure.

Bulk density significantly increased during water deficit and returned to a level not significantly different from that of the continuously flooded plots. The same trend was observed for moisture content, except that at 0-10 cm the moisture content remained lower than that of the continuously flooded plots. Since penetration resistance is highly correlated with moisture content, the higher penetration resistance of the 0-10 cm depth in stressed plots than in the continuously flooded plots, even at 10 d after reflooding, may be explained by the failure of the soil moisture content to recover fully.

Because most soil physical parameters returned to levels near their prestress levels, any long-term effects of water deficit in rainfed lowland rice probably result from lost growth opportunity rather than a continuing soil stress.

Soil and crop management

Management of soil and fertilizer nitrogen

Agronomy and Soils Departments

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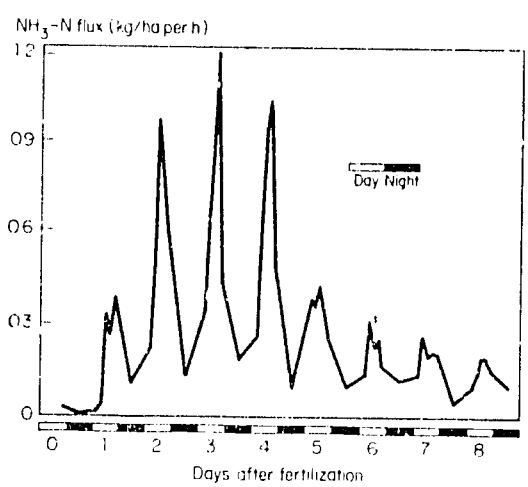
COMPARISON OF TOTAL NITROGEN LOSS AND AMMONIA VOLATILIZATION USING SIMPLE TECHNIQUES

Agronomy Department

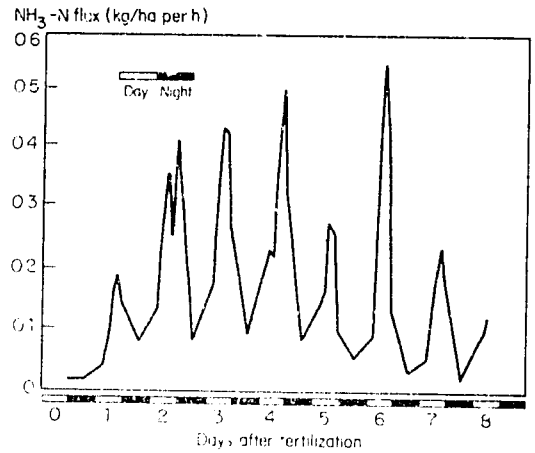
Data on NH_3 volatilization loss, determined from measurements of windspeed and excess NH_3 concentrations over the background NH_3, and total N loss determined by ^{15}N balance techniques were obtained in Calauan, Laguna, Philippines (high CEC soil), and Aguilar, Pangasinan, Philippines (low CEC soil), in the 1986 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 Calauan between 1400 and 1600 h for 4 d after urea surface application at 80 kg N/ha into the floodwater (Fig. 1). In Aguilar, NH_3 loss was lower and volatilization lasted up to day 7, with the highest rate on day 6 (Fig. 2). These periods coincided with daytime fluctuations in floodwater ammoniacal N (AN) concentrations in Calauan. In Aguilar, AN concentrations gradually increased to the highest obtained on days 3 and 4 and remained high until day 7. Thereafter, AN concentrations were negligible.

Maximum values of windspeed, floodwater temperature, and floodwater pH were also recorded. Although floodwater temperatures in Aguilar were higher than in Calauan, a high windspeed of about 8 m/s was recorded in Calauan and a low of 3 m/s in Aguilar. Initial floodwater pH in Aguilar was 6.5-6.6, which slowly peaked to 8.7-8.9.



1. Ammonia fluxes in a circular plot as measured by simplified aerodynamic technique (empirical formula). Calauan, Laguna, Philippines, 1986 DS.



2. Ammonia fluxes in a circular plot as measured by simplified aerodynamic technique (empirical formula). Aguilar, Pangasinan, Philippines, 1986 DS.

Total NH_3 flux as determined by the simplified technique was 30% or 24 kg N/ha in Aguilar out of 80 kg N/ha applied (Table 1).

Ammonia volatilization loss from different fertilizer management treatments. The measured NH_3 flux density was correlated with the product of windspeed and the difference between the NH_3 concentration in floodwater and in air. The resultant equations for the flux F in kg N/ha per h follow:

$$F = K\,\bar{\mu}_{0.8}\,(\bar{c}_{H_2O} - \bar{c}_b) \times 10^{-3}$$

For Calauan, $K = 0.0817$, $n = 51$, $r = 0.92^{**}$

For Aguilar, $K = 0.1400$, $n = 96$, $r = 0.83^{**}$

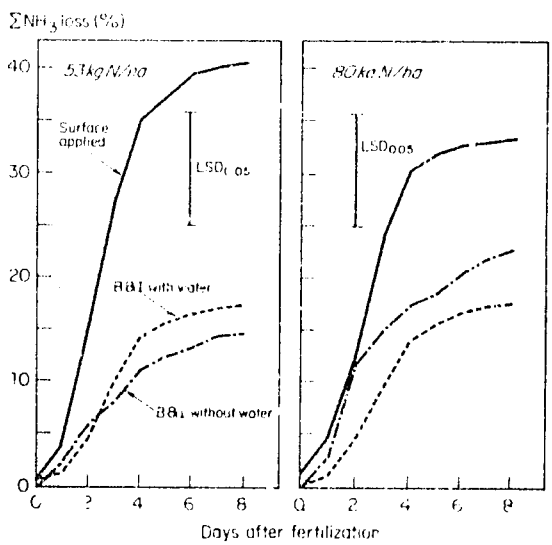
where $\bar{c}_{H_2O}$ is the mean floodwater NH_3 concentration (in g N/m^3) in the miniplot and $\bar{c}_b$ is the mean background NH_3 concentration in the atmosphere at 0.8 m (in g N/m^3). These equations were used to predict NH_3 loss under different management treatments.

In Calauan, the highest cumulative NH_3 volatilization loss was observed with surface-applied urea (Fig. 3). Losses with urea incorporated with and without standing water were similar. Showers, which occurred 1 d after fertilizer incorporation, produced 0.5-1.5 cm surface water with enough floodwater ammoniacal N to cause NH_3 losses

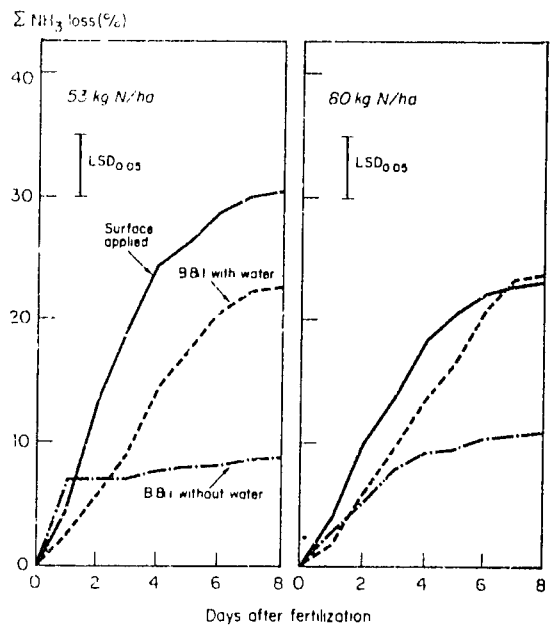
Table 1. Relationship between total N loss and NH_3 volatilization. Aguilar, Pangasinan, Philippines, 1986 DS.

Application method	Rate (kg/ha)	Water depth (cm)	Total N loss (%)	NH_3 loss (%)	Estimated nitrification-denitrification loss[a] (%)
Researchers' split[b]	53	0	44	9	35
Researchers' split[b]	53	5	48	23	25
Farmers' split[c]	53	5	60	30	30
Researchers' split[b]	80	0	50	11	39
Researchers' split[b]	80	5	62	24	38
Farmers' split[c]	80	5	60	23	37
Point placement[d]	53	0	22	0	22
LSD (0.05)	–	–	11	5	–
Farmers' split[e]	80	5	49	30	19

[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 + 1/3 at booting. [d]Urea supergranules. [e]Unreplicated treatment in circular plot using simplified technique to measure NH_3 volatilization.



3. Cumulative NH_3 loss as affected by fertilizer management practice, Calauan, Laguna, Philippines, 1986 DS. B&I = broadcast and incorporated.



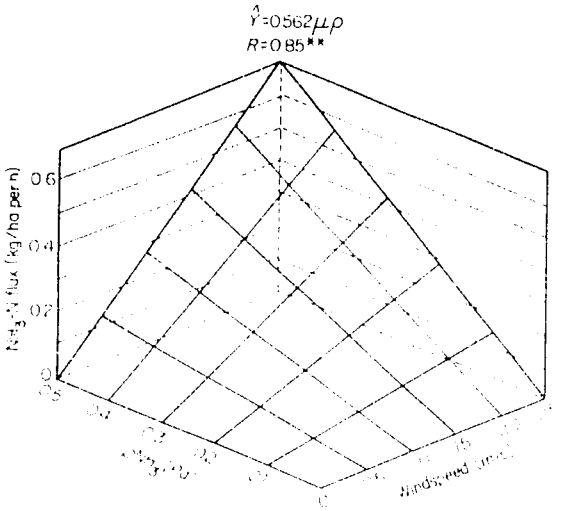
4. Cumulative NH_3 loss as affected by fertilizer management practice. Aguilar, Pangasinan, Philippines, 1986 DS.

similar to that when urea was incorporated with standing water and at times higher.

In Aguilar, volatilization was maximum with surface-applied N (Fig. 4) and least when urea was incorporated into the soil without standing water. At 80 kg N/ha, however, urea incorporation with standing water resulted in loss similar to or higher than that with surface-applied urea.

Our data emphasize the importance of maintaining the saturated soil condition for a few days after N fertilizer application to minimize NH_3 volatilization. Since NH_3 losses were determined from measurements of floodwater parameters and predicted from the measured NH_3 flux by simplified techniques, the absence of floodwater does not guarantee that NH_3 loss without standing water for 4 d was an absolute value.

Combined effects of windspeed and ammonia partial pressure. Stepwise regression analysis showed that only $\mu\rho$ in Aguilar (Fig. 5) gave the strongest correlation with NH_3-N flux, where ρ is the partial pressure and μ is the windspeed. Other



3. Effect of windspeed and NH_3 partial pressure in floodwater on NH_3 flux, Aguilar, Pangasinan, Philippines, 1986 DS. Y = predicted NH_3 flux, μ = windspeed at 0.8 m, ρ = floodwater partial pressure of NH_3.

combinations did not significantly improve the regression model.

The Pangasinan response surface showed that NH_3-N flux is a simple linear function of windspeed and partial pressure (Fig. 5). At any constant windspeed not equal to zero, NH_3-N flux increased linearly with partial pressure. At any constant partial pressure not equal to zero, it increased linearly with windspeed. When either partial pressure or windspeed was zero, NH_3-N flux was zero, regardless of the value of other non-zero variables.

The Calauan response surface showed that NH_3-N flux is a linear function of partial pressure and a quadratic function of windspeed. At any constant windspeed, NH_3-N flux increased linearly with partial pressure. At any constant partial pressure not equal to zero, it increased quadratically with windspeed. At zero partial pressure, NH_3-N flux was zero, regardless of windspeed. At zero windspeed, however, the response surface predicted that NH_3-N flux was not zero and that it increased linearly with partial pressure. NH_3-N flux was zero at zero partial pressure and zero windspeed.

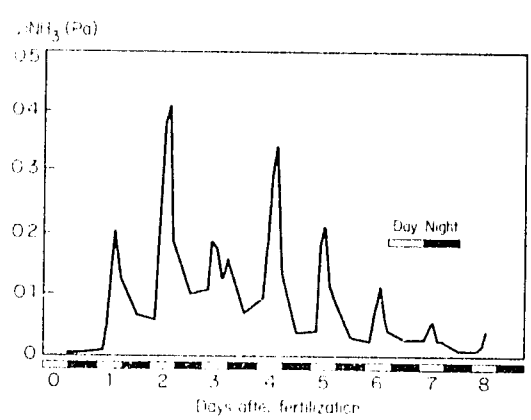
Regardless of the form and type of response surface that best describes a site, NH_3-N flux was strongly correlated with the interaction between windspeed and ρNH_3. When either windspeed or ρNH_3 was low, NH_3-N flux was very low; but when both were high, NH_3-N flux was very high. ρNH_3 is only an indicator of the potential NH_3 loss. Wind is needed to blow the NH_3 vapors above the floodwater for the loss to occur.

The highest ρNH_3 in the floodwater was obtained in Calauan (data not presented) and the lowest in Aguilar (Fig. 6).

The combined effect of ρNH_3 and windspeed is needed for high NH_3 losses. Regardless of the function that best describes the response surface, NH_3-N flux increased with increase in ρNH_3 and windspeed. The maximum value was recorded when ρNH_3 and windspeed were high at the same time.

Of the two response surfaces, that of Calauan gave the higher multiple correlation coefficient. It seemed to satisfy most of the basic assumptions of NH_3 volatilization losses and included a diffusion component. It showed that NH_3-N flux was a quadratic function of windspeed, agreeing with most of the heat and mass transport studies pertinent to windspeed. At zero windspeed, NH_3-N flux was predicted to be directly proportional to ρNH_3.

Contribution of ammonia volatilization to total ^{15}N loss. Total N losses in Calauan (Table 2) under different fertilizer management practices were similar. The estimated nitrification-denitrification loss was maximum when NH_3 loss was minimum, and vice-versa. The two processes were inversely related. Nitrification-denitrification was higher in



6. Partial pressure of NH_3 in floodwater in the miniplot during measurement of NH_3 fluxes, Aguilar, Pangasinan, Philippines, 1986 DS.

Table 2. Relationship between total N loss and NH_3 volatilization. Calauan, Laguna, Philippines, 1986 DS.

Application method	Rate (kg/ha)	Water depth (cm)	Total N loss (%)	NH_3 loss (%)	Estimated nitrification-denitrification loss[a] (%)
Researchers' split[b]	53	0	62	16	46
Researchers' split[b]	53	5	53	17	36
Farmers' split[c]	53	5	59	41	18
Researchers' split[b]	80	0	55	23	32
Researchers' split[b]	80	5	62	18	44
Farmers' split[c]	80	5	65	34	31
LSD (0.05)	–	–	13	11	–
Farmers' split[cd]	80	5	64	54	10

[a]By difference. [b]2/3 basal + 1/3 at 5-7 DBPI. [c]2/3 at 10 d after transplanting + 1/3 at booting. [d]Unreplicated treatment in circular plot using simplified technique to measure NH_3 volatilization.

soils with high organic matter than in those with low organic matter.

Higher total N loss in Aguilar (60%) (Table 1) was obtained with surface-applied urea than with fertilizer incorporated without standing water. Total N losses with fertilizer incorporation with and without standing water were similar at 53 kg N/ha. The implied nitrification-denitrification loss was not affected by N application method and rate.

These data suggest that even if NH_3 volatilization losses are reduced by better agronomic water management, denitrification losses can still be high.

^{15}N balance. Total ^{15}N recoveries under different treatments were similar in Calauan (Table 3), but differences in ^{15}N recovered by rice at 40 d after transplanting (DT) were highly significant. Uptake of the aboveground plant material was higher when urea was incorporated with or without standing water than when it was surface-applied. No exchangeable N in the soil was found in any treatment except in the soil with 80 kg N/ha as urea incorporated without standing water. The contents of the nonexchangeable N and of the roots in the soil were not affected by the treatments.

Total ^{15}N recoveries in Aguilar were high with researchers' split at 40 DT (Table 4). Fertilizer incorporation with and without standing water differed significantly only at 80 kg N/ha. The lowest ^{15}N recovery was obtained when fertilizer was surface-applied. A treatment of point-placed urea supergranules (USG), included as a check, gave the highest total ^{15}N recovery of 78%. ^{15}N recoveries of plants and exchangeable N in the soil

Table 3. Recovery of ^{15}N-labeled urea at 40 d after transplanting (DT) in soil and plant as affected by application method and water depth. Calauan, Laguna, Philippines, 1986 DS.

Application method	Rate (kg N/ha)	Water depth (cm)	Recovery (%) of ^{15}N-labeled urea				
			Plant	Exchangeable N	Nonexchangeable N + roots	Total	Unaccounted for
Researchers' split[a]	53	0	11	4	23	38	62
Researchers' split[a]	53	5	14	4	29	47	53
Farmers' split[b]	53	5	7	5	29	41	59
Researchers' split[a]	80	0	12	10	23	45	55
Researchers' split[a]	80	5	14	3	21	38	62
Farmers' split[b]	80	5	8	3	24	35	65
LSD (0.05)		--	5	7	6	13	13
Farmers' split in circle[c]	80	5	8	6	22	36	64

[a]Urea, basal, broadcast and incorporated (BB&I). [b]Urea topdressed at 10 DT. [c]Unreplicated.

Table 4. Recovery of ^{15}N-labeled urea at 40 d after transplanting (DT) in soil and plant as affected by application method and water depth. Aguilar, Pangasinan, Philippines, 1986 DS.

Application method	Rate (kg N/ha)	Water depth (cm)	Recovery (%) of ^{15}N-labeled urea				
			Plant	Exchangeable N	Nonexchangeable N + roots	Total	Unaccounted for
Researchers' split[a]	53	0	27	2	27	56	44
Researchers' split[a]	53	5	21	2	29	52	48
Farmers' split[b]	53	5	14	2	24	40	60
Researchers' split[a]	80	0	28	2	20	50	50
Researchers' split[a]	80	5	19	1	18	38	62
Farmers' split[b]	80	5	19	1	20	40	60
Point placement[c]	53	0	38	17	23	78	22
LSD (0.05)		–	9	11	7	11	11
Farmers' split in circle[d]	80	5	24	1	26	51	49

[a]Urea BB&I. [b]Urea topdressed at 10 DT. [c]Urea supergranules. [d]Unreplicated.

were highest with point placement. Uptake of the aboveground plant of researchers' split without standing water was highly significant compared with the farmers' split or surface-applied treatment and with the researchers' split treatment with standing water at 80 kg N/ha.

At 40 DT, the trend of plant ^{15}N recovery at the 2 sites followed that of total ^{15}N recovery. Although soil ^{15}N recovery sometimes followed the trend of total ^{15}N recovery, soil nonexchangeable N and roots were not affected by fertilizer management treatment. N uptake by the rice plants when N was basal and incorporated without standing water at both rates was superior to that with other methods.

NITROGEN DYNAMICS AND ^{15}N BALANCE IN LOWLAND RICE SOILS

Agronomy Department

The effect of fertilizer application time and method on N dynamics and ^{15}N balance in transplanted lowland rice was studied in a farmer's field in Pila, Laguna, in 1986 DS. Urea was applied at 58 kg N/ha in all N treatments. A manual injector for liquid urea was developed and compared with conventional (broadcast, and broadcast and incorporated [B&I]) application and USG deep placement. The kinetics and efficiency of ^{15}N uptake by IR64 were established separately for each split application. ^{15}N uptake was determined at 20 DT, 5-7 d before panicle initiation (DBPI), 10 d after panicle initiation (DAPI), 65 DT, and maturity. Potential N loss through NH_3 volatilization was monitored by determining the presence of urea-N and NH_4^+-N concentration in the floodwater at 1400 h after each fertilizer application up to 7 d.

Generally, deep placement (i.e., liquid injection or USG deep placement) gave significantly higher grain yield than did broadcast and B&I, with liquid injection performing best (Table 5). From the first

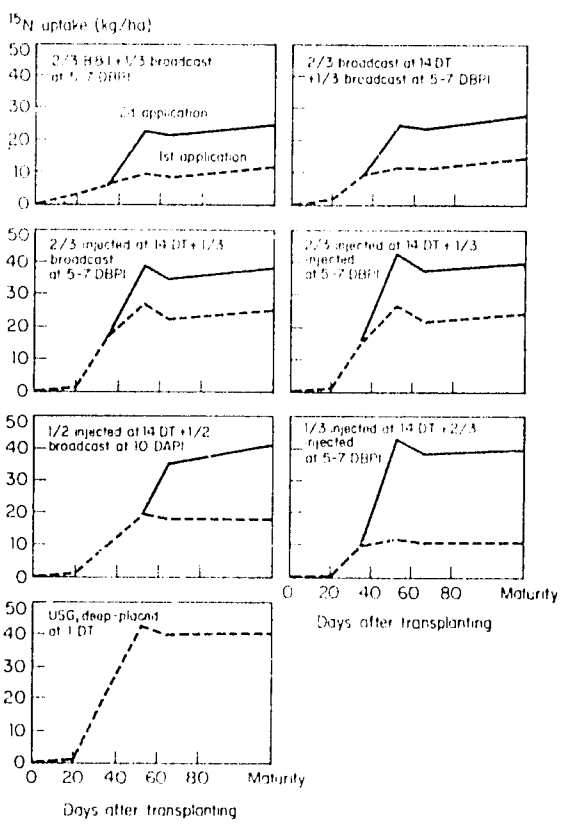
Table 5. Grain yield of IR64 as affected by time and method of fertilizer application. Pila, Laguna, Philippines, 1986 DS.

N treatment[a]	Grain yield (t/ha)
No fertilizer N	5.0 c
2/3 B&I at transplanting + 1/3 broadcast at 5-7 DBPI	6.4 b
2/3 broadcast at 14 DT + 1/3 broadcast at 5-7 DBPI	6.4 b
2/3 injected at 14 DT + 1/3 broadcast at 5-7 DBPI	7.2 a
2/3 injected at 14 DT + 1/3 injected at 5-7 DBPI	7.5 a
1/2 injected at 14 DT + 1/2 broadcast at 10 DAPI	6.9 ab
1/3 injected at 14 DT + 2/3 injected at 5-7 DBPI	7.5 a
All USG deep-placed at 1 DT	7.2 a

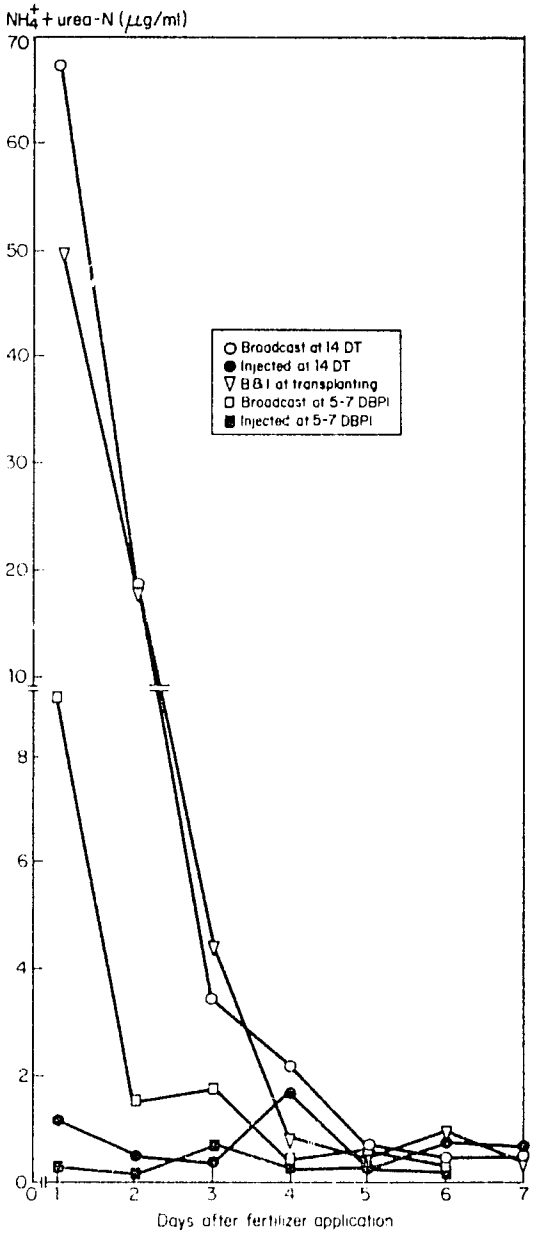
[a]Injection of liquid urea was done at 5 cm soil depth. DT = days after transplanting, DAPI = days after panicle initiation.

application, plant uptake of ^{15}N was lowest with N B&I at transplanting, intermediate when broadcast at 14 DT, and highest when injected at 14 DT. From the second application, uptake of ^{15}N was higher when injected at 5-7 DBPI than when broadcast at 5-7 DBPI. Broadcasting at 10 DAPI showed highest N uptake at maturity which, however, was not reflected in grain production (Fig. 7).

In all treatments, ^{15}N content in the plant decreased at 65 DT (flowering), indicating N loss from upper plant parts. Both USG deep placement and liquid injection produced negligible concentrations of floodwater urea-N and NH_4^+-N compared with broadcast and B&I, which on the first day produced a maximum of 60 μg N/ml and 50 μg N/ml in floodwater, respectively (Fig. 8).



7. ^{15}N uptake by IR64 as affected by time and method of fertilizer application at various growth stages, Pila, Laguna, Philippines, 1986 DS. DT = days after transplanting. DBPI = days before panicle initiation, DAPI = days after panicle initiation.



8. Effect of N application method on NH_4^+-N and urea-N concentration in the floodwater at 1400 h, Pila, Laguna, Philippines, 1986 DS. DT = days after transplanting.

NITROGEN MANAGEMENT AND ^{15}N RECOVERY IN BROADCAST SEEDED AND TRANSPLANTED RICE

Agronomy Department

The responses of broadcast seeded and transplanted IR64 to different N sources and manage-

ment practices were evaluated in DS at the Maligaya Rice Research and Training Center (MRRTC), Muñoz, Nueva Ecija, Philippines.

Grain yield. Basal point placement of USG in broadcast seeded rice (BR) gave the highest yield, but yields were comparable to those with 1) 2/3 urea B&I into 2 cm water before seeding + 1/3 at 5-7 DBPI, 2) 1/3 urea B&I into mud before seeding + 1/3 at 20 DAS + 1/3 at 5-7 DBPI, and 3) 2/3 $(NH_4)_2SO_4$ B&I into mud before seeding + 1/3 at 5-7 DBPI (Table 6). No significant yield difference was observed between 2/3 urea B&I into mud and into 2 cm water. Split application of urea or of $(NH_4)_2SO_4$ to BR at 15 DAS and 10 DAPI increased yields over the control, but yields were about 1 t/ha lower than with N B&I before seeding.

In transplanted rice (TPR), the fertilized treatments significantly increased yields over the nonfertilized control. No significant yield differences were observed among treatments except for prilled urea broadcast into floodwater in equal split doses at 15 DT and 10 DAPI, which gave lower yields (Table 6).

TPR yielded significantly higher than BR with 2/3 urea B&I into mud + 1/3 at 5-7 DBPI. Yields did not significantly differ between BR and TPR when urea was B&I into 2 cm water. The two methods gave similar yields when urea was split-applied at 15 DAS or DT and at 10 DAPI.

At varying N rates, broadcast seeded IR64 yielded lower when urea was split-applied at 15 DAS and 10 DAPI than when 2/3 urea was B&I into mud before seeding + 1/3 at 5-7 DBPI and when USG was basal point-placed (Fig. 9). Basal point-placed USG produced significantly higher yields than did urea applied as 2/3 B&I into mud + 1/3 at 5-7 DBPI at 40 and 87 kg N/ha.

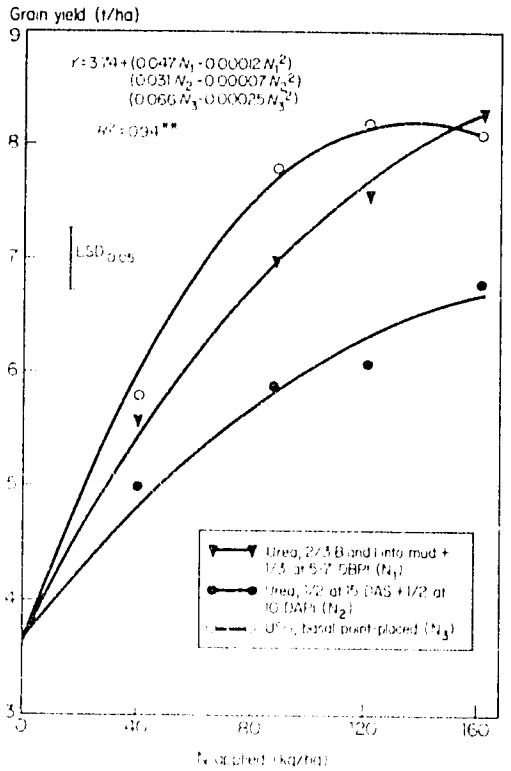
At 40 kg N/ha, plant N of broadcast seeded IR64 did not significantly vary at different growth stages (Fig. 10). But at 160 kg N/ha, N accumulation significantly differed at panicle initiation (PI) and flowering. At PI, plant N was low with urea split-applied at 15 DAS and 10 DAPI because the second dose had not yet been applied.

^{15}N recovery. Using ^{15}N-labeled fertilizer in microplots, BR generally recovered more of the applied N than did TPR (Table 7). ^{15}N unaccounted for in BR was lowest with $(NH_4)_2SO_4$ B&I into mud before seeding + 1/3 at 5-7 DBPI. This, however, was not significantly different from treatments with basal point-placed USG, urea applied in 3 equal-split doses, and urea and

Table 6. Effect of N source, planting, and fertilizer application method on grain yield of IR64. Maligaya Rice Research and Training Center (MRRTC), Nueva Ecija, Philippines, 1986 DS.

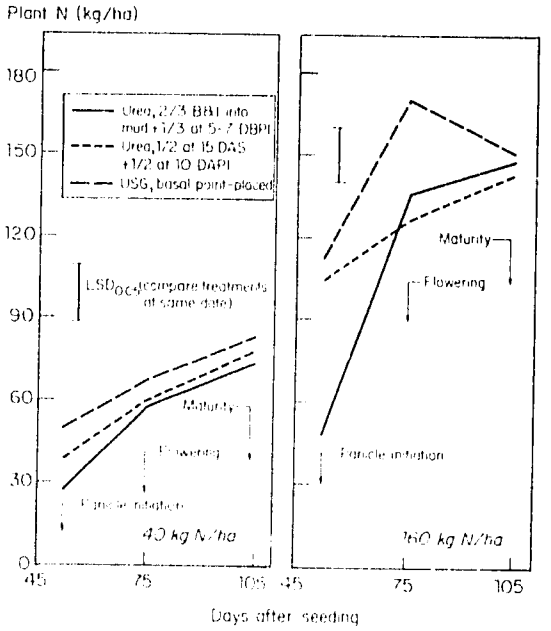
Planting method[a]	N source	N rate (kg/ha)	Application method[b]	Grain yield (t/ha)
BR, mud	–	0	–	3.7 k
BR, water	–	0	–	4.0 k
BR, mud	Urea	87	2/3 B&I into mud + 1/3 at 5-7 DBPI	7.0 efg
BR, water	Urea	87	2/3 B&I into 2 cm water + 1/3 at 5-7 DBPI	7.2 def
BR, mud	Urea	87	1/3 B&I into mud + 1/3 at 20 DAS + 1/3 at 5-7 DBPI	7.7 bcd
BR, mud	Urea	87	1/2 at 15 DAS + 1/2 at 10 DAPI	5.9 hi
BR, mud	USG	87	Basal point placement	7.8 a-d
BR, mud	$(NH_4)_2SO_4$	87	2/3 B&I into mud + 1/3 at 5-7 DBPI	7.5 cde
BR, mud	$(NH_4)_2SO_4$	87	1/2 at 15 DAS + 1/2 at 10 DAPI	5.5 ij
TPR, mud	–	0	–	3.5 k
TPR, water	–	0	–	3.5 k
TPR, mud	Urea	87	2/3 B&I into mud[c] + 1/3 at 5-7 DBPI	7.9 abc
TPR, mud	Urea	87	2/3 B&I into mud[d] + 1/3 at 5-7 DBPI	7.7 a-d
TPR, water	Urea	87	2/3 B&I into 2 cm water + 1/3 at 5-7 DBPI	7.8 a-d
TPR, mud	Urea	87	1/2 at 15 DT + 1/2 at 10 DAPI	6.4 gh

[a]BR = broadcast seeded rice, TPR = transplanted rice. [b]B&I = broadcast and incorporated into mud before seeding or transplanting, DAS = days after seeding, DT = days after transplanting. [c]Urea was B&I into mud and left saturated for 3 d before irrigating on the fourth day. [d]Urea was B&I into mud and irrigated the following day.



9. Effect of N source and application method on response of broadcast seeded IR64 to N, Muñoz, Nueva Ecija, Philippines, 1986 DS. DAS = days after seeding.

$(NH_4)_2SO_4$ applied in 2 equal-split doses. About 64% of the applied N was recovered from the whole plant with basal point-placed USG, of which about



10. Effect of N source and application method on the accumulation of N in broadcast seeded IR64, Muñoz, Nueva Ecija, Philippines, 1986 DS.

Table 7. Effect of planting and fertilizer application methods on ^{15}N recovery of 87 kg N/ha at maturity, MRRTC, Philippines, 1986 DS.

Treatment			^{15}N recovery (% applied N)					
Planting method	N source	Application method	Grain	Straw	Plant	Root	Soil	Unaccounted for
BR	Urea	2/3 B&I into mud + 1/3 at 5-7 DBPI	31	14	45	3	35	17
BR	Urea	2/3 B&I into 2 cm water + 1/3 at 5-7 DBPI	29	14	43	3	36	18
BR	Urea	1/3 B&I into mud + 1/3 at 20 DAS + 1/3 at 5-7 DBPI	37	17	54	4	37	5
BR	Urea	1/2 at 15 DAS + 1/2 at 10 DAPI	39	20	59	3	29	9
BR	USG	Basal point placement	41	24	64	4	30	2
BR	$(NH_4)_2SO_4$	2/3 B&I into mud + 1/3 at 5-7 DBPI	40	20	60	4	35	1
BR	$(NH_4)_2SO_4$	1/2 at 15 DAS + 1/2 at 10 DAPI	41	21	62	3	28	7
TPR	Urea	2/3 B&I into mud[a] + 1/3 at 5-7 DBPI	28	10	38	2	34	26
TPR	Urea	2/3 B&I into mud[b] + 1/3 at 5-7 DBPI	28	11	39	2	38	21
TPR	Urea	2/3 B&I into 2 cm water + 1/3 at 5-7 DBPI	24	9	33	2	38	27
TPR	Urea	1/2 at 15 DT + 1/2 at 10 DAPI	31	10	42	1	25	32
LSD (0.05)			5	3	7	1	4	8

[a]B&I into mud and left saturated for 3 d before irrigating on the fourth day. [b]B&I into mud and irrigated the following day.

2/3 was in the grain. ^{15}N recovery with 2/3 urea B&I into mud was comparable to that with urea B&I into water. Fertilizer application at two equal split doses of urea and $(NH_4)_2SO_4$ gave significantly higher ^{15}N recovery in BR than did 2/3 urea B&I into mud or water. In TPR, unaccounted for ^{15}N was higher (32%) when urea was split-applied in 2 equal doses.

^{15}N recovery in the plant-soil system of transplanted IR64 did not significantly differ between 2/3 urea B&I into mud (and irrigated on the 4th day) and into 2 cm standing water. Two-thirds urea B&I into mud and immediately irrigated the following day gave ^{15}N recovery in the plant similar to that with urea B&I into mud and irrigated on the 4th day. The amount of ^{15}N remaining in the soil, however, was significantly higher when the soil was irrigated after 1 d rather than 4 d.

EFFECTIVENESS OF UREASE INHIBITORS IN LOWLAND RICE

Agronomy Department

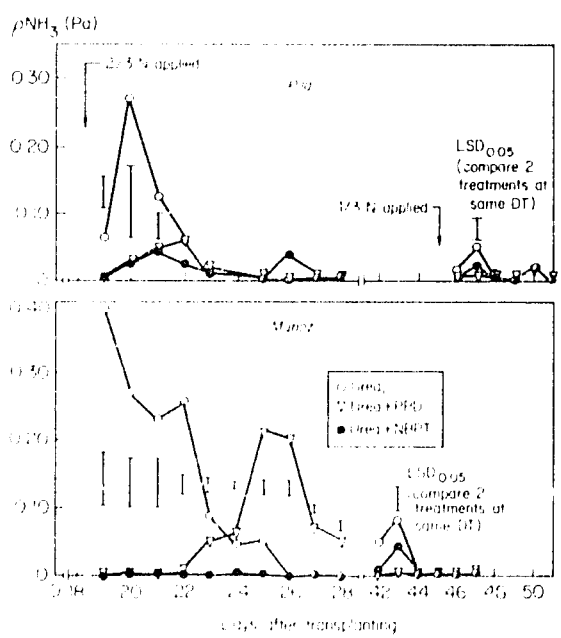
Even though past research has demonstrated 20-60% loss of N fertilizer broadcast without thorough incorporation in ricefields, some Asian rice farmers are reluctant to change from their present methods of fertilization. Urease inhibitors offer one strategy for reducing N loss and increasing rice yield without requiring a change in the farmers' method of N application. In theory, a small quantity of the chemical urease inhibitor, 2% or less by weight, would be added to urea at the production stage. When the urea is applied to a ricefield, the inhibitor would delay urea hydrolysis, thereby preventing NH_3 buildup in the floodwater and subsequent loss of NH_3 to the atmosphere.

Two urease inhibitors, phenyl phosphorodiamidate (PPD) and N-(n-butyl) thiophosphoric triamide (NBPT), were examined in cooperation with the International Fertilizer Development Center (IFDC) at multiple N rates in both Pila, Laguna, and Muñoz, Nueva Ecija.

Ammonia loss. The relative effect of the inhibitors on NH_3 loss was inferred from the equilibrium vapor pressure of ammonia (pNH_3), which was calculated from measured floodwater pH, temperature, and AN concentration. The pNH_3 can provide a relative measure of NH_3 loss among N sources at each site, because at a given windspeed it is directly related to NH_3 volatilization.

Amending urea with either PPD or NBPT reduced the pNH_3 and, hence, NH_3 loss at both sites. NBPT consistently matched or exceeded PPD in the ability to reduce pNH_3 at each N rate and timing at both sites. Following N application at 18 DT in Pila, NBPT reduced pNH_3 by 97, 77, and 74% for 35, 70, and 140 kg N/ha, respectively. The corresponding reductions with PPD were 79, 76, and 13%, respectively. NBPT was even more effective in Muñoz than in Pila. In Muñoz, NBPT reduced pNH_3 by 94, 96, and 98% as compared with 82, 54, and 25% for PPD at 35, 70, and 140 kg N/ha, respectively. Figure 11 shows daily pNH_3 at 1400 h for the rate 70 kg N/ha.

Grain yield. Amending urea with either PPD or NBPT increased grain yield in Muñoz but not in Pila (Table 8). An alternative management practice of broadcasting urea onto drained, saturated soil at 18 DT and 5-10 DAPI offered no apparent advantage over broadcasting urea into standing floodwater with the same timing. This practice



11. Effect of urease inhibitors on pNH_3 at 1400 h, Pila and Muñoz, Philippines, 1986 DS. PPD = phosphorodiamidate, NBPT = N-(n-butyl) thiophosphoric triamide.

Table 8. Effect of N treatment and rate on grain yield of IR58, Pila and Muñoz, Philippines, 1986 DS.

N treatment and rate	Grain yield[a] (t/ha)	
	Pila	Muñoz
N treatment (N)		
N1 Urea, 5 cm water	5.5	6.2
N2 Urea + PPD[b], 5 cm water	5.8	6.7
N3 Urea + NBPT[c], 5 cm water	5.6	6.8
N4 Urea, saturated soil	5.7	6.0
N rate (R)		
0	3.1	3.0
35 kg N/ha	4.5	4.7
70 kg N/ha	5.5	5.9
105 kg N/ha	6.2	7.1
140 kg N/ha	6.4	8.0

[a]Values for N treatment represent the mean of 4 nonzero N rates; values for N rate represent the mean of 4 treatments. [b]Phenyl phosphorodiamidate. [c]N- (n-butyl) thiophosphoric triamide.

never increased plant uptake of N or grain yield (Table 8).

The N response for any treatment clearly followed the quadratic pattern at both sites (Table 8). Combined analyses of variance over the two sites for grain yield revealed that the response to applied N was significantly greater ($P = 0.01$) in Muñoz than in Pila. Although the grain yield with no applied N was comparable in both Pila (3.1 t/ha) and Muñoz (3.0 t/ha), the mean grain yield at 140 kg N/ha was 1.6 t/ha greater in Muñoz than in Pila. The greater grain yield in Muñoz was probably due to greater solar radiation.

Urea savings. The quadratic responses in grain yield to applied N were used to calculate the urea saved at a desired yield with PPD and NBPT (Table 9).

$$\text{Urea saved} = \frac{(N_U - N_{UI})}{N_U} 100$$

where N_U = urea-N required for desired yield, and
N_{UI} = inhibitor amended urea-N required for desired yield.

Since the inhibitors consistently gave higher yields, they reduced the urea required for a desired grain yield. In each experiment in Pila, the urea saved tended to increase with increasing yield from 4.0 to 6.5 t/ha and was slightly greater for PPD than

Table 9. Effect of urease inhibitors on the urea saved at a desired grain yield of lowland rice, Pila and Muñoz, Philippines, 1986 DS.

Desired yield (t/ha)	Urea saved (%)					
	PPD[a]				NBPT[b]	
	Pila			Muñoz, 1986 DS	Pila, 1986 DS	Muñoz, 1986 DS
	1985 DS	1986 DS	1986 DS			
4.0	5.6	14	7.9	18	4.7	19
5.0	7.6	14	11	18	5.7	19
5.5	8.5	15	14	18	7.6	19
6.0	11	17	22	18	13	19
6.5	17	23	—	18	—	20

[a]Phenyl phosphorodiamidate. [b]N- (n-butyl) thiophosphoric triamide.

for NBPT (Table 9). In Muñoz, the urea saved remained constant for yields from 4.0 to 6.5 t/ha and was similar for the 2 inhibitors.

Even though NBPT was more effective than PPD in reducing pNH_3, it was not more effective in increasing grain yield and reducing the required urea.

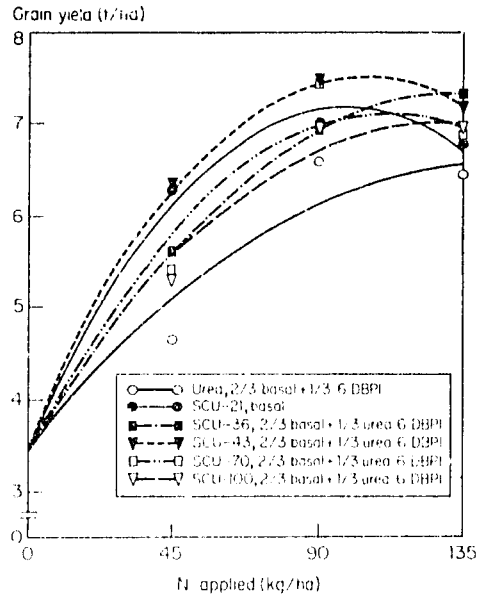
EFFECTIVENESS OF UREA COATING IN LOWLAND RICE

Agronomy Department

Although sulfur-coated urea (SCU) is an effective N source for rice, it is expensive to produce, because large amounts of S, sealant, and conditioner (20% by weight of urea) are required. One way of decreasing the quantity of coating per unit weight of urea is to increase the urea granule size.

Four experimental S-coated, forestry-grade urea fertilizers prepared by IFDC were evaluated in Pila, Laguna, in 1986 DS. The 4 fertilizers were designated by their 7-d release rate in water (SCU-36, SCU-43, SCU-70, and SCU-100). An all-basal application of conventional, granular SCU (designated SCU-21 because of its 21% 7-d release rate in water) served as the reference treatment. Properties of the fertilizers are shown in Table 10.

The quadratic response in IR64 grain yield to applied N is shown in Figure 12. Analysis of variance indicated that mean grain yield was significantly greater for each of the S-coated materials than for regular prilled urea (PU) applied by the recommended best split. Grain yield for the four experimental fertilizers tended to be comparable to that for the conventional SCU-21.



12. Effect of N source on grain yield of IR64, Pila, Laguna, Philippines, 1986 DS.

In each case, coating urea with S reduced the quantity of urea required to obtain a desired grain yield. Table 10 shows the savings in urea for either a 5.0 or 6.0 t/ha yield. All values are relative to the best split for PU. SCU-43 was the most promising of the experimental fertilizers. The coating on urea could be reduced from 20% for SCU-21 to 12.4% for SCU-43 with no change in grain yield or savings in urea.

The greater grain yield with SCU fertilizers than with PU was apparently due to 1) a reduction in N loss and 2) a release of available N that better matched the N uptake pattern of rice. In an

Table 10. Properties of sulfur-coated urea (SCU) fertilizers prepared by the International Fertilizer Development Center and their effects on urea savings at 2 desired grain yields. Pila, Laguna, Philippines, 1986 DS.

N source	Composition[a] (%)					7-d release rate (%)		Urea saving (%) at	
	N	S	Sealant	Conditioner	Total coating	Water	Soil[b]	5.0 t/ha	6.0 t/ha
SCU-21	37	15.6	NA	NA	20.1	21	NA	45	48
SCU-36	39	14.8	0	0	14.8	36	54	29	34
SCU-43	40	9.1	1.2	2.1	12.4	43	33	48	52
SCU-70	41	8.9	0.6	2.2	11.7	70	79	36	39
SCU-100	41	9.8	0	0	9.8	100	100	25	29

[a]NA = not available. [b]Determined in the 5-10 cm layer of simulated wetland soil.

auxiliary 1986 DS experiment, SCU-70 reduced pNH_3 and, presumably, NH_3 loss by 33% compared with PU.

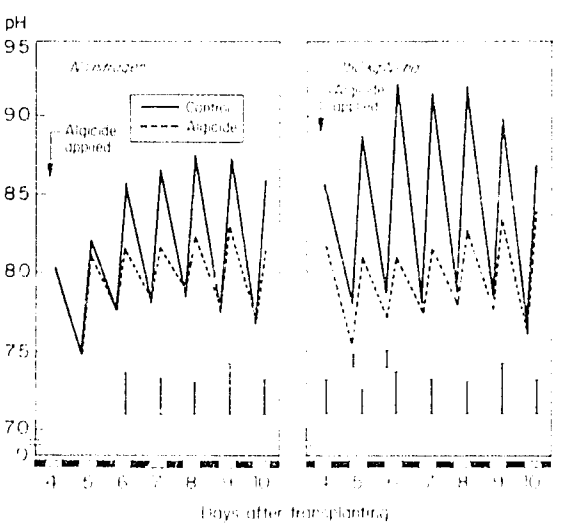
EFFECTIVENESS OF ALGICIDES IN LOWLAND RICE

Agronomy Department

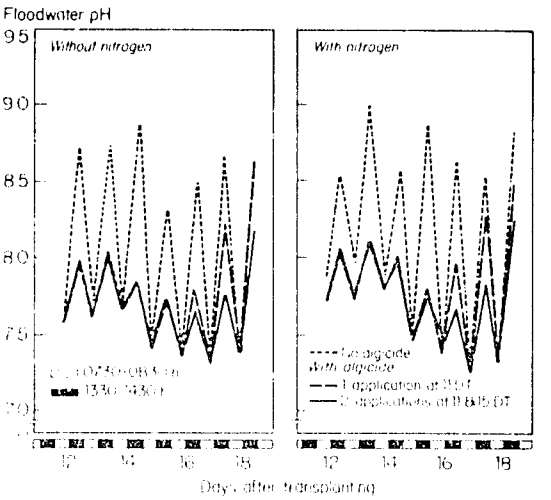
A cooperative project with the Commonwealth Scientific and Industrial Research Organization in Pila, Laguna, in 1986 DS and WS evaluated the effect of algicides in improving N use efficiency in rice by reducing NH_3 volatilization.

Floodwater chemistry. Terbutryn is a triazine herbicide used as an algicide. When applied at 0.1 kg ai/ha, it lowered the maximum pH by 0.79 unit for 6 d with the researchers' split of 150 kg N/ha (Fig. 13). Floodwater pH trends were similar with farmers' split and researchers' split. $CuSO_4$, used as an algicide in DS, was not effective in controlling the floodwater pH. In WS, terbutryn application maintained a floodwater pH consistently lower than that of the control (Fig. 14). However, 2 algicide applications lowered the pH more for 3 d after the second application at 15 DT.

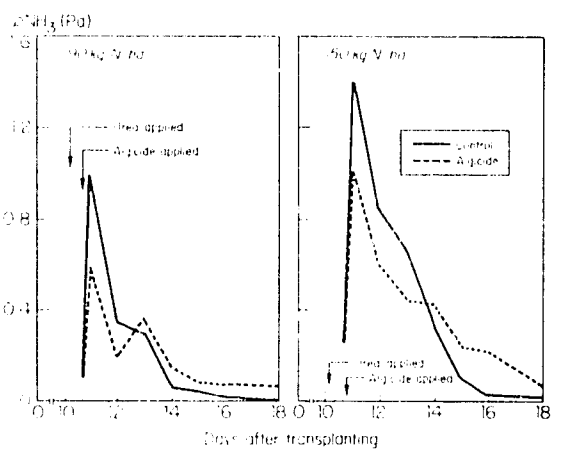
In both seasons, the highest partial pressure of ammonia (pNH_3) was recorded in the control 1 d after urea was applied by farmers' split (Fig. 15,



13. Effect of algicide on floodwater pH, Pila, Laguna, Philippines, 1986 DS. N was 2/3 B&I without water + 1/3 topdressed at 5-7 DBPI. The vertical bars represent LSD values when the variance ratio was significant at the 5% level.



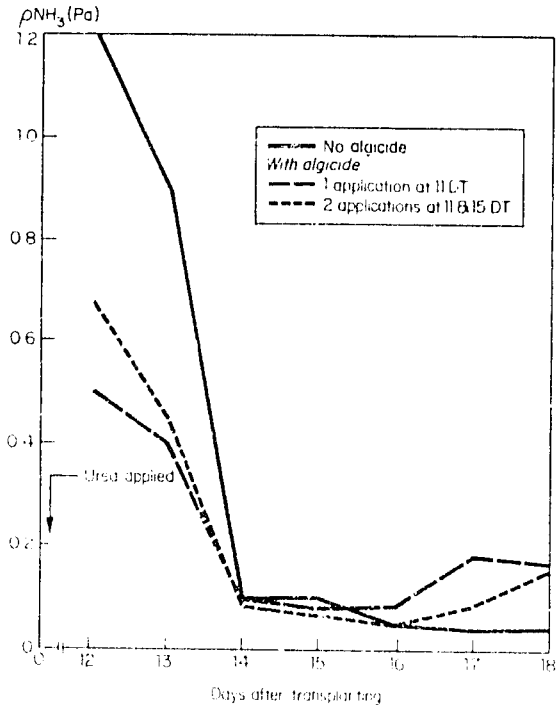
14. Effect of algicide on floodwater pH, Pila, Laguna, Philippines, 1986 WS. N at 87 kg N/ha was applied 1/2 at 11 d after transplanting (DT) + 1/2 at 10 DAPI.



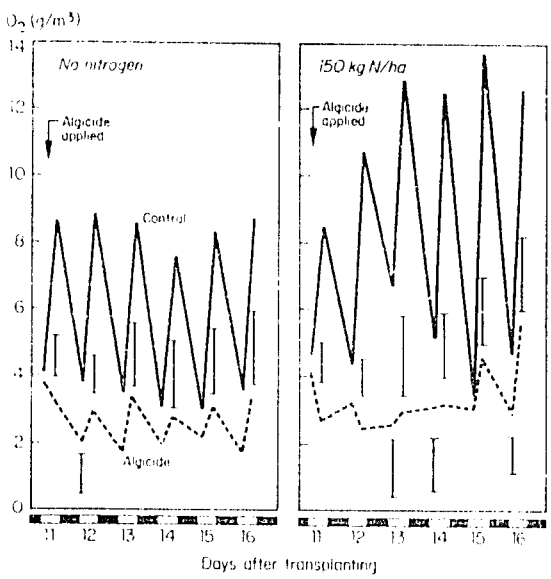
15. Effect of algicide on partial pressure of ammonia (pNH_3) with farmers' split N application (1/2 topdressed at 10 d after transplanting + 1/2 at 10 DAPI). Pila, Laguna, Philippines, 1986 DS.

16). The pNH_3 declined more rapidly in the control than in the algicide-treated plots, but in DS, the pNH_3 exceeded that of the control 3-4 d after algicide was applied (Fig. 15). In WS, pNH_3 with algicide exceeded that of the control 5-6 d after urea was applied (Fig. 16).

The researchers' split of N gave negligible pNH_3 in both seasons. With farmers' split, algicide application maintained a lower O_2 concentration



16. Effect of algicide on partial pressure of ammonia (pNH_3), Pila, Laguna, Philippines, 1986 WS. Urea was applied at 87 kg N/ha (1/2 topdressed at 11 d after transplanting (DT) + 1/2 topdressed at 10 DAPI).



17. Effect of algicide on O_2 in floodwater under farmers' split N, Pila, Laguna, Philippines, 1986 DS. The vertical bars represent LSD values when the variance ratio was significant at the 5% level.

than in the control for 6 d after N application at 0 and 150 kg N/ha (Fig. 17). At 150 kg N/ha, algicide reduced the average O_2 level from 8.4 to 3.0 g/m^3, whereas the corresponding reduction with no N was from 6.0 to 2.7 g/m^3.

Grain yield. The interaction among algicide application, N management practice, and N rate was significant in DS. Terbutryn application with researchers' split at 90 kg N/ha produced significantly higher yields than did $CuSO_4$ application and the control (Table 11). Terbutryn, when applied without N, increased grain yield. In WS, yields with researchers' split and farmers' split were not significantly different (Table 12). N application produced yield significantly higher than that with no fertilizer N by 0.9 t/ha. Two algicide applications gave significantly higher yield than did the control. Yields in WS were low because two typhoons hit the area during early flowering.

VARIETAL DIFFERENCES IN SOIL NITROGEN UTILIZATION

Agronomy Department

Collaborative studies with the University of California, Davis, USA, continued to evaluate the

Table 11. Effect of algicides, N application rate, and fertilizer management on grain yield of IR64, Pila, Laguna, Philippines, 1986 DS.

Treatment[a]	Yield[b] (t/ha)			
	No N	90 kg N/ha	150 kg N/ha	Mean
		Researchers' split		
Control	3.4 a	4.4 b	5.5 a	4.4
$CuSO_4$	2.5 b	4.6 b	5.6 a	4.2
Terbutryn	4.0 a	5.4 a	5.2 a	4.9
		Farmers' split		
Control	2.8 b	5.0 a	4.7 a	4.2
$CuSO_4$	3.2 b	4.6 a	4.7 a	4.2
Terbutryn	3.9 a	4.9 a	4.6 a	4.5

[a]Treatments were applied at 4 days after transplanting (DT) for researchers' split and at 11 DT for farmers' split. $CuSO_4$ rate = 6.0 kg/ha, terbutryn rate = 0.1 kg ai/ha. Researchers' split = 2/3 B&I without water + 1/3 topdressed at 5-7 DBPI. Farmers' split = 1/2 topdressed at 10 DT + 1/2 topdressed at 10 DAPI. [b]Within a fertilizer management practice, means in a column followed by a common letter are not significantly different at the 5% level by LSD.

ability of modern rice varieties and breeding lines to efficiently utilize soil N, a major N source in lowland rice. Using the criterion that rice varieties selected for N utilization efficiency should be capable of performing over varying environmental conditions, field experiments were conducted in 1986 DS and WS on a poor soil (soil N content = 0.08% total N) at MRRTC, Nueva Ecija, Philippines. A split-plot design was used with N level as main plots (no N and 4 N) and 24 rices as subplots with 6 replications. Test rices were 8 varieties each with 100-, 110-, and ≥120-d maturities. A 5-m^2 area was fertilized with ^{15}N-depleted $(NH_4)_2SO_4$ at the rate of 80 kg N/ha in DS and 60 kg N/ha in WS to distinguish between soil and atmosphere-derived N, and fertilizer N in the plants.

Ranking system. At 30 DT and PI, dry matter, total N, percentage of N derived from fertilizer, and dry matter-to-fertilizer N ratio of varieties were evaluated. Panicle weight, panicle weight-to-total N ratio, panicle weight-to-fertilizer N ratio, grain yield, and harvest index were determined at harvest. A variety producing high grain yield with minimum N fertilizer would have a high panicle weight:fertilizer N; the opposite would be true for a variety strongly responsive to N fertilizer or with low efficiency in utilizing soil and atmosphere-derived N (Table 13). By the use of those nine parameters, IR21912-131-3-3-2-2 and IR15323-78-1-3-1 ranked first, and IR19729-5-1-1-3-2 and IR13240-82-2-3-2-3-1 ranked last. IR42, which is known for high soil N use efficiency, ranked 15th in DS and 5th in WS in a low fertility soil at MRRTC. Results with IR42 at MRRTC were consistent with those obtained at IRRI.

Nitrogen response. Rice response to N fertilizer was high at MRRTC because of the site's low N content. Irrespective of rice variety and growth duration, fertilizer N dependence was high and

Table 12. Effect of fertilizer management, N rate, and algicide application on grain yield of IR64, Pila, Laguna, Philippines, 1986 WS.

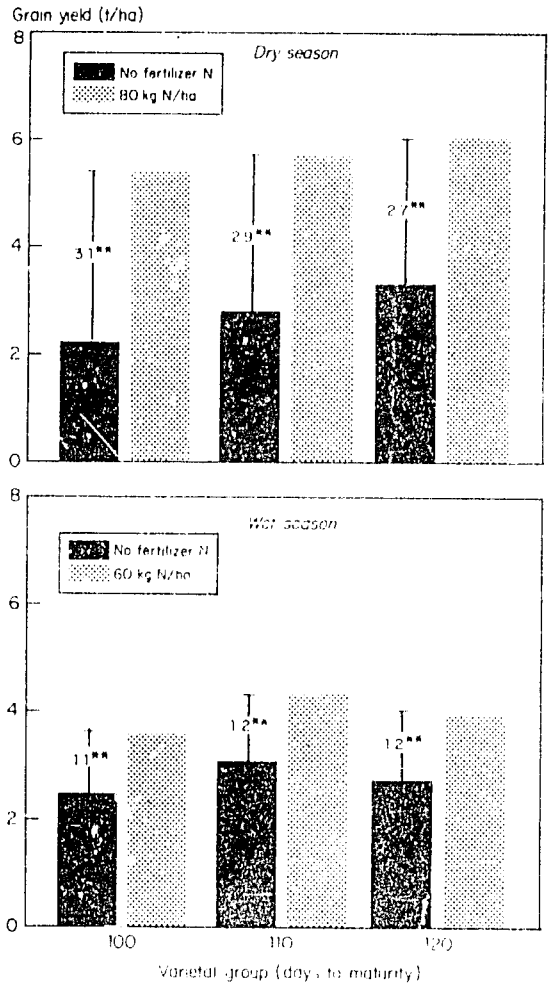
Treatment[a]	Yield[b] (t/ha)
Fertilizer management	
Farmers' split	2.9 a
Researchers' split	3.1 a
N rate (kg/ha)	
0	2.6 b
87	3.5 a
Algicide	
Control	2.9 b
One application	3.0 ab
Two applications	3.2 a

[a]Farmers' split = 1/2 topdressed at 10 days after transplanting (DT) + 1/2 topdressed at 10 DAPI. Researchers' split = 2/3 B&I without water + 1/3 topdressed at 5-7 DBPI. Terbutryn was the algicide used at 0.1 kg ai/ha per application time. One application = applied at 1 DT for researchers' split and at 11 DT for farmers' split. Two applications = applied at 1 and 5 DT for researchers' split and at 11 and 15 DT for farmers' split. [b]Within fertilizer management practice, N rate, or algicide, means followed by a common letter are not significantly different at the 5% level by LSD.

Table 13. Cumulative ranking of 24 varieties and lines based on 9 crop parameters.[a] MRRTC, Nueva Ecija, Philippines, 1985.

Variety or line	Ranking	
	Dry season	Wet season
100-d maturity		
IR8455-78-1-3-3	14	16
IR8608-167-1-2	22	18
IR9729-67-3	11	4
IR9752-1-2-1	17	12
IR19729-5-1-1-3-2	24	19
IR15429-268-1-2-1	21	21
IR19728-9-3-2-3-3	16	8
IR19735-2-3-2-1	20	6
110-d maturity		
IR36	18	13
IR50	13	14
IR13429-150-3-2-1-2	5	2
IR13427-40-2-3-3-3-3	23	22
IR13240-82-2-3-2-3-1	8	24
IR25588-32-2	9	7
IR18349-135-2-3-2-1	3	20
IR21912-56-3-1-2-2	4	23
120- to 135-d maturity		
IR13540-56-3-2-1	2	9
IR21912-131-3-3-2-2	1	3
IR26	10	11
IR2863-38-1	19	10
IR42	15	5
IR8192-200-3-3-1-1	6	15
IR11248-148-3-2-3-3	12	17
IR15323-78-1-3-1	7	1

[a]Panicle weight: fertilizer N in plant, panicle weight: soil N in plant, panicle weight, harvest index, total dry matter: fertilizer N in plant, total dry matter: soil N in plant, panicle weight: total N in plant, total dry matter: total N in plant, and grain yield.



18. Grain yield of rices of different maturities as affected by fertilizer N application. Maligaya Rice Research and Training Center, Nueva Ecija, Philippines, 1986.

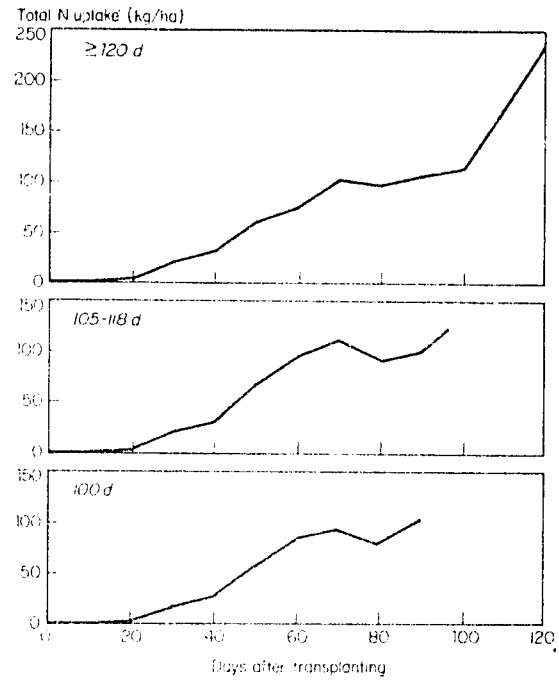
uniform but more pronounced in DS than in WS (Fig. 18).

NITROGEN UPTAKE PATTERNS IN MODERN RICE

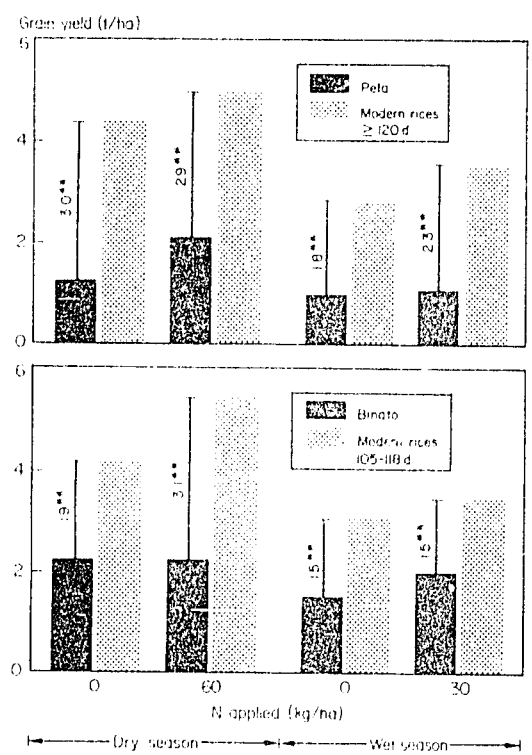
Agronomy Department

A collaborative study with the University of California, Davis, USA, was initiated in 1986 to discover the 1) variations in N uptake pattern of modern rices with different durations, 2) relationship between N utilization and fertilizer N application, and 3) distribution of soil N, fertilizer N, and dry matter during growth.

Nitrogen uptake pattern. The total N uptake pattern of rices of 3 growth durations was initially



19. Total N uptake of rices of 3 growth durations (100-, 105-118, and ≥120-d) at 10-d growth intervals. IRRI, 1986 DS.



20. Grain yield of traditional varieties Peta and Binato and 10 modern rices as affected by N application. IRRI, 1986 DS and WS.

slow at 1-20 DT, increased during tillering up to 70 DT, then slowed down before increasing again during the reproductive and ripening stages (Fig. 19). Generally, short- and medium-duration rices (100-118 d) had lower N uptake than long-duration rices (≥120 d).

Grain yield. The yield of modern rices was related to growth duration. Short-duration rices yielded low during DS and WS. Dependence on N fertilizer application was high and more pronounced in 100-d rices during WS (Table 14). Binato and Peta, both traditional varieties, yielded the least with and without N fertilizer in both seasons (Fig. 20).

NITROGEN MANAGEMENT FOR EARLY-MATURING RICE

Agronomy Department

We continued to evaluate the productivity, brown rice protein (BRP), and lodging resistance of early-maturing elite breeding lines as affected by N application method and rate.

In DS, the promising line IR32307-107-3-2-2 yielded the highest at 8.0 t/ha when SCU was applied at 116 kg N/ha (Table 15). It also gave the highest average yield of 7.2 t/ha and productivity of 75 kg rough rice/ha per day.

In WS, IR41993-131-2-3-1 yielded the highest

Table 14. Grain yield of modern and traditional rices of different growth durations, with and without ^{15}N-depleted $(NH_4)_2SO_4$. IRRI, 1986.

Maturity group (d)	Grain yield (t/ha)					
	Dry season			Wet season		
	No fertilizer N	60 kg N/ha	Difference	No fertilizer N	30 kg N/ha	Difference
100	3.4	4.1	0.7**	2.2	2.9	0.7**
105-118	4.1	5.1	1.0**	2.9	3.3	0.4**
Binato (traditional check)	2.3	2.3	0	1.5	2.0	0.5**
≥120	4.1	4.8	0.7**	2.7	3.2	0.5**
Peta (traditional check)	1.4	2.2	0.8**	1.0	1.1	0.1^{ns}

Table 15. Field duration and productivity of 5 varieties and 9 early-maturing IR rices as affected by N application rate and method. IRRI, 1986 DS.

Entry	Field duration[a] (d)	Grain yield[b] (t/ha)					Av yield	
		No N	116 kg N/ha			150 kg N/ha as urea split	t/ha	kg/ha per day
			Urea split	SCU	USG			
IR8[c]	112	3.9 ef	4.7 f	4.4 g	4.2 g	4.2 f	4.2	38
IR36	93	4.3 cdef	5.3 e	5.4 f	5.7 f	5.4 e	5.2	56
IR42	118	5.4 a	6.9 bc	6.9 bcd	6.9 bcd	7.1 b	6.6	56
IR58	86	4.2 def	6.3 cd	6.1 e	6.3 def	6.5 bcd	5.9	68
IR64	100	5.3 ab	7.1 ab	7.2 b	7.2 b	6.6 bcd	6.7	67
IR31802-48-2-2-2	98	4.7 bcd	6.9 bc	7.1 b	7.1 bc	6.8 bc	6.5	66
IR31868-64-2-3-3-3	96	4.3 cdef	6.0 d	6.3 de	6.4 de	6.1 d	5.8	61
IR32307-107-3-2-2	96	4.9 abc	7.6 a	8.0 a	7.9 a	7.8 a	7.2	75
IR32429-47-3-2-2	90	4.2 def	6.5 bcd	7.2 b	6.5 cde	6.4 cd	6.2	68
IR32429-122-3-1-2	95	4.5 cde	6.5 bcd	6.9 bcd	6.8 bcd	6.7 bcd	6.2	64
IR32843-92-2-2-3	98	5.3 ab	6.3 cd	6.4 cde	6.0 ef	6.5 bcd	6.1	62
IR35293-125-3-2-3	100	4.7 bcd	6.8 bc	7.0 bc	6.7 bcd	7.1 b	6.5	65
IR39385-124-3-3-2-3	86	3.9 ef	6.4 cd	6.2 e	6.3 def	6.9 bc	5.9	69
IR39422-19-3-3-3-3	86	3.8 f	6.0 d	6.4 cde	6.5 cde	6.1 d	5.8	67

[a]Does not include 20 d in the seedbed. [b] Av of 4 replications. CV = 9%. [c]Affected by tungro (RTV).

(4.8 t/ha) when PU was split-applied at 58 kg N/ha (Table 16). This line and IR58 gave the highest productivity of 50 kg rough rice/ha per day. The N response of various IR rices tested was high in DS. There was no response in WS because of severe lodging, which occurred at ripening in fertilized plots.

IR39385-124-3-3-2-3 had the highest grain protein content in DS (Table 17). Results further confirmed the previous report that using slow-release SCU and N deep point placement increased the percentage of grain protein content. Increasing N levels also increased the percentage of BRP content.

Table 16. Field duration and productivity of 4 varieties and 9 early-maturing IR rices as affected by N application rate and method, IRRI, 1986 WS.

Entry	Field duration[a] (d)	Grain yield[b] (t/ha)					Av yield	
		No N	58 kg N/ha			90 kg N/ha as urea split	t/ha	kg/ha per day
			Urea split	SCU	USG			
IR36	96	4.2 ab	3.9 bc	3.8 cde	3.7 cd	3.6 cd	3.8	40
IR42[c]	118	3.5 cd	3.9 bc	3.7 de	4.1 abcd	3.5 d	3.7	32
IR58	85	3.7 bcd	4.4 abc	4.5 ab	4.3 abc	4.2 abc	4.2	50
IR64	104	4.3 ab	4.2 abc	3.9 bcde	4.3 abc	4.3 ab	4.2	40
IR31868-64-2-3-3-3	96	4.0 abc	3.9 bc	3.5 e	3.9 bcd	3.6 cd	3.8	39
IR32307-107-3-2-2	104	4.6 a	4.4 abc	4.1 abcde	3.8 cd	3.6 cd	4.1	39
IR35293-125-3-2-3	104	3.7 bcd	3.8 c	3.7 de	3.6 d	3.7 bcd	3.7	36
IR41985-98-3-1-3-2	92	3.6 bcd	4.0 bc	4.0 bcde	4.3 abc	3.7 bcd	4.0	43
IR41993-131-2-3-1	89	3.3 d	4.8 a	4.7 a	4.6 a	4.7 a	4.4	50
IR41996-12-2-2-3	96	3.7 bcd	4.4 abc	4.3 abcd	4.1 abcd	4.1 abcd	4.1	43
IR41996-50-2-1-3	90	3.8 bcd	4.5 ab	4.5 ab	4.1 abcd	4.4 a	4.2	47
IR42068-22-3-3-1-3	92	4.0 abc	4.5 ab	4.3 abcd	4.5 ab	4.3 ab	4.3	47
IR44595-70-2-2-3	96	4.1 abc	4.0 bc	4.4 abc	3.8 cd	3.6 cd	4.0	42

[a]Does not include 16 d in the seedbed. [b]Av of 4 replications. CV = 9%. IR8 was severely affected by RTV and was harvested at booting. [c]Affected by RTV.

Table 17. Brown rice protein content of 5 varieties and 9 early-maturing IR rices as affected by N application rate and method, IRRI, 1986 DS.

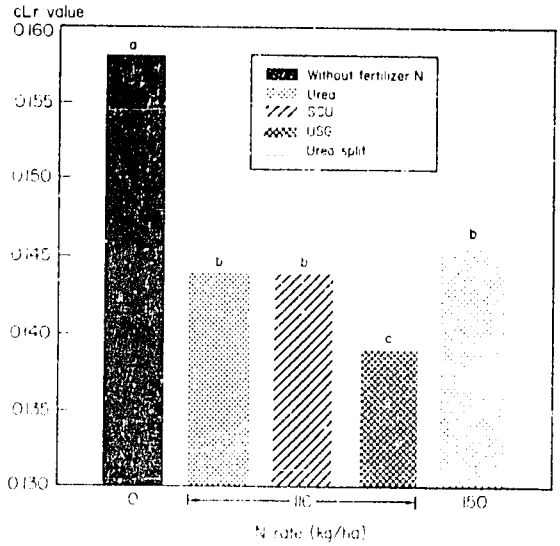
Entry	Brown rice protein[a] (%)					
	No N	116 kg N/ha			150 kg N/ha as urea split	Mean
		Urea split	SCU	USG		
IR8[b]	6.8 cd	7.5 d	7.5 f	7.6 f	7.6 c	7.4
IR36	6.3 d	10.1 a	10.8 a	10.7 a	9.9 ab	9.6
IR42	7.9 ab	8.6 c	9.2 de	8.9 e	9.9 ab	8.9
IR58	7.9 ab	9.3 abc	9.9 bcd	10.1 abc	9.7 ab	9.4
IR64	7.8 ab	8.4 c	9.4 bcde	9.9 abcd	9.3 ab	9.0
IR31802-48-2-2-2	7.8 ab	9.2 bc	9.5 bcde	9.0 de	9.1 b	8.9
IR31868-64-2-3-3-3	7.3 bc	8.6 c	9.6 bcde	9.6 bcde	9.5 ab	8.9
IR32307-107-3-2-2	7.5 abc	8.9 bc	9.7 bcde	9.5 cde	9.4 ab	9.0
IR32429-47-3-2-2	7.4 abc	8.5 c	9.3 cde	9.7 bcde	9.6 ab	8.9
IR32429-122-3-1-2	7.7 abc	8.4 c	9.4 bcde	9.1 de	9.5 ab	8.8
IR32843-92-2-2-3	7.1 bcd	9.0 bc	9.3 cde	10.3 abc	9.4 ab	9.0
IR35293-125-3-2-3	7.4 ab	8.4 c	8.9 e	9.6 bcde	9.0 b	8.7
IR39385-124-3-3-2-3	8.3 a	10.1 a	10.3 ab	10.5 ab	10.1 a	9.9
IR39422-19-3-3-3-3	7.7 abc	9.6 ab	10.2 abc	10.2 abc	9.8 ab	9.5
Mean	7.5	8.9	9.5	9.6	9.4	

[a]CV = 7%. [b]Affected by RTV.

Table 18. Lodging resistance factor (cLr) values of 5 varieties and 9 early-maturing IR rices. IRRI, 1986 DS.

Entry	cLr value[a]
IR8[b]	0.278 a
IR36	0.149 bc
IR42	0.157 b
IR58	0.150 bc
IR64	0.133 de
IR31802-48-2-2-2	0.123 ef
IR31868-64-2-3-3-3	0.152 bc
IR32307-107-3-2-2	0.132 de
IR32429-47-3-2-2	0.150 bc
IR32429-122-3-1-2	0.131 de
IR32843-92-2-2-3	0.109 g
IR35293-125-3-2-3	0.121 efg
IR39385-124-3-3-2-3	0.117 fg
IR39422-19-3-3-3-3	0.142 cd

[a]Av of 5 N treatments and 4 replications. CV = 13%.
[b]Affected by RTV.



21. Lodging resistance factor (cLr) value of rice as affected by N application rate and method (av of 14 rices). IRRI, 1986 DS. Bars with a common letter are not significantly different at the 5% level. CV = 8%.

As in previous years, IR8 was the most resistant to lodging among the rices tested (Table 18). N application reduced lodging resistance (Fig. 21), particularly when USG was deep-placed in the soil.

ALTERNATIVE TECHNOLOGY FOR INCREASING NITROGEN EFFICIENCY IN LOWLAND RICE

Agronomy Department

There was no response to fertilizer N application when traditional variety Binato was used (Table 19, 20). Without fertilizer N, the modern rice IR29723-143-3-2-1 yielded more (1.1 t/ha in DS and 0.7 t/ha in WS) than the traditional variety Binato.

In DS, the N response of IR29723-143-3-2-1 was at least 0.7 t/ha (Table 19). At 58 kg N/ha, the

Table 19. Effect of urea source, application rate, and application method on the grain yield of traditional variety Binato and modern cultivar IR29723-143-3-2-1. IRRI, 1986 DS.

Urea source[a]	N applied (kg/ha)		Application method[b]	Grain yield[c] (t/ha)	
	Binato	IR29723-143-3-2-1		Binato	IR29723-143-3-2-1
–	0	0	No fertilizer N	3.7 a	4.8 h
PU	29	58	Farmers' split	4.1 a	5.5 g
PU	29	58	Researchers' split	3.8 a	6.4 cde
SCU	29	58	BB&I	3.9 a	6.1 d-g
USG	29	58	Point placement by hand	3.9 a	6.9 abc
USG	30	58	Point placement by press wedge	4.0 a	5.6 fg
PU	29	58	Band placement by plunger/auger	4.4 a	6.7 bcd
PU	58	87	Farmers' split	4.4 a	6.3 c-f
PU	58	87	Researchers' split	3.9 a	6.9 abc
SCU	58	87	BB&I	3.9 a	6.9 abc
USG	58	87	Point placement by hand	4.2 a	7.3 ab
USG	53	86	Point placement by press wedge	3.8 a	5.9 efg
PU	58	87	Band placement by plunger/auger	4.2 a	6.1 d-g
PU	80	120	Researchers' split	4.3 a	7.5 a
			V mean	4.0	6.3

[a]PU = prilled urea, SCU = sulfur-coated urea, USG = urea supergranules. [b]Farmers' split = equal-split doses at 10 days after transplanting and 10 DAPI. Researchers' split = 2/3 basal, broadcast and incorporated (BB&I) into mud plus 1/3 top-dressed at 5-7 DBPI. [c]CV = 8%.

Table 20. Effect of urea source, application rate, and application method on the grain yield of traditional variety Binato and modern cultivar IR29723-143-3-2-1. IRRI, 1986 WS.

Urea source	N applied (kg/ha) Binato	N applied (kg/ha) IR29723-143-3-2-1	Application method[a]	Grain yield[b] (t/ha) Binato	Grain yield[b] (t/ha) IR29723-143-3-2-1
–	0	0	No fertilizer N	2.6 abc	3.3 c
PU	29	29	Farmers' split	2.2 abc	3.8 abc
PU	29	29	Researchers' split	2.5 abc	3.8 abc
SCU	29	29	BB&I	2.5 abc	4.0 abc
USG	29	29	Point placement by hand	2.5 abc	4.3 ab
USG	33	34	Point placement by press wedge	2.1 abc	4.1 abc
PU	29	29	Band placement by plunger/auger	2.3 abc	3.7 bc
PU	58	58	Farmers' split	3.0 a	3.8 abc
PU	58	58	Researchers' split	2.8 ab	4.2 abc
SCU	58	58	BB&I	2.7 abc	4.1 abc
USG	58	58	Point placement by hand	1.8 c	4.3 ab
USG	48	57	Point placement by press wedge	2.0 bc	4.7 a
PU	58	58	Band placement by plunger/auger	2.0 bc	4.3 ab
PU	80	120	Researchers' split	2.0 bc	4.7 a
			V mean	2.4	4.1

[a]Farmers' split = equal-split doses at 10 days after transplanting and 10 DAPI. Researchers' split = 2/3 BB&I into mud plus 1/3 topdressed at 5-7 DBPI. [b]CV = 15%.

improved method and timing of N application (researchers' split) significantly increased grain yield by almost 1 t/ha over the farmers' practice. Deep placement of PU by the IRRI-designed plunger/auger machine gave yields comparable to deep placement of USG by hand. Both treatments gave yields comparable to that from the researchers' split application of PU. At 87 kg N/ha, the researchers' split did not significantly outyield the farmers' application method and timing. Furthermore, deep placement of PU by plunger/auger machine gave significantly lower yield than hand point placement of USG. At both intended N rates, point placement of USG by the press wedge machine was consistently inferior to point placement of USG by hand.

In WS, grain yields with different N treatments were comparable (Table 20). However, IR29723-143-3-2-1 produced more than double the yield of Binato with researchers' split at high N.

Table 21. Effect of N fertilizer management practice on grain yield of broadcast seeded flooded rice. IRRI, 1986 DS.

Fertilizer management	Grain yield[a] (t/ha) IR58	IR64	IR29723-143-3-2-1	Mean
No N	3.5 c	3.3 c	4.3 d	3.7 e
80 kg N/ha				
2/3 basal + 1/3 at 5-7 DBPI, all PU	6.1 ab	6.3 b	5.1 c	5.8 d
1/2 at 15 DAS + 1/2 at 10 DAPI, all PU	6.0 ab	6.8 ab	6.5 b	6.4 c
1/2 USG basal + 1/2 PU at 5-7 DBPI	6.1 ab	6.6 ab	6.8 ab	6.5 bc
SCU basal	6.2 ab	6.9 ab	6.7 ab	6.6 bc
2/3 SCU basal + 1/3 PU at 5-7 DBPI	6.1 ab	7.2 a	6.7 ab	6.7 abc
1/2 SCU basal + 1/2 PU at 5-7 DBPI	6.5 a	7.2 a	7.4 a	7.0 a
120 kg N/ha				
2/3 basal + 1/3 at 5-7 DBPI, all PU	6.3 ab	6.6 ab	7.0 ab	6.6 bc
1/2 at 15 DAS + 1/2 at 10 DAPI, all PU	6.5 a	7.0 ab	6.8 ab	6.8 ab
SCU basal	5.7 b	6.5 b	5.6 c	5.9 d
1/2 USG basal + 1/2 PU at 5-7 DBPI	6.6 a	6.8 ab	7.0 ab	6.8 ab

[a]CV = 5%

NITROGEN FERTILIZER EFFICIENCY IN BROADCAST SEEDED FLOODED RICE

Agronomy Department

Earlier studies conducted at IRRI showed that SCU (54 kg N/ha) and PU (120 kg N/ha) B&I gave similar yields in flooded BR rice. In TPR, researchers' timing of N application yielded higher than did farmers' timing.

In DS, IR58, IR64, and IR29723-143-3-2-1 were tested at different N rates and fertilizer management practices. IR58 and IR64 yielded lower than the medium-maturing IR29723-143-3-2-1 when no N fertilizer was applied (Table 21). Yield response was highest at 80 kg N/ha with 1/2 SCU B&I + 1/2 PU topdressed at 5-7 DBPI. The yield of BR IR64 and IR29723-143-3-2-1 with researchers' timing of PU was inferior to yield with farmers' timing (Table 21). In IR58, no yield difference was observed between the two N application timings.

Increasing N fertilizer rate to 120 kg N/ha significantly reduced the yield of SCU-treated plots.

In WS, N application rate was reduced to 60 and 90 kg/ha on IR64 and IR29723-143-3-2-1. PU, the primary source of N, was applied at researchers' and farmers' timing. Both methods were tested at two and three split applications.

Applying N fertilizer did not significantly improve grain yield. At 60 kg N/ha, 1/2 PU applied at 12 DAS and 1/2 at 10 DAPI was more efficient than the recommended best split in converting applied N into grain (Table 22). With basal N, three splits gave no yield advantage over two splits. Using farmers' timing, three split N applications gave lower yields than two equal splits.

The grain yields obtained with deep-placed USG and slow-release SCU were similar to that with PU. Increasing N rate to 90 kg N/ha did not correspondingly increase yield.

Table 22. Effect of N fertilizer management practice on grain yield of broadcast seeded flooded rice, IRRI, 1986 WS.

Fertilizer management	Grain yield[a] (t/ha)		
	IR64	IR29723-143-3-2-1[b]	Mean
No N	3.8 ab	3.3 a	3.5 abc
60 kg N/ha			
2/3 B&I + 1/3 at 5-7 DBPI, all PU	3.8 ab	2.7 ab	3.3 abc
1/2 at 12 DAS + 1/2 at 10 DAPI, all PU	4.2 a	3.4 a	3.8 a
1/3 B&I + 1/3 at 20 DAS + 1/3 at PI, all PU	3.2 ab	3.1 ab	3.2 abc
1/3 at 12 DAS + 1/3 at 30 DAS + 1/3 at PI, all PU	3.9 ab	3.1 ab	3.5 abc
SCU B&I	4.0 ab	3.0 ab	3.5 abc
1/2 USG + 1/2 PU at 5-7 DBPI	4.3 a	2.3 ab	3.3 abc
90 kg N/ha			
2/3 B&I + 1/3 at 5-7 DBPI, all PU	3.6 ab	2.1 b	2.9 bc
1/2 at 12 DAS + 1/2 at 10 DAPI, all PU	3.8 ab	3.2 ab	3.5 abc
1/3 B&I at 1/3 at 20 DAS + 1/3 at PI, all PU	3.9 ab	3.4 a	3.6 ab
1/3 at 12 DAS + 1/3 at 30 DAS + 1/3 at PI, all PU	4.0 ab	3.1 ab	3.6 ab
SCU B&I	3.0 b	2.6 ab	2.8 c
1/2 USG + 1/2 PU at 5-7 DBPI	4.1 ab	3.2 ab	3.6 ab

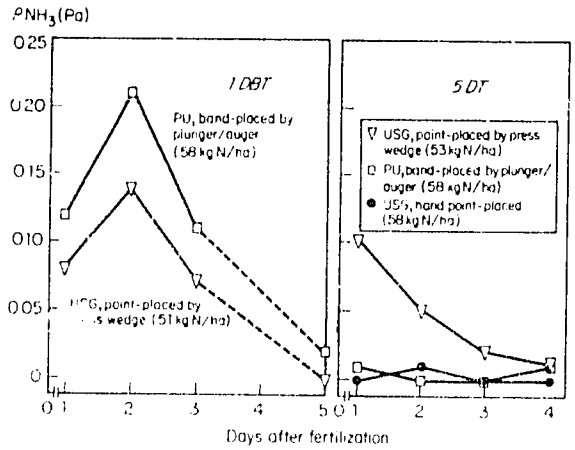
[a]CV: main plot (variety) = 23%, subplot (fertilizer management) = 18%. [b]All treatments lodged.

EVALUATION OF PLACEMENT MACHINES TO INCREASE NITROGEN FERTILIZER EFFICIENCY IN IRRIGATED RICE

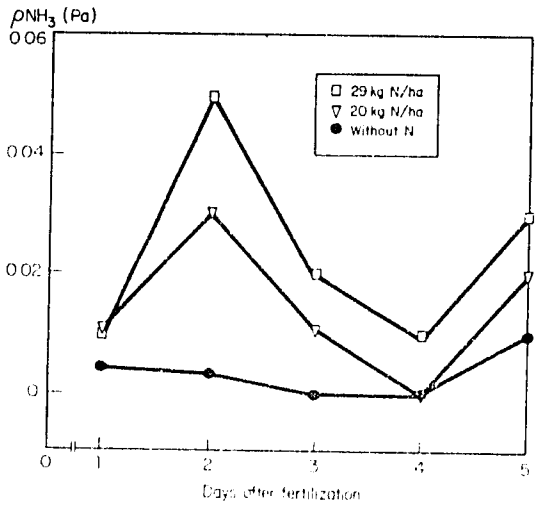
Agronomy Department

Tests on the performance of IRRI-designed fertilizer placement machines compared with that of farmers' practice and timing of urea application and the researchers' improved method and timing continued in 1986 WS.

USG point-placed by press wedge machine either before or after transplanting produced high pNH_3 in the floodwater, indicating higher potential for NH_3 volatilization loss (Fig. 22). Negligible pNH_3 was measured with hand point-



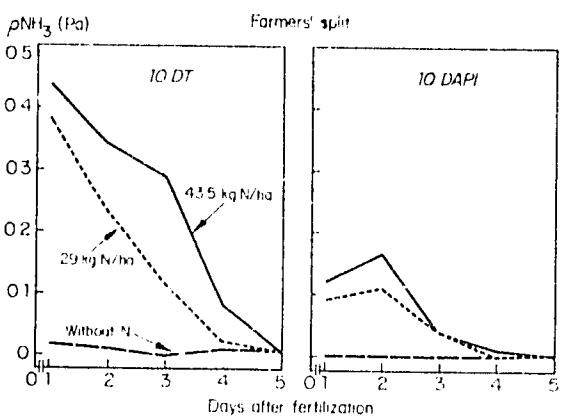
22. Partial pressure of floodwater NH_3 at 1300-1400 h after fertilizer placement in 5 cm standing water by hand or machine at 1 d before transplanting (DBT) and 5 d after transplanting (DT), IRRI, 1986 WS. USG = urea supergranules, PU = prilled urea.



24. Partial pressure of floodwater NH_3 at 1300-1400 h after topdressing urea in 5 cm standing water at 10 DBPI. IRRI, 1986 WS.

placed USG and PU band-placed by plunger/auger machine with 5 cm water at 5 DT. When PU was band-placed by plunger/auger machine at 1 d before transplanting (DBT), higher floodwater pNH_3 was observed than when it was applied at 5 DT. That could be due to the higher floodwater NH_4^+-N concentration.

Topdressing urea with 5 cm standing water at 10 DT gave higher floodwater pNH_3 than when urea was applied at 10 DAPI (Fig. 23). Low floodwater pNH_3 resulted when N was applied by researchers' practice at 10 DBPI (Fig. 24); hence, NH_3 volatilization loss was minimum.



23. Partial pressure of floodwater NH_3 at 1300-1400 h after topdressing urea in 5 cm standing water at 10 d after transplanting (DT) and 10 DAPI. IRRI, 1986 WS.

N application significantly increased grain yields (Table 23). Point placement of USG by hand gave significantly higher yields than did farmers' split. However, the improved researchers' split application of urea did not significantly increase yields over the farmers' split but gave yields comparable to either hand or machine deep point placement with USG. Band placement of PU by plunger/auger machine with about 5 cm water at 5 DT and point placement of USG by press wedge machine without standing water at 1 DBT gave yields similar to that with hand point placement of USG at 5 DT.

The effectiveness of fertilizer application in the reduced soil layer may thus depend on machine performance and soil and water conditions during N application.

EFFECT OF WATER DEPTH AND TIME OF NITROGEN PLACEMENT IN LOWLAND RICE

Agronomy Department

The effects of water depth during fertilizer incorporation and the timing of N placement on grain yield of lowland rice were evaluated in 1986 DS and WS. Medium-maturing IR64 and late-maturing IR29723-143-3-2-1 were the test rices.

No correlation was found between rice variety and fertilizer treatment in both seasons; hence, data were averages of the varieties used.

Table 23. Effect of urea source, application method, and water depth on grain yield of IR64. IRRI, 1986 WS.

Urea source	Application method	N applied (kg/ha)	Water depth (cm) during fertilizer application	Grain yield[a] (t/ha)
–	No fertilizer N	0	–	3.0 c
PU	Farmers' split	58	5.1	3.9 b
PU	Researchers' split	58	0	4.3 ab
USG	Point placement by hand[b]	58	4.9	4.5 a
PU	Band placement by plunger/auger (modified)[b]	58	4.9	4.5 a
USG	Point placement by press wedge (modified)[b]	53	5.0	3.9 b
PU	Band placement by plunger/auger (4-row)[c]	58	0	3.9 b
USG	Point placement by press wedge (4-row)[c]	55	0	4.5 a
PU	Band placement by plunger/auger (4-row)[c]	58	5.1	4.1 ab
USG	Point placement by press wedge (4-row)[c]	51	5.0	4.4 ab
PU	Farmers' split	87	4.8	4.0 ab
PU	Researchers' split	87	0	4.1 ab

[a]CV = 8%. [b]Applied at 5 d after transplanting. [c]Applied at 1 d before transplanting.

The farmers' practice of topdressing urea into the floodwater at 10 DT and 10 DAPI gave significantly lower yields than did B&I of N before transplanting + topdressing at 5-7 DBPI (Table 24). Broadcast and thorough incorporation with a mechanical rotary weeder at 1 DBT of the first N dose with or without standing water at various depths gave comparable yields, suggesting that thorough incorporation of a basal dose is essential, irrespective of water depth at the time of fertilizer N application. Other results, however, suggest that it is desirable to apply the basal N dose onto mud and incorporate it thoroughly without standing water.

Deep placement of USG at 5, 10, 20, or 30 DT was not superior to the recommended urea B&I before transplanting + topdressing at 5-7 DBPI (Table 24). When medium- and late-maturing varieties were used, point placement of N up to 30 DT did not affect yield. However, N deep placement by a machine is not practical beyond 20 DT, because then the well-developed rice roots and canopy hinder the machine's operation.

Table 24. Effects of water depth and time of N application on the grain yield of IR64 and IR29723-143-3-2-1. IRRI. 1986 DS and WS.

Urea source	Application method[a]	Grain yield[b] (t/ha) DS	Grain yield[b] (t/ha) WS
–	No fertilizer N	4.1 c	3.2 d
PU	1/2 at 10 DT + 1/2 at 10 DAPI	5.6 b	4.1 c
PU	2/3 B&I at 1 DBT without water + 1/3 at 5-7 DBPI	6.0 a	4.5 ab
PU	2/3 B&I at 1 DBT with 2 cm water + 1/3 at 5-7 DBPI	5.8 ab	4.5 ab
PU	2/3 B&I at 1 DBT with 4 cm water + 1/3 at 5-7 DBPI	5.8 ab	4.5 ab
PU	2/3 B&I at 1 DBT with 6 cm water + 1/3 at 5-7 DBPI	5.9 ab	4.4 bc
USG	Hand point-placement at 5 DT with 5 cm water	6.0 a	4.8 a
USG	Hand point-placement at 10 DT with 5 cm water	6.0 a	4.7 ab
USG	Hand point-placement at 20 DT with 5 cm water	6.1 a	4.6 ab
USG	Hand point-placement at 30 DT with 5 cm water	6.0 a	4.7 ab

[a]N was applied at 87 kg N/ha in DS and 58 kg N/ha in WS. DBT = days before transplanting, DT = days after transplanting. Topdressing at 10 DT and before or after panicle initiation was done with 5 cm standing water. [b]Av of 4 replications and 2 rices. CV = 6% in DS and 7% in WS.

NITROGEN FERTILIZER MANAGEMENT UNDER SIMULATED RAINFED LOWLAND CONDITIONS

Agronomy Department

Vegetative phase moisture stress. Rice yield response to different N fertilizer management techniques was evaluated at IRRI using the line source sprinkler (LSS) system at five irrigation

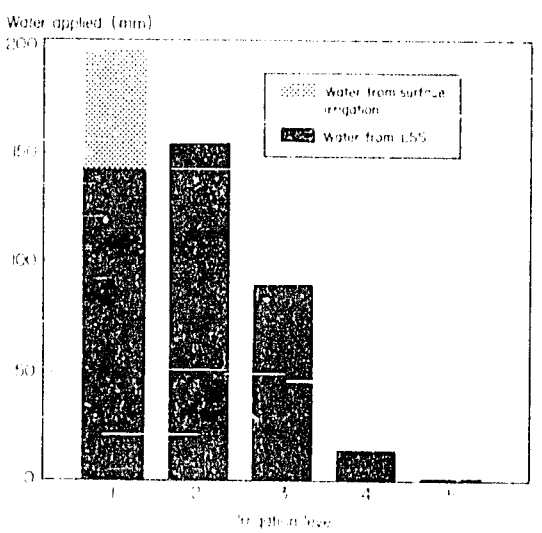
levels and four N treatments. IR64 was the test variety. P at 13 kg/ha and K at 25 kg/ha were basally applied.

The field was surface irrigated to about 2 cm water depth starting at 3 DT. Irrigation level L1 represented continuously flooded rice; it has the same amount of water from LSS as L2, but needed surface irrigation to maintain 5 cm continuous flooding. At 8 DT, the standing water at L2 to L5 was allowed to dry by evapotranspiration and percolation. Irrigation by LSS, positioned between L1 and L2, started at 25 DT and was used twice a week up to 42 DT (3 DBPI).

Pan evaporation was used to determine the water to be applied by LSS. The whole field was reflooded to about 5 cm from PI to 10 d before harvest.

Continuously flooded plots (L1) received the highest amount of water (Fig. 25). L2, L3, and L4 received 153, 90, and 15 mm of water from LSS, respectively. L5, the most stressed treatment, did not receive water from LSS. At the end of the stress period, the degree of soil cracking increased with increasing water stress.

Under any water regime, deep-placed USG gave the highest yield (Table 25), which was comparable to those with the researchers' split of PU (2/3 B&I into mud and 1/3 at PI). The lowest average yield



25. Total water applied from line source sprinkler (LSS) and surface irrigation during vegetative phase stress period. IRRI, 1986 DS.

was obtained with farmers' split of PU (1/2 topdressed at 10 DT and 1/2 at 10 DAPI). L5 produced higher yields than did L1, perhaps because of high mineralization of applied and native N after reflooding. Lower yields at L3 may be attributed to high N losses as a result of alternate wetting and drying cycles.

Results suggest that in relatively fertile soil, high yields can be obtained under mild moisture stress at the vegetative stage as long as there are minimal or no alternate wetting and drying cycles. This is most relevant where water supply is limited. Since continuous flooding is improbable in most rainfed rice areas because of nonuniform rainfall distribution, reduced N fertilizer efficiency results in low yields.

Reproductive phase moisture stress. In a separate experiment, LSS was used to impose an irrigation gradient during the reproductive stage. The yield response of IR64 at five irrigation levels and eight N fertilizer treatments was assessed.

The sprinkler irrigation setup, irrigation scheduling, and computation of the amount of irrigation water were similar to those in the vegetative phase moisture stress experiment. However, all plots were continuously flooded up to PI, after which LSS was used to provide a decreasing amount of water from L2 to L4. L1 represented continuous flooding. All plots were reflooded from heading to 10 d before harvest.

Figure 26 shows the amount of water received by the five irrigation treatments. Alternate wetting and drying cycles occurred at L2-L4. Plant water stress and soil cracking were more evident at L5.

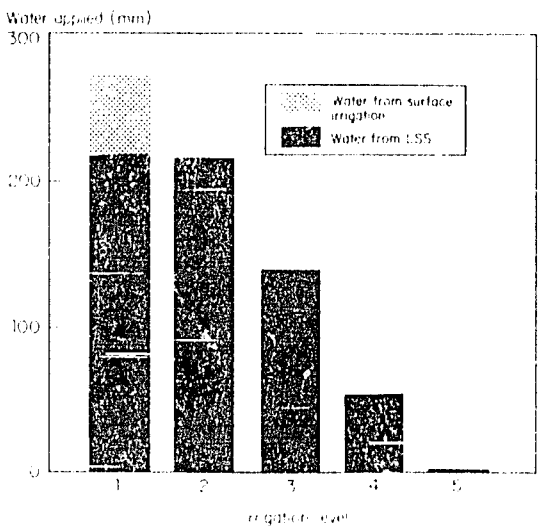
At L1, the highest yield was obtained with slow-release SCU (Table 26). Deep-placed USG and the researchers' split gave comparably high yields. These N treatments also gave high yields at L2-L4. At L5, however, the yield trend was reversed. N treatments that gave the highest yields at L1 produced the lowest yield at L5, probably because the plants that grew profusely before the onset of stress suffered more severely from the effect of moisture stress (such as leaf desiccation) at L5.

A gradually decreasing yield trend was generally observed from L1 to L4 (Table 26). At L5, yields decreased abruptly compared with those at L1; most N treatments reduced more than 50% of yields. In contrast to that in the vegetative phase

Table 25. Grain yield of IR64 with vegetative phase moisture stress, as affected by irrigation level (L1-L5) and N treatment. IRRI, 1986 DS.

N fertilizer treatment[a]	Grain yield[b] (t/ha)					
	L1	L2	L3	L4	L5	Mean
PU, 1/2 at 10 DT + 1/2 at 10 DAPI	4.2 b	4.2 c	3.8 c	4.6 a	4.8 b	4.3
PU, 2/3 B&I onto mud + 1/3 at PI	5.0 a	5.0 ab	4.7 ab	4.7 a	5.5 a	5.0
PU, 2/3 B&I into 5 cm water + 1/3 at PI	4.8 a	4.7 bc	4.3 bc	4.6 a	5.6 a	4.8
USG, hand placed at 1 DT	5.3 a	5.3 a	5.1 a	4.9 a	5.7 a	5.3
Mean	4.8	4.8	4.5	4.7	5.4	

[a]Fertilizer was 58 kg N/ha. DT = days after transplanting, PI = panicle initiation. [b]L1 = continuous flooding, L2 to L4 = water from LSS at a decreasing amount during stress period, L5 = no water from LSS.



2b. Total water applied from LSS and surface irrigation during reproductive phase stress period. IRRI, 1986 DS.

moisture stress experiment, N mineralization during reflooding in this experiment might have been too late to compensate for the severe effects of moisture stress in the reproductive phase.

The results confirmed the sensitivity of the reproductive phase to moisture stress. In areas where water supply is limited, modest amounts of N fertilizer are desirable. A high rate of N application will either increase N losses or aggravate damage caused by water deficit.

NITROGEN MANAGEMENT FOR SIMULATED RAINFED LOWLAND RICE

Agronomy Department

Whereas past research has identified poor crop utilization of N fertilizers and high N losses as major problems for irrigated rice, less is known

Table 26. Grain yield of IR64 with reproductive phase moisture stress, as affected by irrigation level (L1-L5) and N treatment. IRRI, 1986 DS.

N fertilizer treatment[a]	Grain yield[b] (t/ha)					
	L1	L2	L3	L4	L5	Mean
No N fertilizer	4.3 d	3.6 d	3.7 d	3.4 c	2.7 ab	3.5
PU, 1/2 at 10 DT + 1/2 at 10 DAPI	4.5 cd	4.3 cd	4.1 cd	3.9 bc	3.1 a	4.0
PU, 2/3 B&I onto mud + 1/3 at 5-7 DBPI	5.8 a	5.7 a	5.2 ab	5.0 a	2.2 b	4.8
PU, 2/3 B&I into 5 cm water + 1/3 at 5-7 DBPI	5.0 bc	5.2 ab	4.6 bc	5.0 a	2.3 b	4.4
USG, hand placed at 1 DT	6.0 a	5.6 a	5.2 ab	4.5 ab	2.2 b	4.7
USG/PU, 1/2 as USG at 1 DT + 1/2 as PU at 5-7 DBPI	5.6 ab	5.7 a	4.9 ab	4.7 a	2.3 b	4.6
SCU, B&I onto mud	6.1 a	5.5 a	5.4 a	4.9 a	2.2 b	4.8
PU + DCD[c], 1/2 at 10 DT + 1/2 at 10 DAPI	5.0 bc	4.8 bc	4.7 abc	4.4 ab	2.8 ab	4.3
Mean	5.3	5.0	4.7	4.5	2.5	

[a]Fertilizer was 87 kg N/ha. DT = days after transplanting. [b]L1 = continuous flooding, L2 to L4 = water from LSS at a decreasing amount during stress period, L5 = no water from LSS. [c]DCD = dicyandiamide.

about N use and losses in rainfed lowland rice. Therefore, an increasingly major research thrust has been devoted to 1) enhancing our understanding of N transformation under rainfed conditions and 2) identifying effective N management practices for rainfed environments.

In 1986, research in cooperation with IFDC focused on the interaction between N timing and water deficit. Water deficit stress was simulated in DS at Pila, Laguna, by withholding irrigation during either the vegetative or reproductive phase.

Even with water deficit during either the vegetative phase (nonflooded from 15 to 35 DT) or reproductive phase (nonflooded from 41 to 63 DT), grain yields were significantly increased by urea applied at 80 kg N/ha (Table 27). In all cases, the yields were significantly greater for an early (1/2 basal + 1/2 at 37 DT) than for a delayed (1/2 broadcast at 11 DT + 1/2 at 65 DT) application of urea. Early N application apparently improved plant vigor, thus enabling the rice crop to better withstand water deficit during the vegetative and reproductive phases.

Grain yield was lower in the stressed than in the unstressed, continuously flooded treatment (Table 27). This reduction in yield from water deficit tended to be greater for vegetative than for reproductive phase stress.

Table 27. Effect of water regime and N fertilizer timing on grain yield of IR64. Pila, Laguna, Philippines, 1986 DS.

Water regime	N treatment	Grain yield (t/ha)
Continuously flooded	N0, no applied N	3.0
	N1, urea, 1/2 basal + 1/2 at 37 DT	6.7
	N2, urea, 1/2 at 11 DT at 65 DT	4.7
Vegetative phase stress[a]	N0, no applied N	2.2
	N1, urea, 1/2 basal + 1/2 at 37 DT	4.7
	N2, urea, 1/2 at 11 DT + 1/2 at 65 DT	2.9
Reproductive phase stress[b]	N0, no applied N	2.4
	N1, urea, 1/2 basal + 1/2 at 37 DT	5.6
	N2, urea, 1/2 at 11 DT + 1/2 at 65 DT	3.5

Source of variation	*df*	*Mean square*
Water regime (W)	2	10.78**
N treatment (N)	2	41.92**
W X N	4	0.46*
LSD 0.05 (N under same W)	N0 vs N2	0.6
	N0, N2 vs N1	0.5
LSD 0.05 (W under same N)	N0, N2	0.8
	N1	0.6
CV (a) = 15.4%		
CV (b) = 9.2%		

[a]Nonflooded from 15 to 35 d after transplanting (DT).
[b]Nonflooded from 41 to 63 DT.

NITROGEN LOSS IN A MUNGBEAN - LOWLAND RICE CROPPING SYSTEM

Soils and Agronomy Departments

Rice-growing soils in tropical Asia are frequently aerobic during DS but become waterlogged through either irrigation or rainfall in the wet season (WS). The aerobic environment could favor the buildup of soil nitrate, which in turn might be lost upon waterlogging. Field research was conducted at an IRRI lowland site in cooperation with IFDC to determine 1) the accumulation of soil nitrate during and following a DS mungbean crop, and 2) the magnitude of nitrate disappearance upon flooding for a DS rice crop. In both 1985 and 1986, mungbean was planted in February and harvested in April. The land was then left fallow with no weed control for about 1.5 mo until June flooding for a rice crop.

Table 28 shows soil nitrate by layer immediately before the June flooding for 1985 and 1986. Soil nitrate averaged 22 kg N/ha in the top 30 cm in 1985 and 52 kg N/ha in the top 60 cm in 1986. No

Table 28. Soil nitrate-N before a June flooding for lowland rice and following DS mungbean receiving no applied N. IRRI, 1985-86.

Soil depth (cm)	Nitrate-N (kg N/ha)	
	1985[a]	1986[b]
0-10	13	21 a
10-30	9	18 a
30-60	–	13 b

[a]LSD not reported because of significant (P = 0.01) square X tillage treatment X soil depth interaction.
[b]Means followed by a common letter are not significantly different at the 5% level by LSD.

measurements were made below 30 cm in 1985. Tillage method prior to mungbean had no effect on subsequent nitrate accumulation.

After flooding of the land for plowing and land preparation prior to WS rice, the nitrate completely disappeared. No nitrate was detected in the soil when the rice was transplanted about 3 wk after the first flooding. Additional research revealed that less than 6% of the nitrate was converted to NH_4^+-N or organic N. The nitrate was presumably lost by denitrification following the flooding.

The levels of soil nitrate-N at mungbean harvest and immediately prior to flooding increased when 30 kg N/ha was applied to mungbean at planting (Table 29). The 12-kg N/ha increase in nitrate accumulation — and presumable loss when N was applied to mungbean — was not statistically significant ($P = 0.05$). Nonetheless, the result suggests that N fertilization of DS crops in rice-based cropping systems probably needs close scrutiny to minimize the buildup of soil nitrate prior to flooding for the rice crop.

Table 29. Effect of N application to DS mungbean on nitrate-N in the top 60-cm soil layer, IRRI, 1985.

N applied to mungbean (kg/ha)	Nitrate-N (kg/ha)	
	Mungbean harvest[a]	Prior to flooding for rice[b]
0	25	52
30	30	64
$S_{\bar{x}}$[c]	2.0	4.8

[a]16 Apr. [b]2 Jun. [c]Standard error of the mean.

The high nitrate accumulation and its subsequent disappearance, presumably by denitrification, suggest that losses of native N may be serious problems in lowland environments with alternate aerobic and anaerobic conditions. Soil and crop management practices that conserve and utilize native N are needed for environments where nitrate accumulates during DS.

Soil and crop management

Nitrogen fixation and azolla management

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BACTERIAL NITROGEN FIXATION

Soil Microbiology Department

Collection of nitrogen-fixing bacteria from rice. The collection contained more than 150 strains of heterotrophic and photosynthetic bacteria at the end of 1986; several were being characterized biochemically and serologically.

Composition of *Azospirillum* species associated with wetland rice in different soils. The total aerobic heterotrophs and N_2-fixing putative azospirilla associated with the submerged portions of rice plants grown in long-term unfertilized wetland ricefields at five sites in the Philippines were enumerated. Several azospirilla isolates were identified based on cellular morphology and reaction to immunodiffusion and biochemical tests. Azospirilla constitute about 1% of the total aerobic heterotrophs; 88% of these isolates belong to *A. lipoferum*, indicating its preference for colonizing the rice plant (Table 1).

Colonization of roots of two rice varieties by *Azospirillum lipoferum*. Seedlings of IR42 and IR50 were aseptically dipped into a suspension of *A. lipoferum* strain 34H in the dark, and the presence of bacteria on the differentiating regions of the roots was observed by scanning electron microscopy. The bacteria did not colonize the root tips of IR42, but did so in IR50 within 24 h after inoculation. In the early stages, most of the bacteria were embedded in the ruptured mucigel below the root cap cells of IR42 (Fig. 1). Mucigel

1. Scanning electron micrographs of rice root inoculated with *Azospirillum lipoferum* 34H: a) IR42 root tip (below the root cap) showing the ruptured mucigel with bacteria inside, 24 h after inoculation (×520); b) portion of epidermal layer of IR42 root showing fibrillar material (single arrow) and bacteria (double arrows) (×968). IRRI, 1986.

Table 1. Populations of aerobic heterotrophs and azospirilla in submerged portions of rice plants (IR36 at heading) grown in the field with different soils.[a] IRRI, 1986.

Soil	Total heterotrophic bacteria[b] (× 10^7 CFU/g)	Azospirilla: Total (× 10^5/g)	Azospirilla: Percentage of total heterotrophs	Azospirilla: Strains tested (no.)	Azospirilla: Identified as *A. lipoferum* (no.)	Azospirilla: Identified as *A. brasilense* (no.)
Bicol	10.45	3.7	0.36	12	8	4
Maahas	6.8	0.7	0.11	7	7	0
Bay	10.1	3.8	0.37	13	10	3
Maligaya	3.0	3.3	1.0	14	14	0
Luisiana	nd	nd	nd	4	3	1

[a] nd = not determined. [b] CFU/g = colony-forming unit per gram (dry weight) of root (including submerged portion of stem and leaf sheath).

was hardly detectable in IR50. Some fibrillar materials were also observed to entangle the bacteria at certain places where the epidermal cell layer was apparently without mucigel (Fig. 1). When the incubation period reached 48 h, a few 34H cells had become attached to the root hairs, occasionally in a polar fashion. At 72 h after inoculation, all the root hairs were heavily colonized by 34H cells.

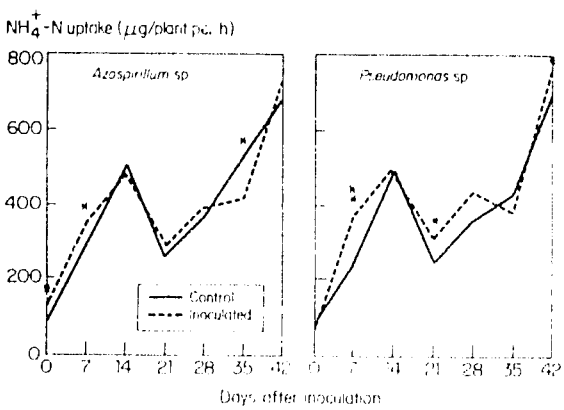
Influence of *A. lipoferum* and *Pseudomonas diazotrophicus* inoculation on mineral uptake and growth of rice in water culture. Seedlings of IR42 were inoculated with N_2-fixing *A. lipoferum* strain 34H or *Pseudomonas diazotrophicus* strain H8 by dipping the roots for 6 h in the inoculum. The plants were grown for 47 d in water culture in the greenhouse in the presence of combined N. Inoculation with *Azospirillum* significantly enhanced NH_4^+-N uptake by rice at 0 and 7 d after inoculation (DAI) (Fig. 2). But at 35 DAI a significant decrease in uptake was observed. *Pseudomonas* inoculation enhanced NH_4^+-N uptake significantly at 7, 14, 21, and 42 DAI. In general, inoculating plants with *Pseudomonas* increased NH_4^+-N uptake more than did *Azospirillum* inoculation.

Azospirillum inoculation significantly increased P uptake by rice at 7, 21, and 28 DAI. With *Pseudomonas* inoculation, P uptake increased at 7, 14, and 28 DAI (Table 2). Shoot dry and fresh weights were increased by *Azospirillum* inoculation. *Pseudomonas* inoculation increased the length, surface area, dry weight of roots, and root weight to shoot weight ratio at 42 DAI. Inoculation with *Azospirillum* reduced root length significantly. Bacterial population counts suggested that both organisms survived on the roots until the end of the experiment. Transmission electron microscopy of inoculated root sections showed bacteria in some of the root cortical cells (Fig. 3). The data suggest that inoculation with diazotrophs promotes plant growth through processes other than N_2 fixation, probably by increasing plant mineral uptake.

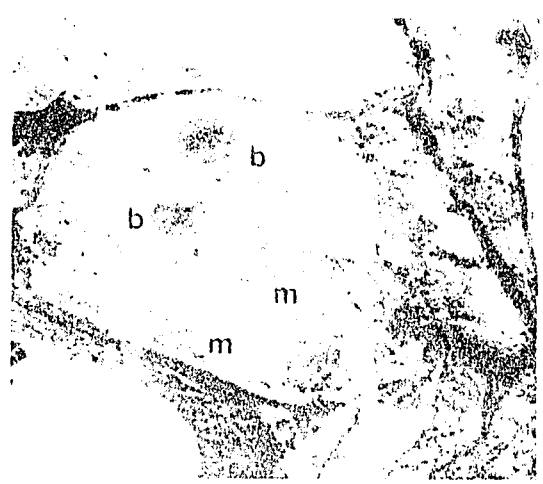
Table 2. Effect of *Azospirillum* and *Pseudomonas* inoculation on P uptake by IR42 in water culture. IRRI, 1986.

Treatment	Amount of P removed from nutrient solution during assay[a] (μg/plant) at						
	0 DAI	7 DAI	14 DAI	21 DAI	28 DAI	35 DAI	42 DAI
			Azospirillum				
Control	2	5	30	25	62	64	52
Inoculated	2	7*	39*	38**	77*	71	56
			Pseudomonas				
Control	2	5	33	26	61	72	60
Inoculated	2	8**	39**	30	68*	78	56

[a]DAI = days after inoculation.



2. Effect of *A. lipoferum* strain 34H and *Pseudomonas* species strain H8 inoculation on NH_4^+-N uptake by rice during growth in hydroponics, IRRI, 1986. * = significant at the 5% level, ** = at the 1% level.



3. Transmission electron micrograph of IR42 root showing the invasion of the root cortical cell by putative *A. lipoferum* 34H (×17000). IRRI, 1986. b = bacterium m = mitochondrion.

Agronomic and cultural practices affecting plant-associated nitrogen fixation. *Effect of inorganic N fertilizer.* We determined the effects of urea application (no N, 60 kg N/ha basal, 40 kg N/ha basal + 20 kg/ha at panicle initiation [PI], and 70 kg N/ha basal + 30 kg N/ha at PI) on plant-associated N_2 fixation (acetylene-reducing activity [ARA]), plant biomass, and grain yield of IR50 and IR54 grown in the field.

At about 25 d after transplanting (DT), ARA per plant of both varieties was low; it subsequently increased. Applying N at PI in IR50 slightly inhibited ARA at heading, but in IR54 had no consistent effect (Fig. 4). ARA per unit of total plant dry weight in both varieties was not significantly different among treatments.

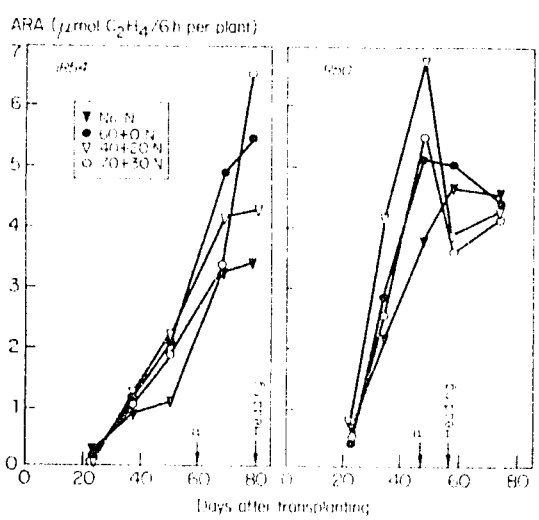
Effect of green manure incorporation. When green manure was incorporated in wetland soil, rice plant-associated N_2 fixation (ARA) was measured at heading for 3 consecutive days. Plants from two fields were sampled.

- *Experiment 1.* Multiple Cropping Department experiment (1985 dry season [DS]) where the second IR54 crop cycle had the following treatments: 1) weed-free fallow, 2) weedy fallow, 3) weedy fallow + 70 kg N/ha, 4) incorporation of *Sesbania cannabina*, 5) *S. cannabina* + 35 kg N/ha, 6) incorporation of *Crotalaria juncea*, and 7) *Lablab purpureus* and *Vigna radiata* (green manure crop was grown for 60 d and incorporated).
- *Experiment 2.* Long-term experiment (1986 DS) where the second IR64 crop was grown with the following treatments: 1) no N, 2) *Sesbania rostrata* grown for 45 d and incorporated, 3) azolla (3 crops) grown for 30 d and incorporated plus one crop after transplanting, and 4) urea (50 kg N/ha).

Incorporation of a green manure crop significantly increased rice plant-associated ARA in both experiments. In the first experiment, mungbean incorporation showed the highest ARA, both per plant and per unit of plant dry weight (Table 3). In the second experiment, ARA per plant was significantly higher in azolla and *Sesbania* plots than in the control, but ARA/g plant dry weight was significantly higher only in azolla-incorporated plants (Table 4).

Effect of plant density. IR54 was planted at different spacings (25 × 25, 20 × 20, 15 × 15, 12.5 × 12.5, and 10 × 10 cm) in a wetland field where *S. rostrata* was incorporated during the 1986 wet season (WS). Rice plant-associated ARA was measured for 3 consecutive days at heading.

The ARA per plant or per gram of total plant dry weight was not significantly different among treatments with different spacings. But the dry weight per plant was significantly different, increasing with decreasing plant density. Thus,



4. Effect of inorganic N fertilizer on acetylene-reducing activity (ARA) associated with field-grown IR54 and IR50, IRRI, 1986. PI = panicle initiation.

Table 3. Effect of incorporation of a green manure crop on plant-associated acetylene-reducing activity (ARA) in IR54, IRRI, 1986.

Treatment	ARA (nmol C_2H_4/6 h)	
	Per plant	Per g of total dry weight
Controls		
Weedy fallow	2100	75
Weed-free	2100	70
Weedy fallow + 70 kg N/ha	2300	67
Incorporation of		
Crotalaria juncea	4700	87
Vigna radiata	4700	97
Sesbania cannabina	4200	82
S. cannabina + 35 kg N/ha	4000	82
Lablab purpureus	3200	83
SE	280	4.9

Table 4. Effect on rice plant-associated ARA of incorporation of *Azolla* and *Sesbania* into and application of urea on wetland soil planted to IR64. IRRI, 1986.

Treatment	ARA (nmol C_2H_4/6 h)	
	Per plant	Per g of total dry weight
Control (fallow)	4500	86
Incorporation of		
S. rostrata	6500**	91
Azolla	6300**	99*
Application of urea (50 kg N/ha)	5300	87
SE	525	5.6

Table 5. Rice plant-associated ARA of IR54 as affected by plant spacing in a lowland soil where a crop of *S. rostrata* had been incorporated. IRRI, 1986.

Plant spacing (cm)	ARA		
	Per plant (μmol C_2H_4/6 h)	Per m^2 (μmol C_2H_4/6 h)	Per g of plant dry weight (nmol C_2H_4/6 h)
25 × 25	1.51	24	0.043
20 × 20	1.37	37	0.044
15 × 15	1.08	48	0.043
12.5 × 12.5	1.14	78	0.059
10 × 10	1.14	114	0.068
SE	0.17	10.5	0.0096

increasing the biomass per plant of a variety does not necessarily increase ARA per plant or ARA per gram of dry weight. However, the ARA increased significantly with increasing density when calculated on a per unit area basis. Rice planted at 10- × 10-cm spacing showed 4 times higher ARA per square meter than that planted at 25- × 25-cm (Table 5).

Varietal differences in associative nitrogen fixation. We studied the N_2 fixation (ARA) associated with the rice plant, dry weights of submerged and aboveground portions of plants at heading, and grain and straw yield at harvest of 37 varieties and lines grown in a wetland field with no inorganic fertilizer in 1985 DS. ARA of each variety was measured for 18 replicated plants for 3 consecutive days at heading.

Short-, medium-, and long-duration groups significantly differed in ARA per plant, ARA per gram of total plant dry weight, root dry weight, total plant dry weight, and harvest index. Varieties with the highest and lowest ARA per plant and ARA per gram of plant dry weight are given in Table 6.

Natural ^{15}N in available soil N and rice plants. The natural abundance of ^{15}N was used to estimate the N contribution by biological N_2 fixation.

The $\delta^{15}N$ value is expressed as

$$\delta^{15}N = \left(\frac{\text{atom \% of sample}}{\text{atom \% of standard}} - 1\right) \times 1000$$

The $\delta^{15}N$ values of available soil N (NH_3 released after 6 wk of anaerobic incubation of soil) in Maahas soil were 8.2 at 0-10 cm, 10.2 at 10-20 cm, and 11.4 at 20-30 cm. Therefore, the distribution of roots would affect ^{15}N values in rice plants. To estimate the contribution of biological N_2 fixation to the rice plant, it is therefore necessary to grow plants in pots with well-mixed soil. The $\delta^{15}N$ values (per thousand) (Table 7) show slight differences among rice varieties.

Table 6. ARA per plant and per gram of plant dry weight of varieties with the highest and lowest ranks among 37 rice varieties and lines tested. IRRI, 1986.

Variety or line	ARA	
	Per plant (μmol C_2H_4/6 h)	Per g of total plant dry weight (nmol C_2H_4/6 h)
Short duration		
IR50[a]	5.0	166
IR25888-7-3-1[b]	2.3	89
SE	0.4	16
Medium duration		
IR19672-140-2-3-2-2[a]	8.7	195
IR18349-22-1-2-1-1[b]	3.6	94
SE	1.0	17
Long duration		
IR24722-88-2-3-3[a]	12.3	235
MGL2[b]	6.6	64
SE	1.3	23

[a]Variety with highest ranking. [b]Variety with lowest ranking.

Nitrogen fixation by heterotrophic bacteria in a flooded soil amended with straw hemicellulose. To examine the ability of N_2-fixing bacteria to utilize and fix N_2 on straw hemicellulose as a sole C source, rice straw was treated with H_2O_2, NaOH,

Table 7. $\delta^{15}N$ values of grain and straw grown in pots.[a] IRRI, 1986.

Variety or line	Growth duration (d)	$\delta^{15}N$ (parts per thousand)	
		Grain	Straw
IR18349-135-2-3-2-1	122	5.19 (8)	5.63 (8)
Hua-chou-chi-mo-mor	101	5.99 (6)	5.81 (6)
IR50	101	5.99 (8)	5.48 (8)
IR42	150	6.07 (7)	5.47 (7)
OS4	122	6.45 (7)	6.24 (6)
Rodjolele	150	6.50 (7)	5.92 (7)
SD		0.38	0.50

[a]Figures in parentheses are the number of replications.

and NaOCl to loosen its components and solubilize the lignin. Treatment with 1% H_2O_2 at pH 11.5 for 6 h solubilized 44% of the lignin and 41% of the hemicellulose. The carbohydrate released in water after autoclaving H_2O_2-treated straw was found to be either xylan or a degraded product that may not have fully broken down to xylose. Treated and untreated straws and glucose were added to sterile flooded soils and inoculated with bacteria. N_2 fixation measured by ^{15}N incorporation demonstrated that H_2O_2-treated straw hemicellulose can be utilized as the sole C source by single or mixed strains of heterotrophs isolated from rice roots, e.g., *A. lipoferum*, *P. diazotrophicus*, *Klebsiella planticola*, and *Enterobacter cloacae* (Table 8). Although the efficiency of N_2 fixation was quite variable among bacterial treatments, *A. lipoferum* alone showed the highest N_2 fixation with glucose or H_2O_2-treated straw.

Table 8. Incorporation of ^{15}N by single and mixed N_2-fixing bacterial strains grown in flooded Maahas clay soil for 30 d with glucose[a] or H_2O_2-treated rice straw[b] as the C source, IRRI, 1986.

Treatment[c]	Atom % ^{15}N[d] excess		Amount of N_2 fixed (µg N/flask)	
	Glucose	H_2O_2-treated straw	Glucose	H_2O_2-treated straw
34H + H8 + EF26 + LL4	0.0054	0.0017	3.9	1.3
34H + H8 + EF26	0.0043	0.0063	3.5	5.2
34H + EF26 + LL4	0.0364	0.0275	28.0	21.4
34H + H8 + LL4	0.0358	0.0061	29.1	4.9
34H	0.0647	0.0536	53.3	43.9
H8 + EF26 + LL4	0.0243	0.0018	19.9	1.4
H8 + EF26	0.0131	0.0028	10.6	2.3
H8 + LL4	0.0348	0.0046	27.0	3.4
H8	0.0459	0.0123	34.8	9.3
EF26 + LL4	0.0211	0.0035	16.5	21.7
SE	0.0016	0.0025	1.7	2.0

[a]0.25% in 20 g sterile soil/flask. [b]0.5% in 20 g sterile soil/flask. [c]34H = *Azospirillum lipoferum*, H8 = *Pseudomonas diazotrophicus*, EF26 = *Enterobacter cloacae*, LL4 = *Klebsiella planticola*. [d]Gas used was 33.82% $^{15}N_2$.

PHOTODEPENDENT NITROGEN FIXATION

Soil Microbiology and Agronomy Departments

Blue-green algae collection (*Soil Microbiology*). Forty-five strains of blue-green algae (BGA) were added to the collection to bring it to 195 strains of 20 genera originating from 21 countries. About 45% of the strains are from Africa and 40% from Asia. The dominant genera are *Nostoc*, *Anabaena*, and *Calothrix*, reflecting the ricefield origin of the collection (Table 9).

The collection has been conserved in liquid BG-11_0 medium in 250-ml flasks under continuous illumination. This method requires subculturing about every 2 mo, is time-consuming, and might lead to significant changes of the strain properties after long-term cultivation under artificial conditions in the laboratory.

Conservation in the dry state was tested and proved to be an efficient method for the short to medium term. Dried soil-based inocula produced in erlenmeyer flasks or on petri plates on soil previously autoclaved at 130 °C for 15 min exhibited good viability. Of 70 strains of 11 genera tested, 67 could be regrown after 20 mo of storage in plastic bottles at room temperature. However, about 30% of the strains were contaminated with algae from the soil, mostly diatoms, so special attention should be paid to soil sterilization.

Ten dried and powdered cultures produced in 20-liter carboys on BG-11_0 medium regrew after 50-56 mo of storage. However, this method requires culturing large quantities of algal material.

Conservation in the dry state of dense cultures produced in 250-ml erlenmeyer flasks, deposited on sterile filter paper strips, dried in a sterile hood at room temperature, and placed in sealed poly-

Table 9. Number and origin of the collection of blue-green algae (BGA). IRRI, 1986.

Genus	BGA collection (no.)						
	Africa		Asia		Europe	Other regions	Total
	Senegal	Others	Philippines	Others			
N_2-fixing							
Anabaena	20	2	5	11	9	3	50
Aphanothece	0	1	1	0	0	0	2
Aulosira	1	1	0	1	0	1	4
Calothrix	14	2	5	3	0	1	25
Cylindrospermum	4	1	1	0	0	0	6
Fischerella	0	3	7	0	0	0	10
Gloeotrichia	1	0	3	0	0	0	4
Nodularia	2	0	1	1	0	0	4
Nostoc	20	6	13	13	2	5	59
Scytonema	6	0	1	1	0	0	8
Tolypothrix	0	0	0	4	0	0	4
Westiellopsis	0	1	0	0	0	0	1
Wollea	0	0	1	0	0	0	1
Subtotal	68	16	38	34	11	10	177
Non-fixing	16	0	0	1	1	0	18
Total	84	16	38	35	12	10	195

ethylene bags proved to be the most convenient and efficient. Among 20 unialgal strains prepared 2 yr previously, 18 were still viable. The non-viability of the 2 other strains was recognized 1 mo after preparation. Sets of these strains were mailed to 12 laboratories around the world with information on how to revive the material, plus a questionnaire. In half of the laboratories, all the strains were regrown; in the other laboratories, most of the strains were regrown.

During 1986 the whole BGA collection was transferred to paper strips. Strains are provided free upon request.

Standardization of methods for field studies (*Soil Microbiology*). *Media and methods of enumeration.* Six of the most common media used for growing BGA were compared for enumerating N_2-fixing BGA in soils and inocula using plate counts and the most probable number method in test tubes (Table 10). With three of the media, counts by the most probable number method were significantly lower than those on plates, indicating that the method, which has been used in many ecological studies, might lead to an underestimation of BGA populations.

Plate counts were lower on Kratz and Myers

Table 10. Enumeration of N_2-fixing BGA on different media. IRRI, 1986.

Medium	Plating[a] (CFU X 10^4/g soil)	Plating[b] (% of average)	MPN[a] (CFU/g soil)
Allen and Arnon (1955)	2.8 X 10^4	108 ± 35 a	2.2 X 10^4
Gerloff (1950)	2.4 X 10^4	107 ± 40 a	5.4 X 10^3
Gorham et al (1964) (ASM)	2.9 X 10^4	119 ± 52 a	1.6 X 10^4
Kratz and Myers (1955)	1.6 X 10^4	64 ± 32 b	2.4 X 10^3
Stanier et al (1971) (BG-11_0)	2.5 X 10^4	102 ± 34 a	5.4 X 10^4
Van Baalen (1965) (Dm)	2.3 X 10^4	95 ± 44 ab	2.4 X 10^3

[a]One soil sample enumerated in triplicate by plating and most probable number (MPN) method. [b]Average ± standard deviation of 15 counts obtained from 5 soil samples and 10 dried inocula and expressed as % of the average of the counts on the 6 media. Values followed by a common letter are not significantly different at the 5% level by the Kolmogornov-Smirnov test.

medium but did not significantly differ among the five other media, although there were significant differences in the sizes of the colonies. Allen and Arnon, BG-11_0, and Dm media permitted faster BGA growth.

Standardization of ARA measurements. The conversion rate from acetylene reduced to ^{15}N fixed was determined under experimental conditions similar to those used for standardized ARA measurements. Composite soil core samples were exposed consecutively to $^{15}N_2$ and C_2H_2, both for 1 h under identical light (5000 lux) and temperature (30 °C) conditions.

Soil covered with a dense algal mat (11 kg N/ha) gave an average ratio of 6.9 after 1 h of incubation. ARA increased with time. Assuming that the rate of $^{15}N_2$ fixation was constant with time, it would appear that ARA measured after 30 min of exposure to acetylene would give a ratio (3.9) closest to the theoretical ratio of 4. Soil covered with a very dense algal mat (21 kg N/ha) gave an average ratio of 30 after 1 h.

Higher solubility of C_2H_2 than of N_2 in water hence faster diffusion of C_2H_2 into the algal mat could account for the higher C_2H_2:N_2 obtained with a thicker algal mat. Soil algal material utilized for these measurements was from soil microplots fertilized to obtain the large algal biomass required for ^{15}N measurements. However, an algal biomass corresponding to 21 kg N/ha is larger than any bloom currently observed in a ricefield.

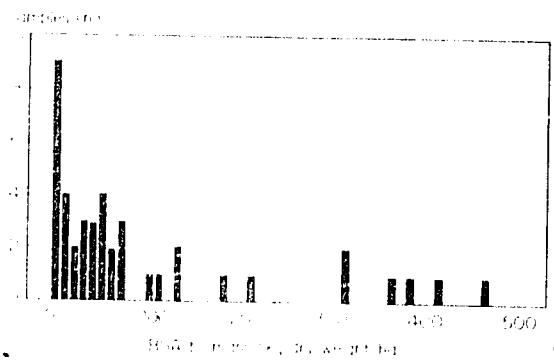
Long-term incubation under acetylene might cause an overestimation of photodependent biological N_2 fixation, whereas most of the other artifacts associated with ARA measurements such as the greenhouse effect and disturbance of the samples might cause an underestimation.

Direct measurement and chemical analysis of BGA biomass, BGA counts by plating, and ARA measurements were performed in plots where N_2-fixing BGA dominated the algal populations. The three variables were highly correlated ($P < 0.01$). The coefficient of correlation between ARA and biomass ($r = 0.75$) was higher than that between ARA and counts ($r = 0.55$). The dry weight of BGA including ash ranged from 4 to 500 kg/ha (mean 97, median 53) (Fig. 5). Specific ARA ranged from 0.1 to 10 nmol acetylene/mg protein per min. A general decrease of the specific ARA was observed at high biomass (Fig. 6).

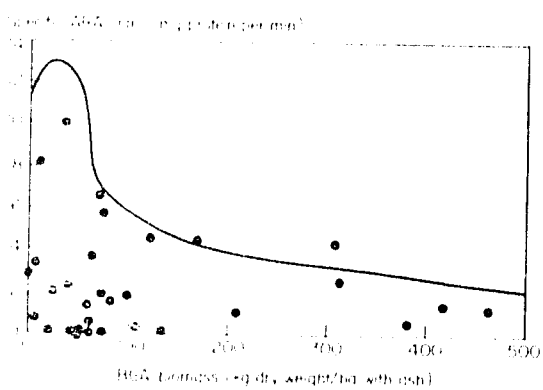
Occurrence of nitrogen-fixing BGA in rice soils (*Soil Microbiology*). In an ongoing study initiated in 1984, the algal population of 160 soil samples from 7 countries was being characterized and quantified.

N_2-fixing strains were present in all samples at densities ranging from 1×10^3 to 8×10^6 CFU/cm^2 (median 6×10^4).

Heterocystous BGA occurred at densities higher than 10^3 CFU/cm^2 in 95% of the samples. The abundance of heterocystous BGA was positively correlated with the pH, available P, and cation exchange capacity (CEC) of the soils. A significant correlation ($P < 5\%$) was also found between the CEC and pH of the soils. Analysis of partial correlations indicated a more marked effect of pH (partial r at constant CEC = 0.497) than CEC



5. Blue-green algae (BGA) biomass in 42 plots, IRRI, 1986. Biomass measurement includes ash



6. Specific ARA of BGA in relation to biomass, IRRI, 1986 DS. Biomass measurement includes ash.

(partial r at constant pH = 0.3) on the abundance of heterocystous BGA. Positive correlations between total algae and C and N content of the soils, and negative correlations between the relative abundance of heterocystous BGA and C and N content of the soils, indicated that soils rich in organic matter have higher total algal populations and lower relative populations of heterocystous BGA.

Nostoc, *Anabaena*, and *Calothrix* were the most frequently recorded genera. *Nostoc* (which forms mucilaginous colonies) was recorded in 99% of the samples and was the dominant N_2-fixing genus in 74% of them. Relatively high occurrence and low frequency of dominance were observed for strains that do not form mucilaginous colonies and are more susceptible to grazing (*Anabaena*, *Calothrix*), indicating that grazing is a major limiting factor in the development of blooms of nonmucilaginous strains active in N_2 fixation in ricefields.

No significant correlation was observed between the relative abundance of the various groups of heterocystous BGA and soil physicochemical properties.

Inoculation experiments (*Soil Microbiology*). *Greenhouse*. ARA and the dynamics of inoculated and indigenous heterocystous BGA were studied for 2 mo in 1-m^2 microplots of 5 soils.

Estimates of the ratio of indigenous to inoculated heterocystous BGA at time intervals ranged from 0.1 to 840 and averaged 104. Only on 11 occasions out of 80 were inoculated heterocystous BGA more numerous than indigenous heterocystous BGA. This was observed with no growth or late growth of indigenous heterocystous BGA, or after the decline of a bloom of indigenous heterocystous BGA.

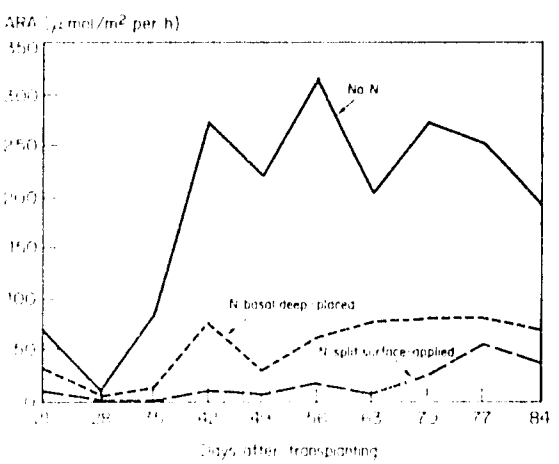
There were conspicuous differences among inoculated strains in their ability to persist in the soils. *Tolypothrix tenuis* was recorded as the most abundant inoculated strain in 65% of the cases. *Aulosira fertilissima* persisted after soil drying, while *Anabaena variabilis* and *Nostoc* sp. disappeared.

On the average, ARA was higher in plots treated with 100 kg of crushed neem seeds (*Azadirachta indica*) ha than in plots with no neem. ARA was correlated with the counts of total heterocystous BGA and indigenous heterocystous BGA but not with the counts of inoculated BGA, indicating that ARA was caused principally by indigenous BGA.

The establishment of inoculated nonindigenous strains was infrequent, and neem application permitted the development of N_2-fixing BGA blooms in all soils.

Field. Inoculation experiments were conducted on the IRRI farm in 1985 WS and 1986 DS. Factors tested together with inoculation were N (none, surface applied, or deep placed), P (basal or split), and neem application. The results follow.

- Surface application of N fertilizer drastically inhibited N_2 fixation for the whole crop cycle during both WS and DS (Fig. 7). The beneficial effect of algal inoculation in the presence of N fertilizers reported in the literature might not be caused only by N_2 fixation by BGA and needs to be further explained.
- Deep placement caused only a partial inhibition of N_2 fixation. In the 1985-86 experiments, inhibition was more pronounced (50-70%) than in previous experiments (30%).
- Split P application was more efficient than basal application in increasing photodependent ARA along the crop cycle, but had no significant effect on grain yield.
- Neem application had a significant effect on grain yield (Table 11).



7. Effect of N fertilizer on ARA, IRRI, 1986 DS. Av of 4 treatments, 5 replications each.

Table 11. Grain yield in inoculation experiment.[a] IRRI, 1986 DS.

Treatment	Grain yield (t/ha)		
	No neem	Neem (100 kg/ha)	Significance of difference
Noninoculated			
Control (no N)	3.7 ± 0.5	4.1 ± 1.0	+
Split N	4.8 ± 0.5	5.3 ± 0.7	+
Deep-placed N	5.4 ± 1.0	5.6 ± 0.7	+
Inoculated			
Control (no N)	4.1 ± 0.6	4.4 ± 0.7	+
Split N	4.7 ± 1.1	5.4 ± 0.9	+
Deep-placed N	6.0 ± 1.2	5.9 ± 0.7	–
Difference (inoculated – noninoculated)			
Control (no N)	0.4[+]	0.3[+]	
Split N	–0.1	0.1[+]	
Deep-placed N	0.6[+]	0.3[+]	

[a] + = Difference significant at the 10% level.

- During WS, inoculation had no effect on yield. During DS, inoculation increased yield by about 9% (significant at the 10% level) in the controls without fertilizer N and in the plots where N fertilizer was deep-placed. There was no effect or a negligible one when N fertilizer was surface applied (Fig. 7).
- The inoculum used during WS was dominated by nonindigenous strains; that used during DS was produced using soil from the field to be inoculated and was rich in indigenous strains. BGA blooms, which were observed in the control plots and in plots where N fertilizer was deep-placed, were of indigenous strains.

Ecological studies showing the presence of heterocystous BGA in all rice soils, field and greenhouse studies showing poor establishment of inoculated nonindigenous strains, and greenhouse and field studies where blooms of indigenous strains were established by appropriate methods of fertilizer application and grazer control, all indicate that research on the agronomic utilization of BGA should emphasize indigenous strains and practices favoring their development rather than inoculation of foreign strains selected in the laboratory.

Floodwater chemistry as affected by algae (*Soil Microbiology and Agronomy*). Three independent experiments of algal flora in relation to the N cycle showed that a large algal biomass is not required for the development of daily variations of pH that cause significant losses of N by NH_3 volatilization.

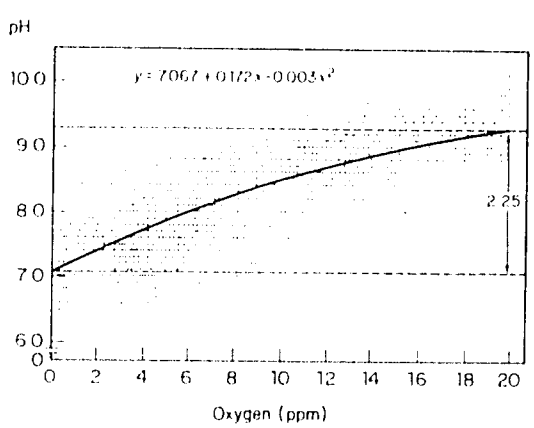
A study of the correlation of dissolved O_2 with the pH of the floodwater of 5 rice soils showed that, on the average, pH increases by 2.25 units when photosynthetic activity in the floodwater increases from none (<1 ppm O_2 in the floodwater) to the value corresponding to a maximum O_2 oversaturation (20 ppm O_2) (Fig. 8).

AZOLLA-*ANABAENA* SYMBIOSIS

Soil Microbiology Department

Azolla collection, species identification, and distribution. *A. pinnata* (var. *africana*) from Madagascar and *A. japonica* (similar to *A. filiculoides*) were added to the collection. A total of 172 accessions were maintained at the end of 1986. In response to requests, 277 samples were sent to 39 people from 14 countries. The growth and survival of the azolla distributed in 1985 were surveyed; about 70% grew. The growth of *A. microphylla* was reported to be poorest in 60% of the cases. Some species of *Euazolla* were correctly identified by megasporocarp structure as *A. filiculoides* 105, 106, 110, and 116; *A. mexicana* 202, 309, and 310; and *A. microphylla* 109 and 203. Although some were misnamed by the collectors, the accession numbers were retained.

Response to high temperature of *Euazolla* from Colombia. Thirteen accessions were obtained from Colombia (Acc. 114, 116-127). Their response to



8. Correlation between dissolved O_2 and pH in the floodwater of rice soils, IRRI, 1986. 1200 data from 5 soils.

high temperature was examined from their growth and ARA at the average temperature of 33 °C with 8 °C difference between day and night. *A. microphylla* 418 and *A. filiculoides* 101 were used as high-temperature tolerant and less tolerant references.

ARA was measured at 0, 2, and 4 d after transferring to 33 °C. The ARA of strain 116 was as low as that of strain 101. Growth at 33 °C continued for 11 d. From the biomass, ARA, and N content at 11 d, strains 116 and 113 were found to be as heat-sensitive as *A. filiculoides* 101. Strains 117-125 produced similar biomass as *A. microphylla* 418, but the N content of *A. microphylla* 417 was highest. The vegetative morphology of strain 116 resembled that of *A. filiculoides* 101. Because none of the tested azolla had yet produced sporocarps, their taxonomical position was not identified and they were temporarily grouped with *A. filiculoides*.

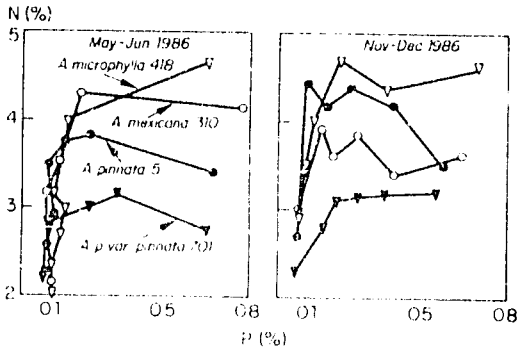
Economical use of P fertilizer for azolla. Up to 10 DAI, P-enriched azolla grew faster than azolla with split application of P. Thereafter, growth slowed down because of deficiency. P fertilizer applied at 16 and 19 d after inoculation of P-enriched azolla (0.8% P on dry weight basis) (Table 12, treatment 7) produced more biomass than basal application (treatment 2), and biomass similar to or higher than that with split application of P to P-deficient (0.19% P) azolla (treatment 1). To prepare P-enriched azolla, 8.8 kg P/ha was applied to the inoculum production plot. Because the biomass of the inoculum plot was 2 kg fresh weight/m^2 and 0.2 kg/m^2 was inoculated into the main field, the P dose in the P-enriched azolla inoculation was equivalent to 0.88 kg P/ha. The ratio of N at 28 d to P applied (P efficiency) was highest in the P-enriched azolla inoculated treatment without further P application. P application to the plots inoculated with P-enriched azolla (treatment 7) gave a P efficiency similar to or higher than for split P application (treatment 1). Inoculation of P-enriched azolla with additional P in the main field is an economical way of applying P to azolla.

Azolla decomposition as affected by species and N content. Most azolla grown in the field is deficient in P and hence low in N. The effect of N content of various azolla species on its decomposability in soil was determined. P-enriched azolla species (*A. pinnata* 5, *A. mexicana* 310, *A. microphylla* 418, and *A. pinnata* var. *pinnata* 701) were inoculated into field plots. As the plants grew, the P content and hence the N content decreased. Samples were taken at intervals with varying N and P contents. *A. microphylla* had the highest N content and *A. pinnata* var. *pinnata* the lowest, though slight differences were found between seasons (Fig. 9). *A. pinnata* var. *pinnata* seems to be tolerant of P deficiency, because it grew further from 3 wk to 4 wk despite its low P content (<0.06%).

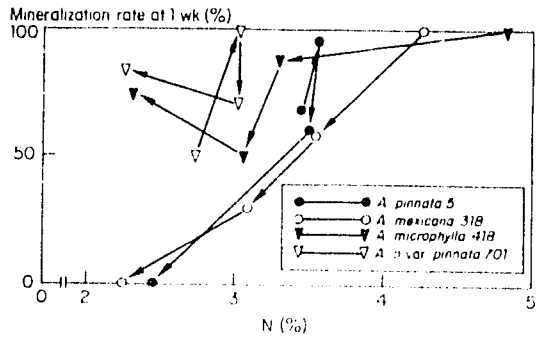
Table 12. Effect of P application method on biomass production of *A. microphylla*, IRRI, 1986 DS and WS.

Treatment[a]	P applied (kg/ha)		Dry season biomass on 28th day			Wet season biomass on 28th day		
	To main field only	Also to inoculum plot (A)	Fresh weight (kg/m^2)	kg N/ha (B)	N-to-P ratio (B/A)	Fresh weight (kg/m^2)	kg N/ha (C)	N-to-P ratio (C/A)
1. Split application	3.93	3.93	2.2	50	13	2.3	49	12.5
2. Basal only	2.18	2.18	1.3	27	12.5	1.0	26	12
3. Basal + 1 split at 16 DAI	3.06	3.06	1.8	36	12	1.4	29	9.6
4. Basal + 2 splits at 16 and 19 DAI	3.93	3.93	1.7	38	9.6	1.9	35	8.9
5. P-enriched azolla	0	0.88	1.4	21	24	1.4	41	47
6. P-enriched azolla + 1 split at 16 DAI	0.88	1.75	1.6	31	18	2.0	52	30
7. P-enriched azolla + 2 splits at 16 and 19 DAI	1.75	2.62	1.8	33	12	2.9	71	27
8. No P	0	0	0.8	15		0.5	12	
SE			0.1	3		0.3	3	

[a]DAI = days after inoculation.



9. N and P contents of azolla during growth from P-sufficient to P-deficient conditions. IRRI, 1986.



10. Mineralization of azolla at 1 wk as affected by N content. IRRI, 1986 DS. Samples were taken at 0, 9, 12, and 24 d after inoculation in the field.

Mineralization of azolla N was determined by incubating fresh azolla in flooded Maahas clay subsoil. The mineralization rates after 1 wk of decomposition (percentage N mineralized at 2 or 3 wk) were determined by both species and N content (Fig. 10). The same N content did not give the same mineralization rate regardless of species. The N in *A. pinnata* var. *pinnata* is most decomposable despite its low N content. Because samples of *A. mexicana* and *A. pinnata* taken at 24 DAI had already decomposed in the field, they did not decompose further during incubation.

Utilization of azolla N by rice. The uptake of azolla N was studied as a coordinated trial by the International Atomic Energy Agency-Food and Agriculture Organization joint project on the use of isotopes in agriculture. ^{15}N-labeled *A. microphylla* was prepared by feeding azolla with labeled $(NH_4)_2SO_4$. Labeled urea or azolla was incorporated at 1 d before transplanting and at 42 DT. The unlabeled N sources were used for the basal application when labeled N sources were incorporated later, and vice versa. The ^{15}N tracer experiment was conducted in a 1- × 1-m microplot in the field. The azolla used for this experiment contained 4.6-4.7% N on a dry weight basis. The recovery of ^{15}N (Table 13) after one rice crop was higher from azolla N than from urea N, and recovery was higher with late application than with basal application.

In an adjacent field, rice yield response to azolla and urea was studied using unlabeled N sources. Because of the difficulty of producing azolla with similar N content, azolla N content used in this experiment was lower (3.9%) than that used for the isotope experiment, and N applied as azolla was slightly different from that of urea. The effect of azolla on rice yield was slightly less than that of urea. Assuming that yield is proportional to N dose, the yield at the same level of N as urea was estimated (Table 14). The estimated rice yield in azolla-incorporated plots was similar to that with urea, suggesting that the slightly lower yield in azolla plots was due to lower N input.

Table 13. ^{15}N balance in urea and azolla applied to wetland rice. IRRI, Sep-Dec 1985.

Treatment[a]		N rate (g/m²)		^{15}N recovery (%)		
1 DBT	42 DT	Total	^{15}N	Crop	Soil	Unaccounted for
^{15}N azolla	^{14}N urea	6.54	3.57	39	50	11
^{14}N azolla	^{15}N azolla	6.78	3.31	73	27	<1
^{15}N urea	^{14}N urea	6.02	3.05	27	38	35
^{14}N urea	^{15}N urea	5.92	3.00	48	22	30
^{14}N urea	^{15}N azolla	6.23	3.31	64	35	<1
SE (n = 6)				6	4	

[a]DBT = days before transplanting, DT = days after transplanting.

N and P contents of azolla from the Philippines. Azolla was collected from ricefields and ponds in 12 regions of the Philippines. The species, field or pond conditions, coverage of azolla, color, healthiness, and treatments were recorded. Soil samples were also taken from some fields. The N and P contents of *A. pinnata* var. *imbricata* were lower than those of *A. microphylla*, but higher than those of *A. pinnata* var. *pinnata* (Table 15). The N and P contents of samples from South Cotabato, Bicol, and Southern Leyte were higher than those from other regions or provinces (Table 16). Only 20% of the samples had N and P contents higher than a sufficient level (4%, or 5.5% on an ash-free basis of N; and 0.4%, or 0.55% on ash-free basis of P) (Fig. 11, 12). In most cases in the Philippines, azolla is deficient in P and hence low in N. Color, healthiness, and coverage on the water surface had some correlation with N and P contents.

Table 14. Grain and straw yield of IR62 treated with azolla and urea fertilizers.[a] IRRI, Sep-Dec 1985.

Treatment		N rate (kg/ha)		Rice yield (t/ha)		Corrected yield (t/ha)	
1 DBT	42 DT	1 DBT	42 DT	Grain	Straw	Grain	Straw
Azolla	Azolla	30	26	5.0	5.5	5.4	5.9
Urea	Urea	30	30	5.6	5.45	5.6	5.45
Urea	Azolla	30	26	5.0	4.95	5.3	5.3
No fertilizer		0	0	3.9	3.3	3.9	3.3
SE (n = 4)				0.2	0.2	0.2	0.2

[a]DBT = days before transplanting, DT = days after transplanting.

Table 15. N and P contents[a] of 3 azolla species.[b] Philippines, 1986.

Dominant azolla species	Samples (no.)	N content (%)		P content (%)	
		Per g dw	Ash-free dw	Per g dw	Ash-free dw
A. pinnata var. *imbricata*	174	3.22 ± 0.83	4.48 ± 0.96	0.274 ± 0.167	0.381 ± 0.231
A. microphylla	28	3.87 ± 0.88	4.89 ± 0.88	0.274 ± 0.149	0.470 ± 0.262
A. pinnata var. *pinnata*	8	2.16 ± 0.49	2.75 ± 0.70	0.[illegible]42 ± 0.038	0.183 ± 0.067

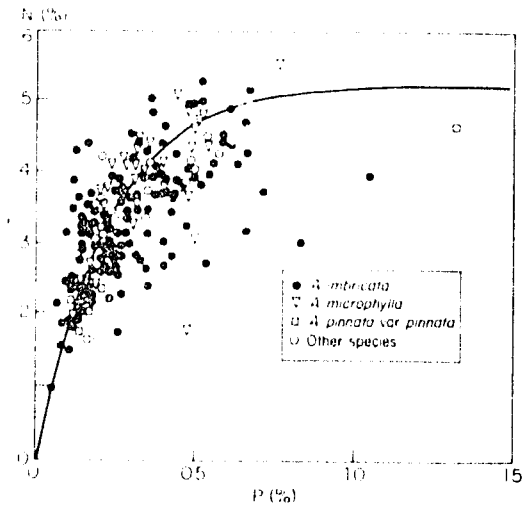
[a]Mean ± standard deviation. [b]dw = dry weight.

Table 16. N and P contents of azolla collected in the Philippines. 1986.

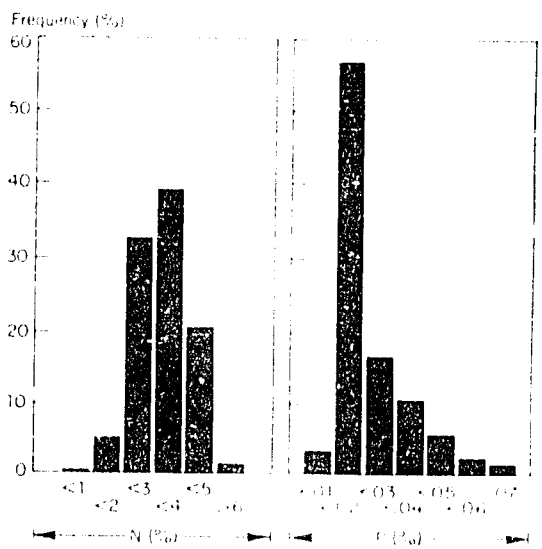
Region	Provinces	Samples (no.)	N (%)	P (%)
1	Abra, Mountain Province	11	3.25	0.26
2	Ifugao, Nueva Vizcaya	14	3.16	0.37[a]
3	Tarlac	1	5.51	0.75
4	Laguna, Occidental Mindoro, Palawan	35	3.17	0.25
5	Albay, Camarines Norte, Camarines Sur, Sorsogon	41	3.75[a]	0.32[a]
6	Aklan, Antique, Capiz	30	2.82	0.25
7	Bohol, Cebu	18	2.80	0.25
8	Leyte	50	3.37	0.29
	Southern Leyte alone	11	4.07[a]	0.39
9	Zamboanga del Norte and Zamboanga del Sur	28	3.35	0.24
11	South Cotabato	9	3.75[a]	0.39[a]
12	Sultan Kudarat	1	4.50	0.58
Total or average		238	3.30	0.29

[a]Higher than average levels.

Establishment of symbiosis in *Anabaena*-free azolla. In cooperation with the Fujian Academy of Agricultural Sciences and the National Azolla Research Center, Fuzhou, China, azolla was freed from the symbiotic alga *Anabaena* by cutting below the apical membrane of megasporocarps. By placing indusium of the same or other species on a cut megasporocarp, algae associated with the indusium infected germinating azolla, and symbiosis was re-established. Thus, recombination of *Anabaena* to *Anabaena*-free azolla was successful.



11. P and N contents of azolla. Philippines, 1986.



12. Distribution of N and P in azolla (n = 174). IRRI, 1986.

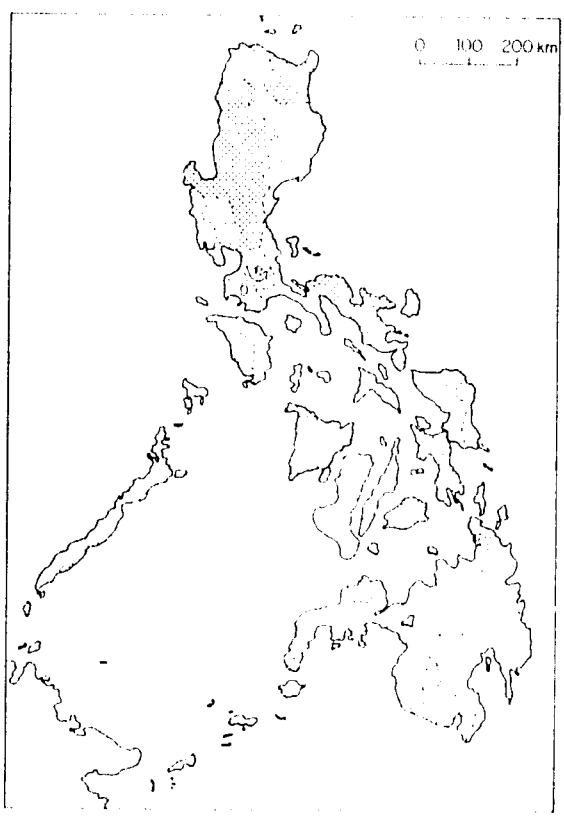
Details are given in the section on Cooperative Country Projects.

AZOLLA PESTS

Entomology and Soil Microbiology Departments

Distribution of confirmed insect pests. At the end of 1986, 12 species of insect pests of azolla had been confirmed, as follows:

- Diptera (Chironomidae): *Chironomus crassiforceps* Kieffer, *C. javanus* Kieffer, *C. kiiensis* Tokunaga, *Polypedilum anticum* Johannsen, and *P. suturalis* Johannsen
- Coleoptera (Curculionidae): *Apion* sp., *Bagous affinis* Hustache, and *Nanophyes insularis* Hustache
- Lepidoptera (Pyralidae): *Elophila entxalis* (Swinhoe) (caseworm), *E. nigralbalis* (Caradja) (caseworm), *E. responsalis* (Walker) (caseworm), and *Ephestiopsis vishnu* Roesler et Kuppers (spinning worm)



13. Distribution of the spinning worm *Ephestiopsis vishnu* on azolla in the Philippines, 1986.

Figures 13 and 14 show the distributions of the four most important pyralid pests in the Philippines. In April and May, it was confirmed that the spinning worm *Tp. vishnu* feeds on an indigenous species of *Azolla pinnata* in Nueva Vizcaya, Ifugao, Benguet, and Mountain Province, Philippines, and that the caseworm *El. nigralbalis* feeds on the indigenous species in the same four provinces and in one additional province (Ilocos Sur). This means that the two species are indigenous in the Philippines and probably not recent introductions with azolla from other countries.

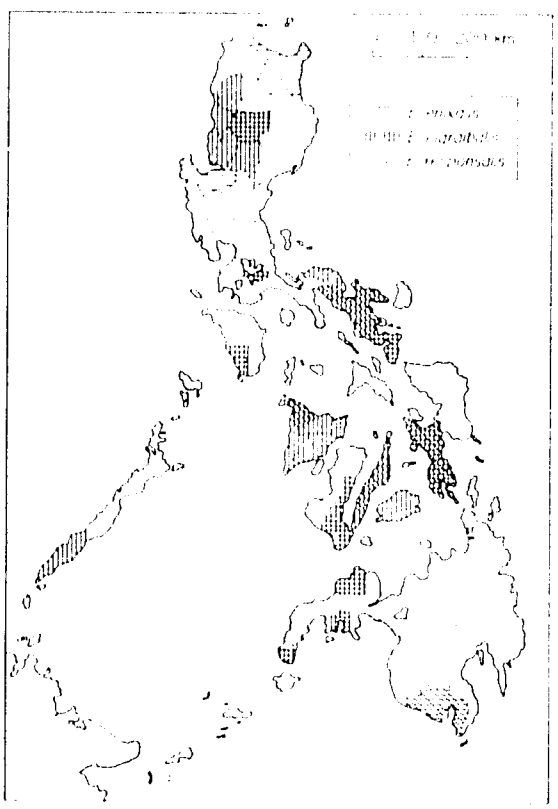
Prevalence of four pyralid moths. The seasonal prevalence at IRRI of four pyralid moths, measured by light trap catches and weekly sampling, is shown in Figure 15.

Biomass and yield loss. The standing and harvested biomass in insecticide-treated and untreated plots of two azolla species is illustrated in Figure 16. Standing and harvested biomass, larval populations, and pupal populations of the spinning worm and caseworm complex, and yield loss at the IRRI farm are summarized in Table 17. The average yield loss was 57% in *A. microphylla* (Acc. 418) and 45% in *A. pinnata* var. *imbricata* (Acc. 5).

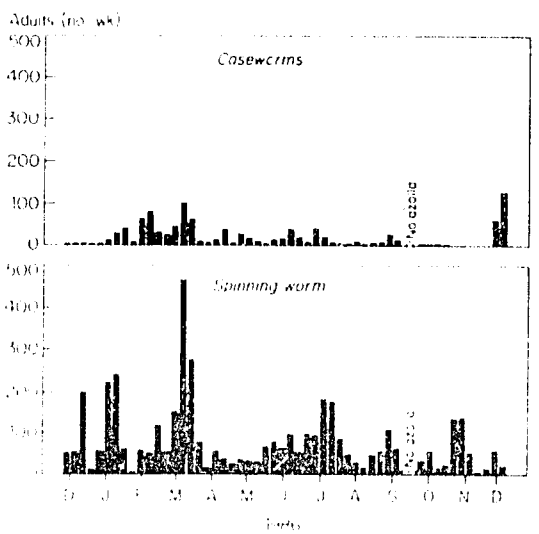
Figure 17 summarizes production biomass, yield loss, and insect populations in insecticide-treated and untreated plots of two azolla species in a related experiment. The final average yield loss was 29% in *A. microphylla* and 33% in *A. pinnata* var. *pinnata*.

Screening azolla against spinning worms. Out of 142 accessions, 111 were evaluated against spinning worm larvae within 14 d after 5 newly emerged water cultured pairs were released per container in the greenhouse. Only one strain (*A. pinnata* var. *africana* 715 from Madagascar) had no damage in all six plots for three replications. Five accessions (109, 311, 312, 313, and 315) were severely damaged, but some survived. The five should be tested further. The remaining 105 accessions were heavily infested. In the field, Acc. 701 was seldom attacked at maturity by spinning worm larvae and only occasionally by caseworm *El. nigralbalis* larvae, but it was eaten by spinning worm larvae under the nutritionally rich conditions in the IRRI greenhouse.

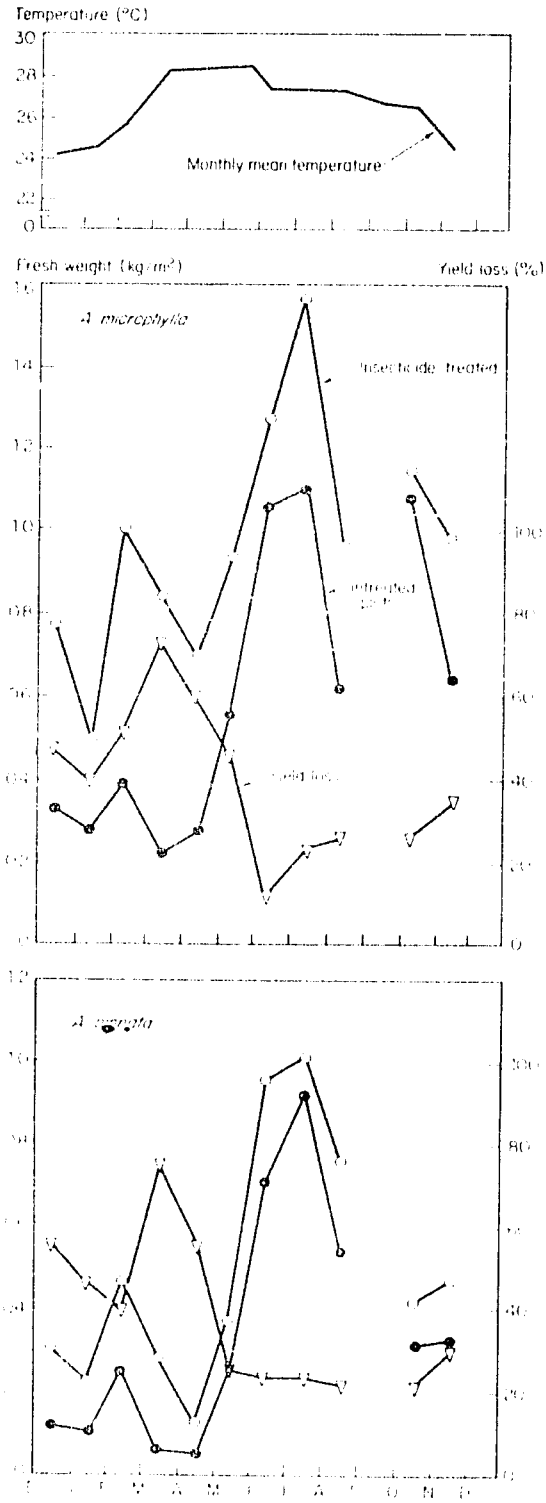
Snails in fresh water containing azolla. In 1985-86, 22 species of snail were confirmed to be



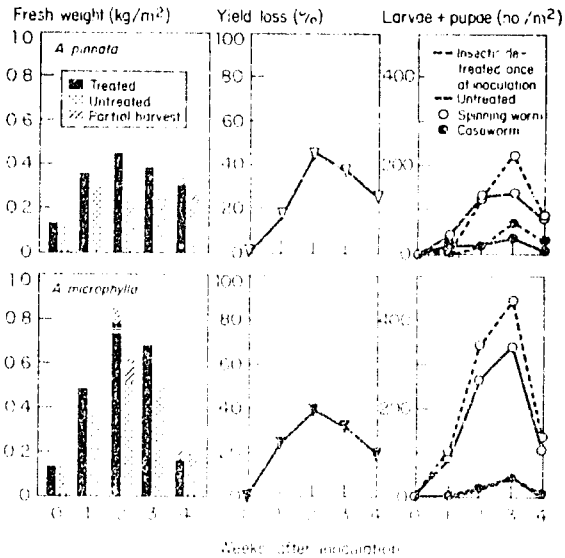
14. Distribution of 3 caseworm *Elophila* spp. on azolla in the Philippines, 1986.



15. Light trap catches of caseworms *Elophila emixalis*, *E. nigralbalis*, and *E. responsalis* and of the spinning worm *Tphestiopsis vishnu*, IRRI 1985-86.



16. *Azolla microphylla* and *A. pinnata* standing biomass in insecticide-treated and untreated plots and yield loss at IRRI, Jan-Dec 1986.



17. Production biomass (av values for 8 inc) of *A. microphylla* and *A. pinnata* and insect pest populations, IRRI, 1986.

prevalent in fresh water containing azolla in the Philippines (Table 18). Three species of *Pomacea* (= *Ampullaria* = *Ampullarius*) were introduced via Taiwan, China, or directly from South America, or from Florida, USA. Apple snails (*P. canaliculata* were found mostly in Luzon and attacked azolla, young rice seedlings, and other plants. Two species of Lymnaeidae (*Lymnaea auricularia* and *L. rubiginosa*) and two species of Planorbidae (*Gyraulus convexiusculus* and *Indoplanorbis exustus*) also attacked azolla. Four chemicals were evaluated against the apple snail and the Nile tilapia *Sarotherodon niloticus*. Triphenyltinacetate 60WP was very effective against snails but was acutely toxic to tilapia. Clonitralide 70WP was the next most effective, but had high fish toxicity. Metaldehyde 6G was effective, and less toxic to fish (Fig. 18). Ethoprophos 10G was ineffective.

Surveys on pests outside the Philippines. Another caseworm, *El. turbata* (Butler), was confirmed to attack *A. japonica* in Kyushu, Japan. The spinning worm larvae were collected on an indigenous strain of *A. pinnata* var. *imbricata* at Banepa, Bhaktapur, Galchhi (Narayani Province), and Pokhara (Gandaki Province) in Nepal, and six larvae of *El. nigralbalis* were collected on the strain from Phewa Lake, Pokhara. Two larvae of *El.*

Table 17. Standing and harvested biomass of 2 azolla species, larval populations, and pupal populations of the spinning worm and caseworm complex, and yield loss. IRRI, Jan-Dec 1986.

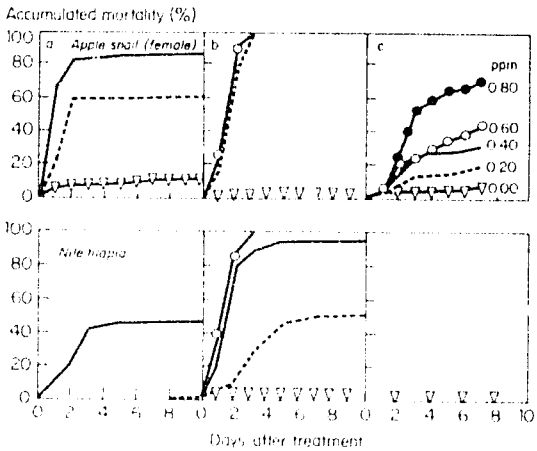
Insecticide treatment[a]	Biomass (kg fresh weight/m²)				Larvae + pupae (no./m²)				Estimated yield loss (%)			
	Standing		Harvested		Spinning worm		Caseworm		Standing biomass		Standing and harvested biomass	
	Av	Range	Av	Range	Av	Range	Av	Range	Av	Range	Av	Range
					A. microphylla							
Treated	0.95	0.16-2.76	0.49	0.11-2.08	0.0	--	0	—	42	0.1-85	57	5-93
Untreated	0.57	0.03-1.82	0.03	0-0.63	203	0-1387	35	0-524				
					A. pinnata var. *imbricata*							
Treated	0.50	0.03-1.92	0.10	0-0.95	0	--	0	—	38	0.1-84	45	0.1-91
Untreated	0.34	0.01-1.40	0	-	50	0-694	64	0-585				

[a]Diazinon 5G at 2 kg ai/ha applied several times depending on insect incidence.

Table 18. Snails (Mollusca, Gastropoda) found in fresh water in ricefields containing azolla. Philippines, 1985-86.

Family	Species	Samples collected from
Neritidae	*Clithon corona* (Linne)	Luzon (Laguna)
	C. faba (Sowerby)	Luzon (Laguna)
Viviparidae	*Vivipara burroughiana* (Lea)	Luzon, Palawan
Pilidae = Ampullariidae	*Pila ampullacea* (Linne)	Luzon, Palawan
	= *Ampullaria ampullacea*	
	= *Pila luzonica*	
	P. scutata (Mousson)	Luzon, Palawan
	= *Ampullaria scutata*	
	Pomacea canaliculata (Lamarck)[a]	Luzon, Mindanao
	= *Ampullaria canaliculata*	
	= *Ampullarius canaliculata*	
	P. cuprina (Reeve)[a]	Luzon (Laguna)
	= *Ampullaria cuprina*	
	P. gigas (Spix)[b]	Luzon (Laguna)
	= *Ampullaria gigas*	
Bulimidae	*Oncomelania quadrasi* (Moellendorff)[c]	Leyte
	Melanoides granifera (Lamarck)	Luzon (Laguna)
	M. maculata (Born)	Luzon (Laguna)
	M. plicaria (Born)	Luzon (Laguna)
	M. punctata (Lamarck)	Luzon (Laguna)
	M. rustica (Mousson)	Luzon (Laguna)
	M. torulosa (Bruguiere)	Luzon (Laguna)
	M. tubercurata (Muller)	Luzon (Laguna)
	Thiara rudis (Lea)	Luzon (Laguna)
Lymnaeidae	*Lymnaea (Radix) auricularia* (Linne)	Luzon, Cebu
	L. rubiginosa (Michelin)	Luzon (Laguna)
Physidae	*Physastra hungerfordiana* Nevill	Luzon (Laguna)
Planorbidae	*Gyraulus convexiusculus* (Hutton)	Luzon, Mindanao, Cebu
	Indoplanorbis exustus (Deshayes)	Luzon (Laguna)

[a]Introduced from Taiwan, China. [b]Introduced from the USA. [c]Intermediate host of *Schistosoma japonicum*.



18. Field evaluation of 3 chemicals (a, clomitralide 70 WP; b, triphenyltinacetate 60 WP; c, metaldehyde 6 G) against female apple snail *Pomacea canaliculata* and toxicity to Nile tilapia *Sarotherodon niloticus*. IRRI, 1986.

Enixalis were collected from an aquatic plant other than azolla in Phewa Lake. This indicates that the three insects are indigenous in Nepal and were probably not introduced through recent azolla inocula.

AZOLLA APPLIED RESEARCH

Training and Technology Transfer, and Soil Microbiology Departments

The azolla growth trials in Baybay, Leyte, were continued to February 1986 to complete a year of study. During the final 6 mo, *A. caroliniana* 301 was included with the previous 3 azolla species. This time the initial inoculum was reduced to 250 g fresh azolla/m^2 and growth was extended to 2 wk. At 2 wk, the azolla was harvested. After determining the biomass, 250 g fresh weight was returned to each quadrant. Net azolla biomass accumulation was obtained on a monthly basis from September 1985 to February 1986. Sclophos was added at 2.2 kg P/ha twice in 2 wk. Monocrotophos was used at 0.5 kg ai/ha when insect attack was observed.

In Baybay, Leyte, *A. microphylla* 418 consistently produced the highest monthly accumulated biomass for the last 6 mo of the trial (Table 19). The biomass produced was equivalent to 270 kg N/ha in 181 d.

The results demonstrate that none of the four azolla strains has the capacity to sustain and maintain high biomass production continuously for a year. The minimum growth among the azolla strains tested varied from season to season and from species to species. Azolla can be successfully grown in Leyte during certain months and can therefore be utilized as an organic N fertilizer during that time.

Table 19. Monthly accumulated azolla biomass in a farmer's field in Baybay, Leyte, Philippines, Sep 1985 to Feb 1986.

Azolla strain	Monthly accumulated biomass[a] (kg fresh weight/m^2)						
	Sep	Oct	Nov	Dec	Jan	Feb	Total
A. pinnata var. *imbricata* 5	2.5	2.7	2.1	2.8	1.6	3.3	15.0
A. microphylla 418	3.0	3.1	2.4	3.4	2.6	3.8	18.0
A. pinnata var. *pinnata* 701	2.3	2.5	2.0	2.1	1.9	2.8	13.6
A. caroliniana 301	1.4	2.3	1.4	2.3	2.2	3.3	12.9
SED	.06	0.1	.08	.07	.04	.09	

[a] Av of 3 replications.

Soil and crop management

Management of organic manures

Soil Microbiology, Multiple Cropping, Soils, and Agronomy Departments and Rice Farming Systems Program

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EFFECT OF AZOLLA AND SESBANIA GREEN MANURES ON LOWLAND RICE

Soil Microbiology Department

A long-term experiment to compare the effects of two green manure crops that can grow under flooded conditions — *Azolla microphylla* 418 and *Sesbania rostrata* — on rice yield and soil fertility was begun in March 1985. Treatments were 1) no N and no green manure, 2) urea at 50 kg N/ha (30 at transplanting and 20 at panicle initiation [PI]), 3) azolla incorporated, and 4) sesbania incorporated. Sesbania grew for 45-50 d until incorporation at 1 d before transplanting (DBT) rice. Azolla grew for 30 DBT and was incorporated twice before and once after transplanting. It was inoculated again and incorporated at 32 d after transplanting.

During the first rice crop, sesbania incorporation increased rice yield over urea, which outyielded azolla. The low effectiveness of azolla was caused by its low biomass and low N content (2.0% on dry weight basis) (Table 1). In the second rice crop, sesbania flowered earlier and accumulated less N so that responses to it and to azolla were about equal. The third crop showed even greater similarity of azolla and sesbania treatments.

RHIZOBIA GERMPLASM COLLECTION FOR GREEN MANURE

Soil Microbiology Department

Several strains of rhizobia from nodules of diverse green manure crops (*Sesbania rostrata*, *Sesbania* china type, *S. chizea*, *S. cannabina*, *S. sesban*, *Vigna radiata*, and *Aeschynomene* sp.) were isolated and maintained. The abilities of isolates to form nodules on their homologous hosts were confirmed by the plant infection method.

NITROGEN FIXATION BY ROOT AND STEM NODULES OF *SESBANIA ROSTRATA*

Soil Microbiology Department

During 1986 dry season (DS), a pot experiment was conducted to study the relative contribution of N_2 fixation by stem and root nodules after inoculating *S. rostrata* grown in flooded and nonflooded soils with a specific *Rhizobium* (ORS571). Seed inoculation was made by pelleting the seeds with a mixture of *Rhizobium*, gum arabic, and charcoal. Stem spray inoculation was made at 30 d after emergence (DE). The root and stem nodules were counted and their nitrogenase activity measured at 40 DE.

Rhizobium-inoculated plants (seed + soil + stem, and only stem-inoculated) produced significantly more root and stem nodules and higher nitrogenase activity (Table 2, 3). Uninoculated plants produced only root nodules attributed to native *Rhizobium*. Plants grown under nonflooded conditions showed more nodules and nitrogenase activity than those grown under flooded conditions. At this growth stage of sesbania, N_2 fixation by root nodules is more important than that by stem nodules.

EFFECT OF *RHIZOBIUM* INOCULATION METHOD ON NODULATION AND NITROGEN FIXATION BY *SESBANIA ROSTRATA*

Soil Microbiology Department

Greenhouse. During 1986 DS, the effects of spraying the stem of *S. rostrata* with *Rhizobium* — with different concentrations of gum arabic as a sticking agent, soil, and crushed nodule suspension — on the nodulation, N_2 fixation, and plant biomass of *S. rostrata* grown in flooded and nonflooded soils were studied. A streptomycin-and

Table 1. Azolla and sesbania green manure as biofertilizers for lowland rice, IRRI, 1985 WS-1986 DS.

Crop	Season and dates	Variety	N input[a] (kg/ha)			Grain yield (t/ha)			
			Urea	Azolla	Sesbania	No N	Urea	Azolla	Sesbania
1st	1985 WS (9 May - 20 Aug)	IR54	50	26	74	4.6	5.5	4.8	6.0
2d	1986 DS (23 Oct 1985 - 10 Feb 1986)	IR54	50	96	64	4.0	5.2	6.1	5.6
3d	1986 WS (6 Jun - 26 Sep)	IR54	50	87	79	4.9	5.9	6.4	6.3

[a]N input by sesbania roots was not included.

Table 2. Effect of inoculating *Rhizobium* ORS571 by soil, seed, and stem spray and by stem spray alone on root and shoot nodules of *Sesbania rostrata* at 40 d after emergence (DE). IRRI, 1986.

Treatment	Nodules (no./plant)					
	Flooded soil			Nonflooded soil		
	Root	Shoot	Total	Root	Shoot	Total
Control	17	0	17	26	0	26
Stem inoculated	23	45	68	27	63	90
Soil, seed, and stem inoculated	29	49	78	36	58	94
SE	3	2	4	2	4	4

Table 3. Effect of inoculating *Rhizobium* ORS571 on acetylene-reducing activity (ARA) of *S. rostrata* at 40 DE. IRRI, 1986.

Treatment	ARA (μmol C_2H_4/plant per h)					
	Flooded soil			Nonflooded soil		
	Root	Shoot	Total	Root	Shoot	Total
Control	5.0	0.2	4.4	4.7	0.5	4.6
Stem inoculated	10.9	5.4	15.4	10.6	8.2	18.6
Soil, seed and stem inoculated	16.0	7.6	23.2	12.6	12.9	25.2
SE	0.5	0.3	1.0	0.4	0.9	1.3

spectinomycin-resistant mutant from *Rhizobium* strain ORS571 was grown in tryptone glucose yeast extract broth for 48 h and was suspended in sterile water with or without gum arabic at a final density of about 10^8 cells/ml. A soil suspension was prepared by homogenizing 10 g of wet soil (dry weight basis) into 100 ml of sterile water, and a nodule suspension was prepared by crushing 0.25 g of fresh stem nodules (dry weight basis) from *S. rostrata* into 100 ml of sterile water. Soil and nodule suspensions contained about 10^5 and 10^8 most probable number/ml of *Rhizobium*, respectively. Each plant received about 5 ml of one of the bacterial suspensions at 30 DE.

Significant differences among treatments were found in nodule number, nodule dry weight, N_2-fixing activity (acetylene-reducing activity [ARA]), and total plant biomass. *Rhizobium*-inoculated plants had more nodules and higher ARA when grown under nonflooded conditions than plants grown under flooded conditions. On the other hand, the total biomass of plants grown under flooded conditions was higher. A 40% suspension of gum arabic produced the most stem nodules, the highest dry weight, and the highest N_2 fixation and plant biomass. In this experiment, several of the uninoculated plants also produced delayed and infrequent nodules. Almost all of the stem nodules in control plants contained antibiotic-resistant *Rhizobium*, suggesting natural infestation from the inoculated plants. The exact mechanism of this infestation is not yet known, but it might occur through wind, humidity, or insects.

Field experiment. As the greenhouse experiment showed, stem nodules are formed by aerial inoculation of *Rhizobium*. Inoculation by spraying the aerial portion is much easier than soil inoculation.

Natural infection from a stem nodule-bearing plant to a nonbearing one may be easy. To test the feasibility of stem spray inoculation, 2,000 m^2 of upland field were grown with *S. rostrata* without stem nodules and were spray-inoculated twice with *Rhizobium* strain ORS571 with 40% gum arabic. About the same area was grown with uninoculated sesbania as a control. Profuse nodulation occurred within 7-10 d of spraying, with significant nitrogenase activity (Table 4).

Spontaneous stem nodulation was observed in the uninoculated field, probably enhanced by the onset of rain. Spontaneous stem nodulation was difficult and infrequent during DS.

RESPONSE OF *SESBANIA ROSTRATA* TO INOCULATION METHOD AND SOIL TYPE

Multiple Cropping Department

A pot experiment where inoculation treatments were studied in a randomized complete block design was conducted with four replications. Factors studied were soil type and inoculation method. The soil media — all from the Philippines — were clay loam from IRRI (Los Baños); clay from Cavinti, Laguna; and sandy loam from Guimba, Nueva Ecija.

Total dry matter yield (TDMY) and N accumulation per plant with Los Baños and Guimba soils

Table 4. Effect of stem spray inoculation of *Rhizobium* strain ORS571 on nodule dry weight and N_2 fixation (acetylene reduction) in *S. rostrata* grown in the field. IRRI, 1986.

Treatment[a]	Nodule dry weight (g/plant)	Acetylene-reducing activity	
		Acetylene (µmol/plant per h)	Acetylene (µmol/g dry weight of nodules per h)
First spray			
Control (uninoculated)	0.06	2.4	40.0
Stem (spray) inoculated	0.26**	14.4**	55.3
Second spray			
Control (uninoculated)	0.04	1.5	38.9
Stem (spray) inoculated	0.81**	56.3**	69.5**

[a]First and second sprays were at 90 and 110 DE. Nodule weight and nitrogenase activity were recorded at 15 and 35 d after first and second inoculation.

were comparable and were significantly higher than those obtained with Cavinti soils (Table 5). Seed and stem inoculation yielded significantly higher TDMY and N accumulation over the seed or stem inoculation methods or uninoculated treatments. However, because of the variable responses of soil media, a significant interaction between soil type and inoculation method was observed.

Plants in Los Baños and Guimba soils had higher ARA than those in Cavinti soil (Fig. 1). However, the pattern and extent were similar to effects observed for TDMY and N accumulation. The lower ARA response in Cavinti soil was probably associated with pH (4.8) lower than that in Los Baños (6.2) or G[illegible]ba (6.4).

TIME OF *SESBANIA ROSTRATA* INCORPORATION

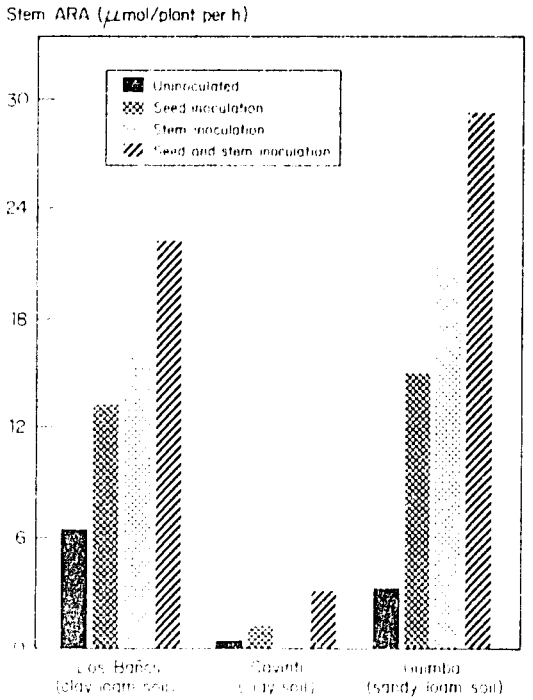
Multiple Cropping Department

The effect of *Sesbania rostrata* incorporation on the performance of the following rice crop was studied in experiments in three farmers' fields in an irrigated rice-growing area in Solana, Cagayan, Philippines. Sesbania was grown and incorporated at three crop ages. Those treatments were compared with a fallow period preceding the rice crop.

Table 5. Total dry matter yield (TDMY) and N accumulation of *S. rostrata* at 30 d after emergence as affected by inoculation method and soil type. IRRI, 1985 WS.

Inoculation method	TDMY (g/plant)				N accumulation (mg/plant)			
	Cavinti	IRRI	Guimba	Mean	Cavinti	IRRI	Guimba	Mean
No inoculation	0.25	1.20	1.37	0.94	5.55	37.81	39.67	27.68
Seed inoculation	0.28	1.12	1.74	1.04	9.30	40.00	57.31	35.53
Stem inoculation	0.25	1.37	1.60	1.07	5.75	49.33	56.44	37.17
Seed and stem inoculation	0.68	1.88	1.45	1.34	21.88	59.08	53.95	44.97
Mean	0.37	1.39	1.54	1.10	10.62	46.56	51.84	36.34

Source of variation	*df*	*Mean square values*	
Replications	3	0.015	0.008
Treatments	11	7.094**	0.879**
Soil media (S)	2	6.546**	0.805**
Inoculation (I)	3	0.344**	0.060**
S × I	6	0.204**	0.014*
Error	33	0.007	
CV (%)		7.5	21.7



1. Nitrogen fixation in stem nodules of *Sesbania rostrata* inoculated with ORS 571 at 45 d after emergence, IRRI, 1985 WS. ARA = acetylene-reducing activity.

during which the weed population was allowed to grow and was incorporated at rice transplanting. This treatment also received 40 kg N/ha as urea.

The biomass accumulation of the sesbania incorporated at 45 DE was similar to that of the weedy fallow (Table 6), while incorporation at 65 DE produced more than double the biomass.

Progressively later incorporation times of sesbania increased tiller number (Table 7). Plant height tended to increase, but the effect was not significant. Grain yields were not significantly affected by sesbania incorporation time.

Table 6. Biomass accumulation of *S. rostrata* and fallow weed vegetation before incorporation for rice production in irrigated farmers' fields. Solana, Cagayan, Philippines, 1986 WS.

Treatment	Dry biomass (t/ha)
Sesbania incorporation at 65 DE	7.6
Sesbania incorporation at 55 DE	5.5
Sesbania incorporation at 45 DE	3.2
Weeds + 40 kg N/ha	3.6

Table 7. Effect of *S. rostrata* incorporation on the following rice crop in irrigated farmers' fields. Solana, Cagayan, Philippines, 1986 WS.

Treatment	Grain yield (t/ha)	Tillers (no./hill)
IR36		
S. rostrata incorporation at 65 DE	2.5	17.6
S. rostrata incorporation at 55 DE	3.0	15.2
S. rostrata incorporation at 45 DE	1.9	13.6
Weeds + 40 kg N/ha	3.1	11.5
BPI-10		
S. rostrata incorporation at 65 DE	2.6	13.5
S. rostrata incorporation at 55 DE	3.1	14.3
S. rostrata incorporation at 45 DE	3.6	13.5
Weeds + 40 kg N/ha	3.2	11.5
Analysis of variance		
Variety	*	ns
Time of incorporation	ns	**
Variety × time	ns	ns

EFFECT OF COWPEA RESIDUE INCORPORATION ON RICE YIELD AND NITROGEN UPTAKE

Rice Farming Systems Program

The effect of cowpea residue incorporation into the soil on succeeding rice was evaluated with different N rates. Cowpea cultivar IT82D-889 was dibbled into untilled lowland rice fallow on 23 Dec 1985 and harvested on 14 Mar 1986; per hectare, it produced 1.0 t grain and 2.3 t stover containing 54 kg N/ha, which was incorporated in the soil after harvest. IR64 was transplanted on 1 Apr. Two-thirds of the N was incorporated at 1 DBT and one-third at PI. Cowpea residue incorporation increased rice yield and N uptake (Table 8).

EFFECT OF INCORPORATION OF RICE STRAW, AZOLLA, AND *SESBANIA ROSTRATA* ON NH_4^+-N IN FLOODED SOILS

Soils Department

We studied the effect of incorporating rice straw, azolla, and *Sesbania rostrata* on the NH_4^+-N release pattern in flooded soils in the greenhouse. One soil had high organic matter (OM) content while three others had low OM (Table 9). Organic substrates (Table 10) were added at a N equivalent

Table 8. Grain yield and N uptake by rice as affected by cowpea residue incorporation and N rate.[a] IRRI, 1985-86.

Treatment (kg N/ha)	Grain yield (t/ha)		N uptake (kg/ha)	
	Fallow	Residue incorporated	Fallow	Residue incorporated
0	3.5 c	4.5 c	36.2 c	50.8 c
30	4.0 bc	4.5 c	41.3 bc	50.3 c
60	4.6 b	5.7 b	49.3 b	66.1 b
90	6.0 a	6.4 a	70.7 a	80.0 a
120	6.3 a	6.7 a	74.7 a	87.2 a

[a] LSD (0.05) = 0.8 t/ha for grain yield and 11.7 kg/ha for N uptake.

rate of 116 kg/ha, both in the presence and in the absence of rice plants (IR36).

The results confirmed earlier findings on a Haplaquoll (Annual report for 1985) that rice straw addition causes net immobilization of N in all soils, independent of their C or N content (Fig. 2).

The same N equivalent of azolla released less N than sesbania despite its lower C:N, perhaps because of the higher lignin content of azolla.

The kinetics of NH_4^+-N after straw incorporation was also studied in a field experiment at IRRI with IR29723-88-2-3-3. The soil was a Tropaquept (clay, pH 6.2, organic C 1.6%, N 0.15%, cation exchange capacity [CEC] 350 mmol/kg). The soil was presubmerged for 3 wk. Straw was applied to the floodwater and incorporated at 2 DBT.

Table 10. Chemical analysis of organic materials.

Organic matter	Air-dry weight (%) of			C:N
	N	P	K	
Sesbania rostrata	3.81	0.22	3.23	11
Azolla microphylla	4.25	0.26	2.09	9
Rice straw	0.64	0.07	1.85	62

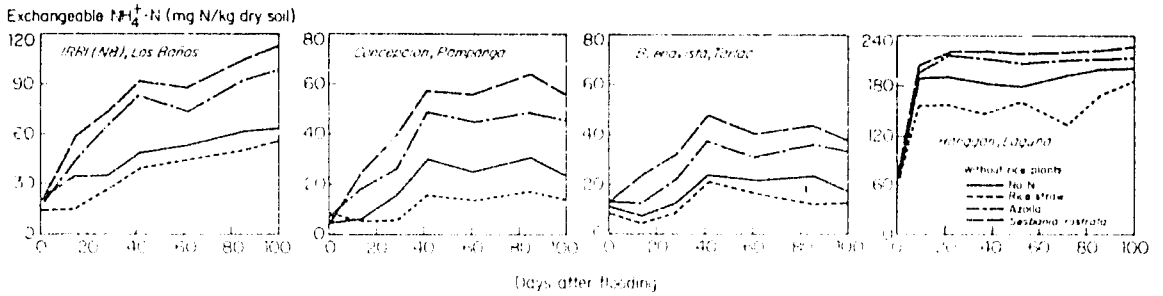
The kinetics of NH_4^+-N was similar to that in the pot experiments, but in the field experiment we detected no net immobilization; instead, there was an increased release of NH_4^+-N at the end of the season (Fig. 3, 4). Placing the straw in the floodwater for 3 wk before incorporation might have caused both effects. The NH_4^+-N flush occurred too late to benefit the rice crop.

The NH_4^+-N kinetics in the floodwater showed the same pattern as in the soil solution. The highest concentration of NH_4^+-N was found in the topsoil (Fig. 3b) during the first 20 d after flooding. In general, the concentration of NH_4^+-N in the soil solution was low. The pattern of exchangeable NH_4^+-N (Fig. 4) reflects the N dynamics most clearly, with peak concentrations after flooding, at PI (because of topdressing), and at ripening. The fact that topdressing of urea had hardly any effect on the NH_4^+-N concentration in the soil solution was related to the high CEC and high plant uptake.

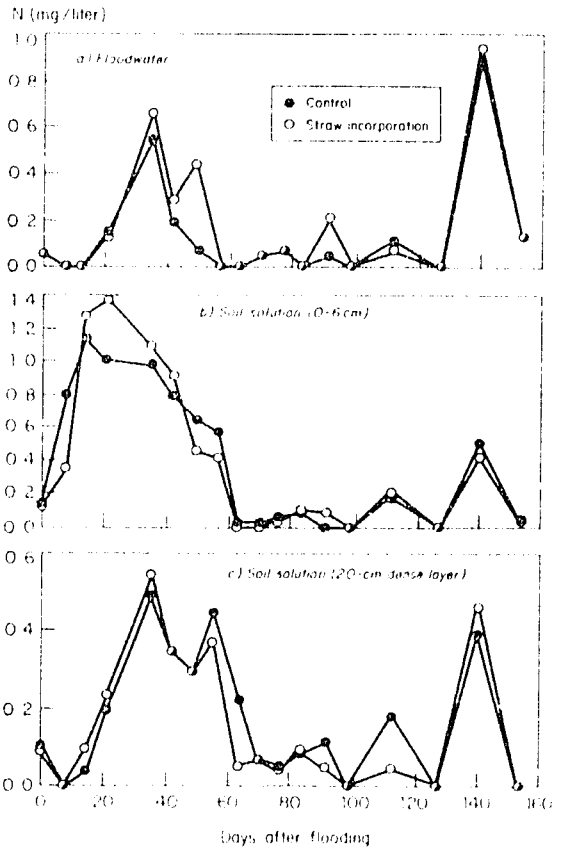
No significant difference was found in grain yields (4.3-4.5 t/ha).

Table 9. Characteristics of the Philippine experimental soils (0 15 cm).

Soil characteristic	IRRI (N8), Los Baños	Buenavista, Tarlac	Concepcion, Pampanga	Hanggan, Laguna
pH (1:1)	6.2	7.3	5.7	6.8
Organic C (%)	1.2	0.45	0.53	3.6
Total N (%)	0.12	0.04	0.05	0.30
CEC (mmol/kg)	323	94	48	448
Exchangeable K (mmol/kg)	10.1	1.4	2.3	8.4
Olsen P (mg/kg)	29	14	27	13
Available Zn (mg/kg)	0.32	2.3	4.5	0.57
Total Fe (%)	6.9	2.1	1.5	5.3
Total Mn (%)	0.144	0.084	0.031	0.117
Sand (%)	16	56	73	12
Silt (%)	42	35	19	37
Clay (%)	42	9	8	51
Texture	Silty clay	Sandy loam	Sandy loam	Clay



2. Changes in exchangeable soil NH_4^+-N in 4 flooded soils as affected by incorporation of rice straw, azolla, and *Sesbania rostrata*. IRRI greenhouse, 1986.



3. Effects of rice straw incorporation on NH_4^+-N kinetics. IRRI, 1986.

EFFECT OF LONG-TERM RICE STRAW AMENDMENTS ON RICE GRAIN YIELD

Soils Department

The long-term experiments on straw amendments continued. Straw application increased rice grain yields in Block L2 (Table 11) in both DS and wet season (WS). At all other sites, no differences in grain yield were detected except for the straw compost treatment in Block L3 (Table 12).

WEED INCORPORATION IN FLOOD-PRONE RAINFED LOWLAND RICE

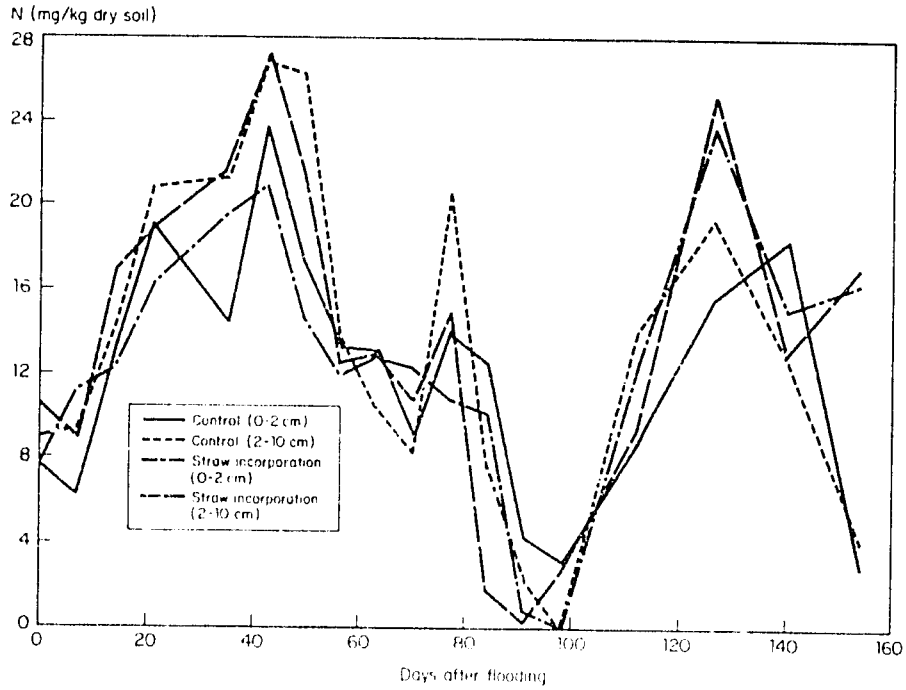
Multiple Cropping Department

In many rainfed lowland rice areas, large amounts of weed biomass accumulate during the fallow period between DS and WS.

We evaluated the effect of weed incorporation on the growth and yield of two rice cultivars under flood-prone rainfed lowland conditions on an alluvial terrace of the Cagayan River. Before the experiment was established, the average growth of weeds on adjacent weedy fields was determined and analyzed for N content and other elements (Table 13). Soil N content was low, while P was high (Table 14).

The average amount of fresh weed biomass observed before transplanting — 22 t/ha — was the basis for incorporation: W1 was the base amount, W2 was double the average, and W3 was 5 times the base amount applied. In the W0 treatment, all surface weed biomass was removed. Urea fertilizer at 0, 30, or 60 kg N/ha was applied and incorporated at transplanting. These rates were compared with weed application alone or in combination with urea N.

The weed biomass contained 1.2% N (dry weight basis) for a total of more than 40 kg N present in the weed biomass. A flash flood of 75 cm depth submerged the crop for 5 d at 1 mo after trans-



4. Effects of rice straw incorporation on the kinetics of exchangeable NH_4^+-N. IRRI, 1986.

Table 11. Effects of water regime in combination with straw amendments on the mean yield of 3 varieties (IR36, IR62, and IR64) on a Tropaquept. IRRI, Block L2, 1986 DS and WS.

	Grain yield (t/ha)			
	Dry season (28th crop)		Wet season (29th crop)	
	No straw	With straw	No straw	With straw
Dry fallow	2.9	3.4**	2.8	3.3*
Dry fallow + mid-season drainage	2.8	3.2**	2.9	3.2*
Flood fallow + mid-season drainage	3.6	3.7 ns	2.7	2.9*

planting (Fig. 5). Floodwater stagnated in the field at 10 cm depth for 2 mo following submergence, causing low yields.

Weed incorporation consistently increased the number of tillers and plant vigor at 30 d after the flood (Table 15). The yield increased with higher rates of weeds (Fig. 6). N applied in combination with weeds showed a very modest increase in yield

Table 12. Effect of 4 straw treatments on the mean grain yield of 3 varieties (IR36, IR56, and IR64) on a Tropaquept. IRRI, Block L3, 1986 DS and WS.

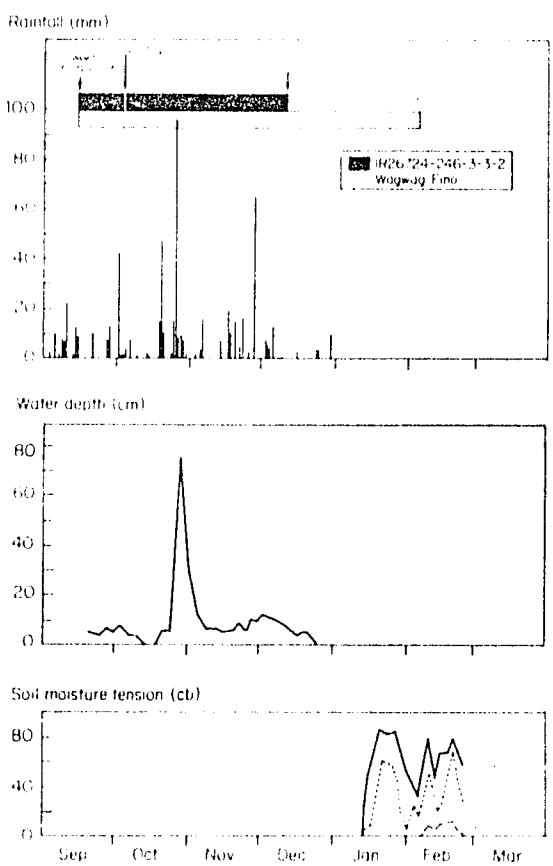
Treatment	Grain yield (t/ha)	
	Dry season (28th crop)	Wet season (29th crop)
Straw removed	2.8 b	2.7 a
Straw burned	2.9 b	2.8 a
Long straw added	3.0 b	2.9 a
Straw compost added	3.5 a	2.9 a

Table 13. Chemical analysis of weed samples incorporated. Solana, Cagayan, Philippines, 1985 WS.

Weed chemical property	Content
Major elements (%)	
N	1.21
P	0.30
K	1.90
Mg	0.30
Ca	0.53
Minor elements	
Cu (ppm)	5.40
Mn (ppm X 10^2)	4.47
Zn (ppm)	50.00
Fe (%)	0.37
SiO_2 (%)	6.03

Table 14. Textural and chemical analysis of soil samples and chemical analysis of weed samples at the experimental site. Stratum 3, Solana, Cagayan, Philippines, 1985 WS.

Soil property	Content at soil depth of 0-15 cm	15-30 cm	Interpretation
Soil texture (%)			Clayey
Clay	60	61	
Silt	38	36	
Sand	2	3	
Chemical			
pH (1:1 wt/vol H_2)	6.3	6.6	Slightly acid
Organic C (%)	1.5	1.0	Low
Total N (%)	0.10	0.07	Low
CEC (meq/100 g air-dried soil)	44.1	44.4	Very high
Available P (ppm air-dried soil)	30.1	10.1	Very high
Available Zn	0.26	0.09	Deficient



5. Rainfall, surface hydrology, and soil moisture tension during the growing period of rainfed rice after weed incorporation, IRRI, 1986. F = flowering.

above the same treatment with weed incorporation alone. The effect of 30 kg N was equivalent to that of incorporating the fallow weed vegetation (i.e., W1). Yields were highest with the incorporation of 5 times the average observed amount of fallow weed biomass (W3); yield was 0.8 t/ha higher than on W0 plots and about 40% higher than in W2 plus 30 kg N/ha (Fig. 6). The results suggest that OM incorporation can play a positive role in rice recovery from submergence and in yield performance under flood-prone conditions.

INTEGRATED NITROGEN MANAGEMENT IN LOWLAND RICE

Agronomy Department

We continued to evaluate supplementary N fertilizer sources in the eighth (DS) and ninth (WS) consecutive crops at IRRI (Table 16) and in a farmer's field in Victoria, Laguna (Table 17).

Azolla, fresh rice straw, and rice straw compost at both sites were superior to the control. Similar results were obtained with sesbania and soybean as green manure at IRRI. In DS in the farmer's field and in WS at IRRI, azolla performed better than fresh rice straw and rice straw compost.

At IRRI, azolla, rice straw compost, and soybean in DS were comparable to prilled urea (PU) but inferior to urea supergranules (USG). But in WS, azolla and sesbania were as effective as USG. In the farmer's field, only azolla was comparable to PU in both seasons.

Combined applications of organic sources with PU or USG consistently gave better yields than did the control. The yields were comparable to that with PU and in many cases with USG placement. At IRRI in DS, azolla with USG performed better than PU alone.

MINERAL SOLUBILITY RELATIONSHIPS IN A CONTINUOUSLY FLOODED ZINC-DEFICIENT SOIL

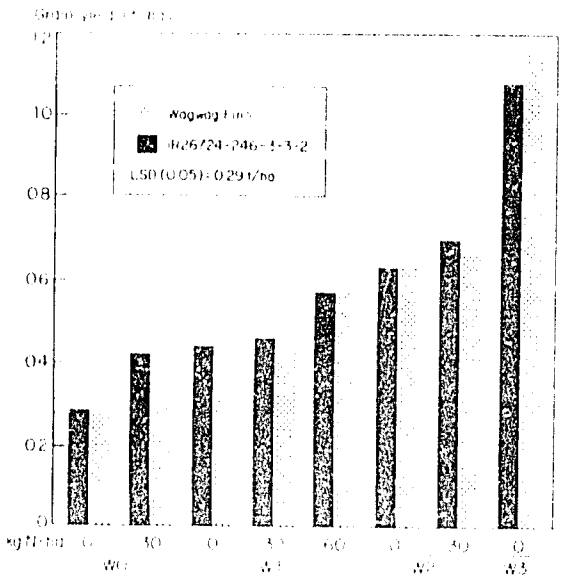
Soils Department

To gain a better understanding of the mineral phases that may be important in the control of Zn in soil solutions of Zn-deficient soils, a laboratory experiment was conducted using Lipa clay loam (Typic Hydraquent) from the IRRI Zn screening site in Bay, Laguna. This soil is noncalcareous with

Table 15. The effect of amount of weed incorporated and rate of N on tillering and vigor at 30 d after flooding, plant height at harvest, and number of panicles/m² on 2 cultivars. Solana, Cagayan, Philippines, 1985 WS.

Treatment[a]	Tillers (no.) 30 d after flood		Plant vigor[b] 30 d after flood		Plant height (cm) at harvest		Panicles (no./m²)	
	IR26724-246-3-3-2	Wagwag Fino	IR26724-246-3-3-2	Wagwag Fino	IR26724-246-3-3-2	Wagwag Fino	IR26724-246-3-3-2	Wagwag Fino
W0 N0	5.3	7.3	5.3	6.7	70	80	133	118
W0 N30	4.3	7.3	5.7	4.7	64	91	158	116
W1 N0	5.7	103	4.6	5.0	71	84	169	140
W1 N30	4.3	10.0	5.0	5.0	67	91	154	173
W1 N60	6.7	8.0	4.0	5.0	81	96	183	176
W2 N0	7.0	13.7	4.7	4.7	78	89	189	169
W2 N30	9.0	10.3	4.0	3.7	82	93	186	190
W3 N0	11.0	13.3	1.7	2.3	89	105	209	219

[a]W0 = weed biomass removed, W1 = base amount (22 t/ha), W2 = amount double the average, W3 = amount 5 times the base, N0 = no N, N30 = 30 kg N/ha, N60 = 60 kg N/ha. [b]1 = extra vigorous, 9 = poor.



6. Effects of amount of weeds incorporated and rate of N on the grain yield of 2 cultivars. Solana, Cagayan, Philippines, 1985 WS. For weed incorporation levels, see Table 15.

Table 16. Effect of supplementary N fertilizer source on grain yield of IR64. IRRI, 1986.

N source[a]	Grain yield[b] (t/ha) Dry season (8th crop)	Wet season (9th crop)
No fertilizer N (control)	3.5 f	2.8 e
Single sources		
PU, BS	5.5 bcd	3.9 abc
USG	6.3 a	4.2 a
Fresh azolla, soil incorporated	5.0 de	4.1 a
Fresh rice straw, soil incorporated	4.7 e	3.5 cd
Rice straw compost, soil incorporated	5.1 cde	3.3 d
Fresh sesbania, soil incorporated	5.4 bcd	4.0 ab
Combined sources[c]		
Fresh azolla + PU, BS	5.5 bcd	3.6 bcd
Fresh rice straw + PU, BS	5.7 abc	4.2 a
Rice straw compost + PU, BS	5.4 bcd	4.0 ab
Fresh azolla + USG	6.2 a	3.5 cd
Fresh rice straw + USG	6.0 ab	4.1 a
Rice straw compost + USG	5.9 ab	3.6 bcd

[a]PU = prilled urea, BS = best split, USG = urea supergranules. All treatments applied at equal N rates: 116 kg N/ha in DS and at 58 kg N/ha in WS. For BS application, 2/3 urea was broadcast and incorporated (B&I) at planting and 1/3 topdressed at 5-7 d before panicle initiation (DBPI). In DS, sesbania was replaced by soybean. [b]CV = 8% in DS and 7% in WS. [c]For combined applications, 58 kg N/ha in DS and 29 kg N/ha each of organic and inorganic sources in WS.

pH 7.3, 3.6% organic C, 0.34% N, CEC 50 meq 100 g, 80 mg total Zn kg, and 0.4 mg available Zn kg. Samples of saturated soil were placed in 3-liter pots and maintained in a continually wet condition at 25 ± 2 °C. Treatments were a control and the following, each per kilogram of soil: 300 mg soil P as KH_2PO_4, 500 mg S as K_2SO_4, 5 g freshly precipitated $Fe(OH)_3$, 1.5 g freshly precipitated FeS, 10 g hydrated silica, and 50 g finely divided $CaCO_3$ (calcite). The treatments were repeated with and without 40 mg Zn as $ZnSO_4$. Samples for solution analysis were obtained at 7, 23, 42, 71, and 87 d after treatment.

The $Fe(OH)_3$, FeS, silica, and calcite treatments had little or no effect on Zn and most other soil

Table 17. Effect of supplementary N fertilizer source on grain yield of IR64. Victoria, Laguna, Philippines, 1986.

N source[a]	Grain yield[b] (t/ha)	
	Dry season (8th crop)	Wet season (9th crop)
No fertilizer N (control)	4.6 f	3.2 d
Single sources		
PU, BS	6.7 abc	4.1 ab
USG	7.2 a	4.2 a
Fresh azolla, soil incorporated	6.7 abc	3.8 bc
Fresh rice straw, soil incorporated	5.8 de	3.6 c
Rice straw compost, soil incorporated	5.6 e	3.6 c
Combined sources[c]		
Fresh azolla + PU, BS	6.0 cde	4.1 ab
Fresh rice straw + PU, BS	6.4 bcd	4.1 ab
Rice straw compost + PU, BS	6.6 abc	3.9 abc
Fresh azolla + USG	6.8 ab	4.1 ab
Fresh rice straw + USG	6.3 bcde	4.2 a
Rice straw compost + USG	6.7 abc	4.0 ab

[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 B&I at planting and 1/3 topdressed at 5-7 DBPI. [b]CV is 7% in DS and 5% in WS. [c]For combined applications, 58 kg N/ha in DS and 29 kg N/ha each of organic and inorganic sources in WS.

solution components. The calculated mineral solubility saturation indices, log IAP/Ksp (IAP = ion activity product), for day 42 (Table 18), however, show that the silica treatment raised the silica concentration to equilibrium with amorphous silica, and the PO_4^{3-} addition increased the oversaturation with respect to vivianite and hydroxy-apatite. The undersaturation with respect to calcite in the $CaCO_3$ treatment may be a reflection of a small (0.1 unit) underestimation of the pH.

The addition of SO_4^{2-} was accompanied by a very significant addition of K^+, which resulted in the displacement of Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+}, and Na^+ from the exchange complex, increasing the solution concentrations of these ions. Ca^{2+} and Mg^{2+} accounted for most of the increase. After 42 d, the SO_4^{2-} treatment still had Ca^{2+} equal to three times that of the other treatments. The concentration of Fe^{2+} decreased much more rapidly and by day 71 was the same as in the other treatments. Because no fresh organic matter was added, SO_4^{2-} reduction to S^{2-} was very slow, with about half of the added SO_4^{2-} reduced by day 42. There was no measurable additional accumulation of S^{2-} in the SO_4^{2-} treatment. The high degree of oversaturation with respect to precipitation of PO_4^{3-}, S^{2-}, and some of the CO_3^{2-} minerals (Table 18) appears to be maintained indefinitely. Lack of crystallinity of the mineral phases may contribute to the oversaturation with respect to well-crystalline solids, but blockage of crystal growth sites by organic and other anions may also contribute to the oversaturation. The high oversaturation with respect to ZnS (wurtzite) may reflect the difficulty in forming a separate phase in a system low in total Zn.

Table 18. Saturation indices (log IAP/K_{sp}) of CO_3^{2-}, PO_4^{3-}, and S^{2-} mineral phases and amorphous silica in a continuously flooded Zn-deficient soil 42 d after treatment. Bay, Laguna, Philippines, 1986.

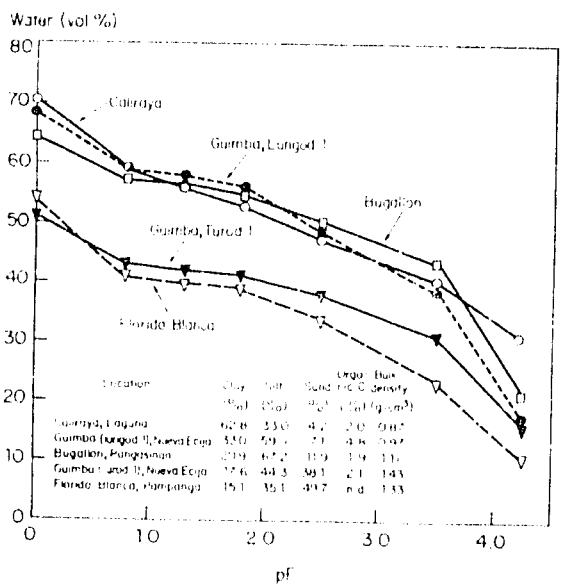
Treatment	Solution pH	Saturation index							
		Calcite $CaCO_3$	Siderite $FeCO_3$	Rhodochrocite $MnCO_3$	Vivianite $Fe_3(PO_4)_2 \cdot 8H_2O$	Hydroxy-apatite $Ca_5OH(PO_4)_3$	Troilite FeS	Wurtzite ZnS	Amorphous silica $SiO_2 \cdot nH_2O$
Control	6.87	−0.20	1.0	0.4	2.6	4.04	1.2	4.2	−0.14
PO_4^{3-}	6.86	−0.13	0.7	0.4	4.0	7.98	0.8	3.6	−0.04
PO_4^{3-} + Zn	6.80	−0.33	0.4	0.2	3.7	7.78	0.3	3.5	−0.02
SO_4^{2-}	6.84	0.13	1.1	0.7	2.3	4.87	1.3	4.3	−0.18
SO_4^{2-} + Zn	6.84	0.10	1.0	0.6	2.1	4.79	1.0	4.0	−0.19
$Fe(OH)_3$	7.13	−0.06	1.2	0.4	2.4	3.79	1.4	4.5	−0.25
$Fe(OH)_3$ + Zn	7.12	−0.06	1.2	0.6	1.8	3.70	1.1	4.5	−0.29
FeS	6.95	−0.21	0.9	0.4	2.4	4.20	1.2	4.4	−0.20
FeS + Zn	7.01	−0.09	1.0	0.4	2.7	4.51	1.1	4.4	−0.22
Silica	6.87	−0.20	1.0	0.4	2.8	4.38	1.1	4.3	−0.03
Silica + Zn	6.99	−0.06	1.2	0.6	3.2	4.89	1.2	4.5	−0.03
$CaCO_3$	6.86	−0.17	1.0	0.4	2.3	3.90	1.1	4.1	−0.17
$CaCO_3$ + Zn	6.78	−0.22	1.0	0.4	2.4	3.43	0.9	4.2	−0.18

These results demonstrate that silica, $CaCO_3$, FeS, and $Fe(OH)_3$ have little direct effect on soil solution Zn and most other soil solution ions. In continually flooded neutral and alkaline soils, Zn is likely controlled by formation of a S^{2-} phase — possibly a mixed phase with Fe^{2+}.

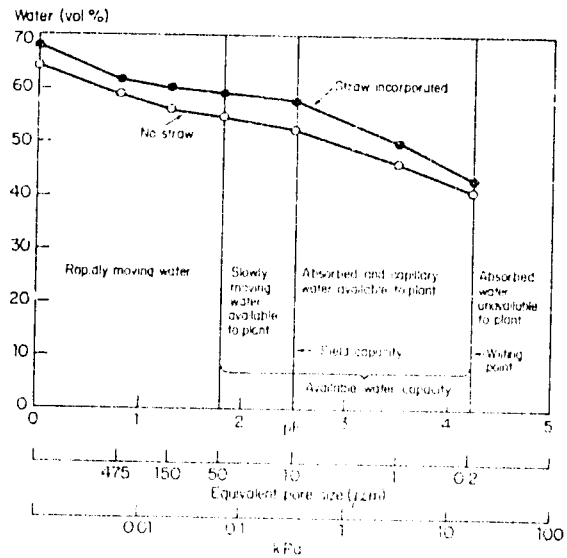
EFFECT OF ORGANIC AMENDMENTS ON SOIL WATER SUCTION

Soils Department

The effect of organic amendments on pore size pattern and soil water retention was investigated in long-term experiments at the IRRI farm. Water retention curves describing the pore size distribution of various characteristic Philippine soils are given in Figure 7. Straw amendments since 1973 in a dry fallow - rice - rice cropping system in Block L3 increased the available water capacity



7. Characteristic water retention curves of Philippine rice soils.



8. Effect of rice straw incorporation on water retention curves, Tropaquept, IRRI L3, 1986.

from 33.5 to 41.9 mm for the first 25 cm of the profile (Fig. 8)

Total porosity reached 70% for OM-treated soils, with a bulk density of 0.84 g/cm^3, while the control had 65% OM and 0.89 g/cm^3 bulk density. The increase at pF 4.2 might have been caused by colloidal organic matter with its high specific surface and water-holding properties. The effect of bulk density becomes evident when expressing changes in weight % rather than volume %.

$$\% \text{ (cm}^3/\text{cm}^3) = (\text{g/g}) \times \text{bulk density}_{soil}/\text{density}_{water}$$

The change of 2.5 volume % is equivalent to 12.7 weight %.

In a long-term experiment in Block UB4, where upland crops follow rice, no differences in the water retention curves were found when the means of all residue treatments were compared with those of all nonresidue plots.

The mechanism for the different results in Blocks UB4 and L3 still needs elucidation.

Soil and crop management

Management of other nutrients

Agronomy Department

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P-ADSORPTION ISOTHERMS OF THREE P-DEFICIENT ACID SOILS

Acidic and P-deficient surface soils (20 cm) were collected from 3 sites in the Philippines — Iloilo, Claveria, and Caliraya — and tested for P-adsorption isotherms. The soil from Iloilo was acid sulfate under lowland conditions. The two other soils were developed under upland conditions from volcanic ash. Some chemical and other characteristics of the soils are given in Table 1.

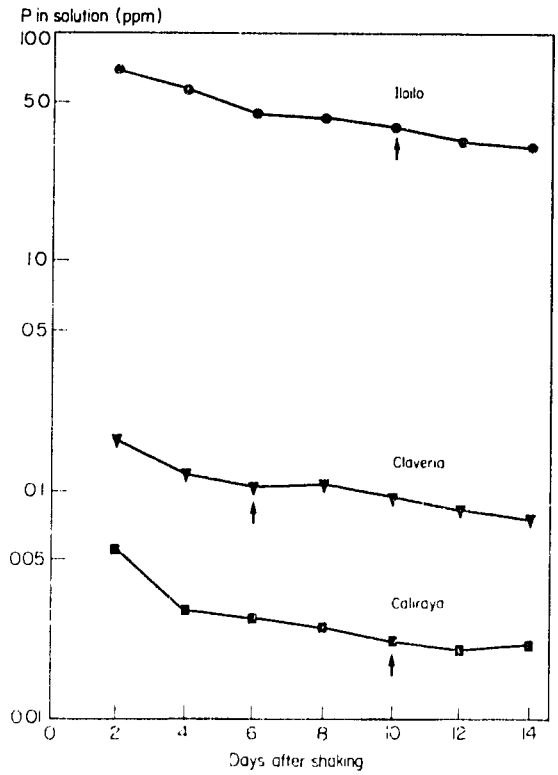
The Claveria soil needed 6 d to equilibrate with P added, while the Iloilo and Caliraya soils needed up to 10 d (Fig. 1).

There were large differences in P-sorption among the three soils (Fig. 2). Adsorption of P by Iloilo soil was lower than by Claveria and Caliraya soils, possibly because Iloilo soil had the least clay and active Fe contents. The soils studied had different P fixation capacities: medium for Iloilo, high for Claveria, and very high for Caliraya.

Table 1. Properties of 3 P-deficient, acid soils, Philippines.

Soil property	Iloilo	Claveria	Caliraya
pH: H_2O (1:1)	3.90	3.92	4.62
0.01 M $CaCl_2$ (1:1)	3.54	3.76	3.98
1 N KCl (1:1)	3.46	3.73	3.70
Organic C (%)	1.26	2.02	2.79
Total N (%)	0.098	0.184	0.269
C:N	14.00	11.00	10.00
Exchangeable bases (meq/100 g)[a]			
Na	0.038	0.010	0.089
K	0.079	0.132	0.162
Mg	0.430	0.260	0.660
Ca	0.910	0.650	0.650
Total exchangeable bases (meq/100 g)[a]	1.457	1.052	1.561
CEC (meq/100 g)[a]	6.0	13.0	20.0
Total P (ppm)	276	986	704
Available P (ppm)[a]			
Bray II	14	9	4
Olsen	10	5	1
Active Fe (%)	1.9	5.5	4.3
Active Mn (%)	0.058	0.280	0.190
Particle size (%)			
Clay	31	65	74
Silt	33	31	22
Sand	36	4	4
Soil taxonomy	Typic Sulfaquept	Ultic Haplorthox	Orthoxic Palehumult

[a]Air-dried soil.



1. Equilibration time of Iloilo, Claveria, and Caliraya soils. IRRI, 1986. Arrows indicate calibration time.

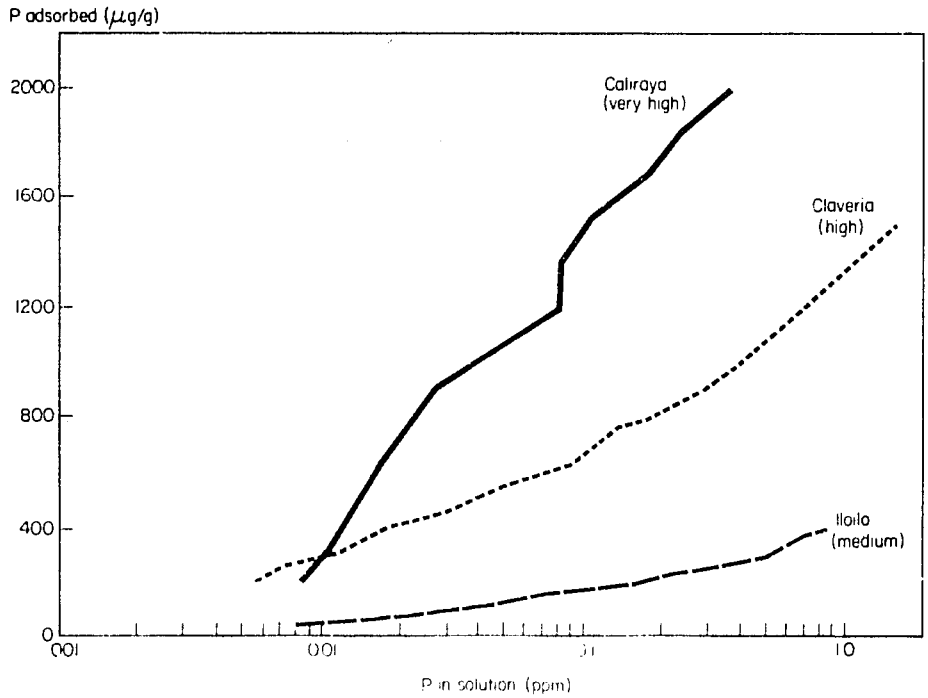
At 0.07 ppm P in solution, which is reportedly the external P requirement for rice, the P requirement is 68 kg/ha for Iloilo, 300 kg/ha for Claveria, and 575 kg/ha for Caliraya.

Field verification is needed to determine the relative P application rates needed for sustained crop growth.

POTASSIUM-ZINC INTERACTIONS IN LOWLAND RICE

Trials were continued in Bugallon and Mangatarem, Pangasinan, Philippines, in 1986 to evaluate the response to K and Zn of IR36 in the dry season (DS) and IR62 in the wet season (WS). Table 2 lists the soil properties.

On Bugallon soil (pH 6.2), Zn application alone at any rate significantly increased yield in DS (Fig. 3). Applying 20 kg Zn/ha gave yields comparable to the highest yield obtained. In WS, no significant response to Zn was recorded. K alone at



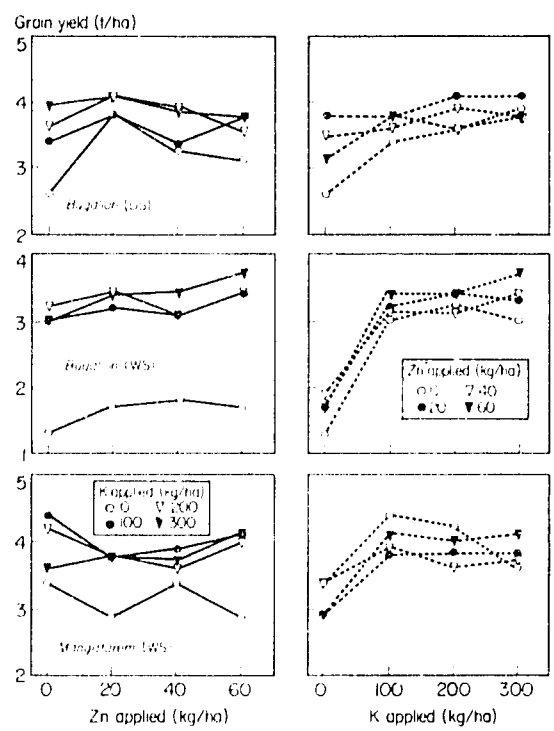
2. P-adsorption isotherms of Iloilo, Claveria, and Caliraya soils. IRRI, 1986.

100 kg/ha increased yield by 1.7 t/ha. K at 300 kg/ha with 60 kg Zn/ha significantly increased yield further.

Table 2. Properties of soils for trials on K-Zn interaction, Bugallon and Mangatarem, Pangasinan, Philippines, 1986.

Soil property	Bugallon[a]	Mangatarem[b]
pH:H_2O (1:1)	6.2	7.5
Organic matter (%)	2.6	2.1
Total N (%)	0.14	0.09
Available Olsen P (ppm)	nil	nil
Exchangeable cations (meq/100 g)		
Na	0.17	0.28
K	0.05	0.07
Mg	13	25
Ca	13	14
Ca:K	261	205
Mg:K	264	362
Ca:Mg	0.99	0.57
(Ca+Mg):K	525	568
CEC (meq/100 g)	26	37
Available Zn (ppm, Katyal and Ponnamperuma)	0.15	0.06
Texture	Loam	Silty clay

[a]Fine loamy mixed isohyperthermic Typic Haplustoll.
[b]Fine mixed isohyperthermic Aquic Haplustoll.



3. Grain yield of IR36 in DS and IR62 in WS as affected by K and Zn fertilization. Bugallon and Mangatarem, Philippines, 1986.

At Mangatarem (pH 7.5), Zn application did not increase yield (Fig. 3). K applied alone at 100 kg/ha significantly increased grain yield, but increasing the K rate to 300 kg/ha significantly decreased yield.

At both sites, yields did not significantly differ among all Zn application rates at the same K levels. Only in Bugallon in DS were yield differences among Zn levels observed. Likewise, application of K alone at any rate increased yield in both seasons.

Response to Zn and K was due to the critical soil Zn (<1.0 ppm) and K (<0.20 meq/100 g) levels. More Zn is needed if Mg levels are high (Ca/Mg <2.0) or if (Ca+Mg)/K is high. The results varied with site because of imbalances in the soil nutrients.

LONG-TERM FERTILITY TRIALS

Long-term fertility trials continued at IRRI, at three Bureau of Plant Industry (BPI) experiment stations, and in farmers' fields.

IRRI. The 44th (DS) and 45th (WS) consecutive crops were grown in irrigated plots using IR8, IR64, and IR29723-143-3-2-1. Rice virus diseases, however, damaged IR8 in both seasons.

N application significantly increased yield. P or K fertilizer applied alone or with N gave no response. IR64 and IR29723-143-3-2-1 gave highest yields with NPK application. When rice straw compost was a partial N source, yields were comparable to those when the fertilizer source was inorganic (Table 3). Thus, after 45 successive high-yielding rice crops, Maahas clay continues to provide adequate P and K, although the nutrients, particularly K, in the irrigation water may be contributory to the P and K requirements.

Bureau of Plant Industry stations. In Maligaya, the grain yield in DS from plots with applied N was significantly higher than that from the control plots. There was strong P response, with N-P interaction, but no K response (Table 4).

Yields in WS were low because of heavy rains at the crop reproductive stage.

In Bicol, IR8 was severely damaged by virus disease in both seasons. All cultivars suffered from insufficient water supply from tillering to early reproductive stages. N fertilization produced a significant yield response, but highest yields were obtained when NPK was applied (Table 5), indicating that both P and K are needed to maintain high yields on this soil.

Table 3. Effect of NPK fertilizer on yield of test rices in the long-term fertility trial. IRRI, 1986.

Fertilizer (kg/ha)			Yield[b] (t/ha)		
N[a]	P	K	IR64	IR29723-143-3-2-1	Mean
			Dry season		
0	0	0	3.0 b	4.0 b	3.5 b
140	0	0	6.0 a	6.8 a	6.4 a
0	13	0	3.4 b	3.6 b	3.5 b
0	0	25	3.3 b	3.7 b	3.5 b
140	13	0	6.2 a	7.1 a	6.6 a
140	0	25	5.9 a	6.7 a	6.3 a
140	13	25	6.4 a	7.3 a	6.8 a
140[c]	13	25	6.1 a	7.2 a	6.6 a
			Wet season		
0	0	0	2.5 c	2.0 c	2.2 d
60	0	0	4.0 ab	3.7 ab	3.8 bc
0	13	0	2.8 c	2.3 c	2.6 d
0	0	25	2.5 c	2.2 c	2.4 d
60	13	0	4.3 a	4.2 a	4.2 a
60	0	25	3.5 b	3.8 ab	3.7 bc
60	13	25	4.3 a	3.7 ab	4.0 ab
60[c]	13	25	3.7 b	3.5 b	3.6 c

[a]Includes topdressing at 5-7 d before panicle initiation (DBPI) of 40 kg N/ha in DS and 20 kg N/ha in WS. [b]Within a season, figures in a column followed by a common letter are not significantly different at the 5% level by Duncan's multiple range test (DMRT). CV = 9% for DS and 12% for WS. [c]24 kg N/ha from rice straw compost.

At the Visayas station in Iloilo, N and P but not K gave responses (Table 6).

Farmers' fields. The 20th (DS) and 21st (WS) crops in Luisiana, Laguna (Aquic Troporthent), and the 17th (DS) and 18th (WS) crops in Tanay, Rizal (Vertic Tropaquept), were grown in farmers' fields (Table 7, 8). IR64 and IR29723-143-3-2-1 were used.

In DS, IR29723-143-3-2-1 gave the highest N response (NPK vs PK) of 3.1 t/ha on Luisiana soil. In both seasons, P response (NPK vs NK) was more consistent in Luisiana than in Tanay. Response to K was obtained at both sites in WS only.

Highest yields were from NPK-treated plots.

IR29723-143-3-2-1 gave the highest yield and outyielded IR64 in WS.

In acid soil in Luisiana, the various NPK

Table 4. Effect of NPK fertilizer on yield of test rices in the long-term fertility trial. Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines, 1986.

Fertilizer (kg/ha)			Yield[b] (t/ha)		
N[a]	P	K	IR8	IR64	IR29723-143-3-2-1
			Dry season		
0	0	0	2.5 c	2.0 c	2.9 d
140	0	0	3.8 b	3.6 b	4.3 c
140	26	0	6.4 a	6.9 a	7.1 b
140	0	50	3.7 b	3.6 b	3.8 cd
140	26	50	7.0 a	6.8 a	7.8 ab
140	26	50+25	6.8 a	7.0 a	8.2 a
			Wet season		
0	0	0	2.4 b	2.3 bc	2.4 ab
70	0	0	2.5 b	1.9 c	2.1 b
70	26	0	2.4 b	3.0 ab	2.7 ab
70	0	50	2.0 b	2.4 bc	2.4 ab
70	26	50	2.8 ab	3.0 ab	3.1 a
70	26	50+25	3.3 a	3.4 a	2.9 ab

[a]Includes topdressing at 5-7 DBPI of 40 kg N/ha in DS and 30 kg N/ha in WS. [b]Within a season, figures in a column followed by a common letter are not significantly different at the 5% level by DMRT. CV = 12% for DS and 18% for WS.

Table 5. Effect of NPK fertilizer on yield of test rices in the long-term fertility trial. Bicol Experiment Station, Pili, Camarines Sur, Philippines, 1986.

Fertilizer (kg/ha)			Yield[b] (t/ha)	
N[a]	P	K	IR64	IR29723-143-3-2-1
			Dry season	
0	0	0	2.2 d	2.6 d
140	0	0	3.4 bc	4.0 c
140	26	0	4.1 abc	5.7 b
140	0	50	3.2 c	4.0 c
140	26	50	4.3 ab	6.8 a
140	26	50+25	4.6 a	6.4 ab
			Wet season	
0	0	0	2.1 b	2.2 c
70	0	0	2.4 b	3.0 b
70	26	0	3.3 a	3.8 a
70	0	50	2.0 b	2.6 bc
70	26	50	3.6 a	4.0 a
70	26	50+25	3.8 a	3.9 a

[a]Includes topdressing at 5-7 DBPI of 40 kg N/ha in DS and 30 kg N/ha in WS. [b]Within a season, figures in a column followed by a common letter are not significantly different at the 5% level by DMRT. CV = 13% for DS and 14% for WS.

Table 6. Effect of NPK fertilizer on yield of test rices in the long-term fertility trial. Visayas Experiment Station, Hamungaya, Iloilo City, Philippines, 1986.

Fertilizer (kg/ha)			Yield[b] (t/ha)		
N[a]	P	K	IR8	IR64	IR29723-143-3-2-1
			Dry season		
0	0	0	1.9 b	2.6 c	2.0 c
140	0	0	3.6 a	4.7 b	3.0 b
140	26	0	4.3 a	5.8 a	4.6 a
140	0	50	2.7 b	4.2 b	3.1 b
140	26	50	4.5 a	5.9 a	4.9 a
140	26	50+25	4.5 a	6.5 a	4.7 a
			Wet season		
0	0	0	2.6 c	3.3 c	2.8 c
70	0	0	4.1 ab	3.8 bc	3.4 bc
70	26	0	4.4 a	5.3 a	5.3 a
70	0	50	3.5 b	4.3 b	3.9 b
70	26	50	4.1 ab	5.3 a	5.3 a
70	26	50+25	4.1 ab	5.4 a	5.3 a

[a]Includes topdressing at 5-7 DBPI of 40 kg N/ha in DS and 30 kg N/ha in WS. [b]Within a season, figures in a column followed by a common letter are not significantly different at the 5% level by DMRT. CV = 13% for DS and 10% for WS.

fertilizer combinations did not affect pH, total N, or exchangeable Ca (Table 9). Plots that continuously received P for 20 croppings had a soil P content of 2.6 ppm or higher than the control. K application alone increased the K content of the soil to almost twice the level in soil that did not receive K for the past 20 croppings. Zn content is still sufficient irrespective of treatment.

Table 7. 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, Luisiana, Laguna, Philippines, 1986.

Fertilizer treatment[a]	Yield[b] (t/ha)			
	DS		WS	
	IR64	IR29723-143-3-2-1	IR64	IR29723-143-3-2-1
Control	2.9 cd	2.6 d	2.0 d	2.8 c
N	4.6 b	5.4 b	3.8 a	3.7 b
P	3.3 c	3.2 c	2.4 cd	2.8 c
K	2.9 cd	2.5 d	2.6 c	2.9 c
NP	5.5 a	5.5 ab	3.7 ab	4.0 b
PK	3.2 c	2.9 cd	2.2 cd	3.1 c
NK	4.7 b	5.0 b	3.4 b	3.1 c
NPK	5.8 a	6.0 a	4.1 a	4.6 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 = 9% for DS and 11% for WS.

Table 8. Effect of NPK on yield of IR64 and IR29723-143-3-2-1 in the 17th (DS) and 18th (WS) consecutive crops. Long-term fertility trial, Tanay, Rizal, Philippines, 1986.

Fertilizer treatment[a]	Yield[b] (t/ha)			
	DS		WS	
	IR64	IR29723-143-3-2-1	IR64	IR29723-143-3-2-1
Control	3.3 d	3.5 c	2.4 c	3.3 d
N	5.2 ab	4.7 b	3.5 a	3.5 d
P	3.7 c	3.8 c	2.5 c	3.9 bc
K	2.8 d	3.8 c	2.9 b	3.4 d
NP	5.3 ab	5.5 a	3.3 a	4.2 b
PK	3.3 cd	3.7 c	2.7 bc	3.9 bc
NK	5.3 ab	5.4 a	3.5 a	4.0 b
NPK	5.4 a	5.3 ab	3.6 a	4.7 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 = 11% for DS and 7% for WS.

Table 9. Soil analyses during the 20th crop in the long-term fertility trial. Luisiana, Laguna, Philippines, 1986 DS.

Fertilizer (kg/ha)			Soil character[a]					
N	P	K	pH (1:1)	Total N (%)	Available P (ppm, Bray 2)	Exchangeable K (meq/100 g soil)	Exchangeable Ca (meq/100 g soil)	Available Zn (ppm, K & P)
0	0	0	4.7	0.17	5.4	0.19	6	4.18
120	0	0	4.6	0.18	5.5	0.19	5	4.57
0	17	0	4.6	0.17	8.6	0.17	6	4.62
0	0	33	4.6	0.17	5.6	0.34	6	4.15
120	17	0	4.6	0.18	8.7	0.14	6	4.88
0	17	33	4.6	0.17	8.9	0.29	6	4.72
120	0	33	4.6	0.18	5.9	0.26	5	4.60
120	17	33	4.6	0.18	8.0	0.17	6	4.94

[a]Mean of IR64 and IR29723-143-3-2-1.

In the high-pH soil in Tanay, P fertilization was probably the most critical fertilizer requirement, as plots that did not receive P for the 17th cropping were very deficient in P (<10 ppm critical limit for Olsen P analysis), while those that received P continuously had a P content 3 times higher than those without P (Table 10).

EVALUATION OF SULFUR SOURCES FOR LOWLAND RICE

The evaluation of five S fertilizers — urea S, elemental S, $(NH_4)_2SO_4$, gypsum, and S bentonite — was continued during 1986 WS in the greenhouse and in the field at three locations using IR64.

Greenhouse. Three rates of S — 0, 20, and 40 kg/ha — were evaluated for each of the sources. The chemical characteristics and texture of the soils used are presented in Table 11.

Based on the average of 6 soils, the grain yield without S was only 21 g/pot (Table 12). NPK application increased yield by only 8 g/pot. The highest grain yield increase of 29 g/pot was obtained from plants receiving 40 kg S/ha as urea S. Yields from all S sources except S bentonite were statistically the same at 20 kg S/ha, beyond which there was no significant increase in yield. Gypsum at 40 kg S/ha produced even lower yield. The yield with S bentonite did not significantly differ from those with NPK and the control,

Table 10. Soil analyses during the 17th crop in the long-term fertility trial. Tanay, Rizal, Philippines, 1986 DS.

Fertilizer (kg/ha)			Soil character[a]					
N	P	K	pH (1:1)	Total N (%)	Available P (ppm, Olsen)	Exchangeable K (meq/100 g soil)	Exchangeable Ca (meq/100 g soil)	Available Zn (ppm, K & P)
0	0	0	7.5	0.19	4.0	0.16	41	0.21
120	0	0	7.4	0.20	3.2	0.15	40	0.31
0	17	0	7.2	0.20	12.4	0.14	39	0.44
0	0	33	7.5	0.20	4.3	0.20	41	0.16
120	17	0	7.1	0.21	10.3	0.15	38	0.41
0	17	33	7.3	0.20	12.9	0.21	40	0.33
120	0	33	7.5	0.20	3.0	0.17	39	0.23
120	17	33	7.2	0.21	10.1	0.18	39	0.48

[a]Mean of IR64 and IR29723-143-3-2-1.

Table 11. Chemical characteristics and texture of apparently S-deficient soils studied in the greenhouse and in the field. IRRI, 1986.

Location	pH (1:1)	CEC (meq/100 g)	Organic C (%)	SO_4^{2-}-S (ppm)	Total S (ppm)	Clay (%)	Soil texture
San Juan, Batangas[a]	7.1	36	1.5	0.6	216	48	Silty clay
Santa Maria, Pangasinan[a]	7.1	37	1.3	nil	198	48	Silty clay
Bacnotan, La Union	6.1	14	0.5	4	135	15	Sandy loam
Moncada, Tarlac	7.0	33	1.2	nil	146	37	Silty clay loam
Aguilar, Pangasinan	6.5	23	1.6	14	265	21	Loam
Natividad, Pangasinan	5.8	13	0.5	nil	–	18	Silty loam
South Sulawesi, Indonesia[b]	6.2	25	1.2	1.7	200	30	Silty clay loam

[a]Soils used in greenhouse and field trials. [b]Soil used in field trial only.

Table 12. Effects of 5 sources and 2 rates of applied S on grain yield and S uptake in grains of IR64, IRRI greenhouse, 1986 WS.

S source	No S	20 kg S/ha	40 kg S/ha	
	Grain yield[a] (g/pot)			*Mean*
Control	21 d			21
NPK	29 c			29
$(NH_4)_2SO_4$		44 ab	45 ab	45
Elemental S		46 ab	47 a	47
S bentonite		27 cd	27 cd	27
Gypsum		46 ab	39 b	43
Urea S		46 ab	50 a	48
	S uptake[b] (mg/pot)			*Mean*
Control	2 d			2
NPK	4 d			4
$(NH_4)_2SO_4$		41 abc	49 ab	45
Elemental S		38 bc	38 bc	38
S bentonite		7 d	4 d	6
Gypsum		51 ab	33 c	42
Urea S		53 a	43 abc	48

[a]Av of 6 soils. Values from all treatments followed by a common letter are not significantly different at the 5% level by DMRT. [b]From the San Juan soil only. Values from all treatments followed by a common letter are not significantly different at the 5% level by DMRT.

Table 13. Effect of 5 sources and 2 rates of applied S on the grain yield of IR64 from 2 Philippine field trials, 1986 WS.

S source	Grain yield[a] (t/ha)			
	No S	20 kg S/ha	40 kg S/ha	Mean
	Batangas			
Control	2.6 d			2.6
NPK	2.7 d			2.7
$(NH_4)_2SO_4$		5.4 ab	5.4 ab	5.4
Elemental S		5.1 ab	5.2 ab	5.2
S bentonite		3.4 c	3.4 c	3.4
Gypsum		4.9 b	5.4 ab	5.2
Urea S		5.4 ab	5.6 a	5.5
	Pangasinan			
Control	2.0 d			2.0
NPK	3.8 c			3.8
$(NH_4)_2SO_4$		4.2 abc	4.2 abc	4.2
Elemental S		4.6 ab	4.5 ab	4.6
S bentonite		4.0 bc	4.3 abc	4.2
Gypsum		4.4 abc	4.1 abc	4.3
Urea S		4.3 abc	4.8 a	4.6

[a]Within a site, values from all treatments followed by a common letter are not significantly different at the 5% level by DMRT.

indicating that S bentonite did not release sufficient S to the plants. Urea S appears to be the most effective. The highest number of tillers was also obtained from urea S at 40 kg S/ha. Straw yields with $(NH_4)_2SO_4$, elemental S, gypsum, and urea S at 20 kg S/ha did not differ.

S uptake of grain was determined from the plants grown in the San Juan soil only, where marked response to S was observed (Table 12). The highest S uptake (53 mg/pot) was obtained from urea S at 20 kg S/ha. S uptake with $(NH_4)_2SO_4$ and elemental S did not increase beyond the rate of 20 kg S/ha. S uptake was depressed with 40 kg S/ha from gypsum and urea S; it was lowest in the S bentonite-treated plants and was the same as in the NPK treatment and the control.

Field. In 1986 WS, two field trials were conducted in Batangas and Pangasinan, Philippines, and one collaborative field trial in Maros, South Sulawesi, Indonesia. The chemical characteristics and textures of the soils at the three sites are presented in Table 11.

At the Batangas site, grain yield increase over the control because of S application ranged from 0.8 to 2.9 t/ha (Table 13). Urea S at 40 kg S/ha produced the highest yield of 5.6 t/ha. No significant difference in yield at tillering was recorded between the rates of 20 and 40 kg S/ha. Without S, NPK gave no response. Urea S at 40 kg S/ha gave the highest straw yield, but it was not significantly different from elemental S, $(NH_4)_2SO_4$, and gypsum at the same rate.

At the Pangasinan site, grain yield increase over the control because of S application ranged from 2.2 to 2.6 t/ha (Table 13). Urea S at 40 kg S/ha produced the highest yield of 4.8 t/ha, which was significantly higher than that with NPK alone. All other sources at both rates of S except for elemental S were not significantly different from NPK. No significant difference in yield was recorded between the two rates for any source. Grain yield increase because of NPK was 1.8 t/ha. The highest number of tillers was obtained from $(NH_4)_2SO_4$ at 20 kg S/ha but was not significantly different from elemental S and gypsum at the same rate or elemental S, gypsum, and urea S at 40 kg S/ha. Straw yields with $(NH_4)_2SO_4$, elemental S, and S bentonite were statistically the same at 20 kg S/ha, but no differences were recorded at 40 kg S/ha.

No significant difference in grain yield between the rates of 20 and 40 kg S/ha for any S source was observed at Maros. S bentonite gave an average grain yield of 2.8 t/ha, which was not significantly

different from the yields of the NPK treatment and the control. With the other sources, yield increases over the control ranged from 2.6 to 2.9 t/ha.

Straw yield was highest with $(NH_4)_2SO_4$, followed by gypsum, elemental S, and urea S. However, the sources did not significantly differ. S bentonite yielded only 3 t straw/ha. S uptake in grains at both rates of $(NH_4)_2SO_4$, elemental S, and urea S was statistically the same. S uptake in grains was highest with elemental S at 40 kg S/ha (Table 14).

Both greenhouse and field trials indicated that all S sources except S bentonite were equally effective for lowland rice, especially at the Batangas and Maros sites, where S response was very marked (Fig. 4). The rate of 20 kg S/ha was adequate to support a normal crop of rice at the 3 field sites.

INFLUENCE OF WATER MANAGEMENT ON SULFUR AVAILABILITY FOR RICE

Three Luzon soils were subjected to three types of water management and two S levels in the greenhouse to determine their influence on S availability. IR64 was the test variety. The chemical properties and textures of the soils are presented in Table 11.

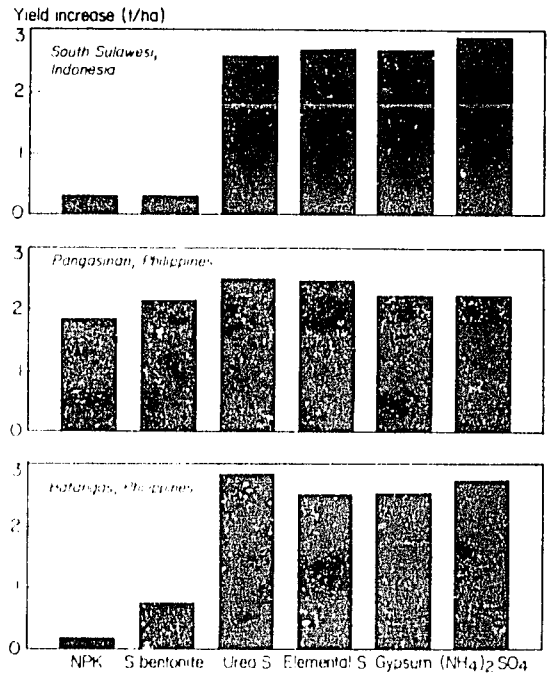
With native S in the soil, grain yield was highest with predrying, then alternate wetting and drying, for all soils except La Union soil. In this soil, yield was at the same level of significance with predrying before continuous flooding (Table 15).

With 30 ppm S, no significant difference in yield was observed among the 3 types of water management in Santa Maria soil. However, significant differences were observed in Batangas soil. In La Union, grain yield in soil subjected to continuous flooding was not significantly different from that with the other types of water management.

Table 14. Effect of 5 sources and 2 rates of applied S on S uptake of IR64 grains in the field, Maros, South Sulawesi, Indonesia, 1986 WS.

S source	S uptake[a] (kg/ha)			
	No S	20 kg S/ha	40 kg S/ha	Mean
Control	1.2 e			1.2
NPK	1.8 c-e			1.8
$(NH_4)_2SO_4$		3.1 a-d	3.4 a-c	3.3
Elemental S		3.2 a-d	4.7 a	4.0
S bentonite		2.0 b-e	1.6 de	1.8
Gypsum		2.8 b-e	3.4 a-c	3.2
Urea S		3.1 a-d	3.5 ab	3.3

[a]Values from all treatments followed by a common letter are not significantly different at the 5% level by DMRT.



4. Grain yield increase of IR64 over the control with application of NPK and NPK + S fertilizers in 3 field trials in the Philippines and Indonesia, 1986 WS.

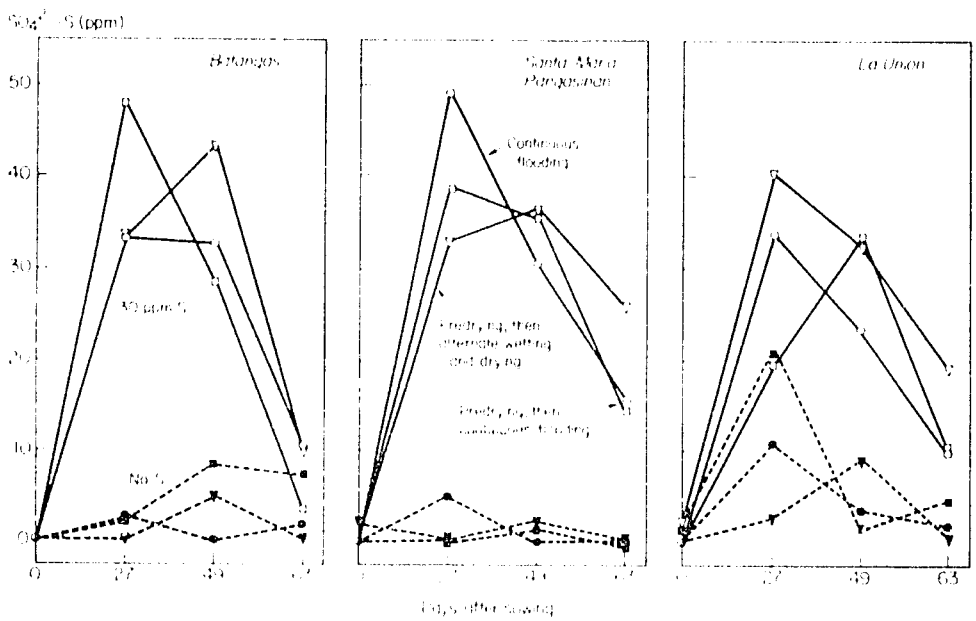
The availability of SO_4^{2-}-S was highest at maximum tillering in Batangas and Santa Maria, with native and applied S in soils that were subjected to predrying, then alternate wetting and drying. A similar trend was observed in La Union with only native S.

In continuous flooding, SO_4^{2-}-S content was highest at the seedling stage in all 3 soils with native and applied S. In predrying followed by continuous flooding, availability of SO_4^{2-}-S was highest at the seedling stage in Batangas and Santa Maria soils with 30 ppm S. With native S in soil, however, SO_4^{2-}-S content was highest at maximum tillering. In La Union, SO_4^{2-}-S content was highest at maximum tillering with applied S and at the seedling stage in soil with native S.

Table 15. Grain yield of IR64 grown in 3 soils under 3 types of water management[a] and 2 S levels. IRRI greenhouse, 1986 DS.

Soil	S level (ppm)	Grain yield[b] (g/pot)		
		M_1	M_2	M_3
San Juan, Batangas	0	0.7 i	12.4 g	0.9 i
	30	67.3 a	46.8 c	55.0 b
Santa Maria, Pangasinan	0	15.9 g	23.7 f	2.7 hi
	30	46.2 c	40.5 cd	46.5 c
Bacnotan, La Union	0	2[illegible].7 f	29.6 ef	9.0 gh
	30	43.9 cd	31.1 ef	37.3 de

[a]M_1 = predrying, then continuous flooding; M_2 = predrying, then alternate wetting and drying; M_3 = continuous flooding.
[b]Values for all treatments followed by a common letter are not significantly different at the 5% level by DMRT.



5. SO_4^{2-} S content of 3 Luzon soils under 3 types of water management at 3 growth stages of IR64: 27 d after seeding (DAS) = seedling stage, 49 DAS = maximum tillering, and 63 DAS = panicle initiation. IRRI greenhouse, 1986.

VARIETAL TOLERANCE FOR LOW SULFUR IN SOIL

Fourteen rice cultivars were evaluated in the field in South Sulawesi, Indonesia, to determine their tolerance for low S in soils. The same rices were grown on apparently S-deficient Batangas soil in the greenhouse at IRRI. The chemical properties and textures of the soils used are presented in Table 11.

With the application of S, IR54, IR64, and IR29697-65-2-3-3 produced yield increases of more than 100% in the field, suggesting that these rices are less tolerant of low S in soils (Table 16). Except for IR54, however, the same trend was not observed in the greenhouse. IR36, IR60, IR13540-56-3-2-1, and IR28222-9-222 were relatively tolerant in the field but not in the greenhouse. IR30, IR34, IR58, IR21820-154-3-2-2-3, IR31802-48-2-2-2, IR31917-31-3-2, and IR32429-47-3-2-2 were consistently more tolerant in both field and greenhouse. The inconsistency of results between the field and greenhouse tests may have been influenced by the soil volume used and the differential root development of rices under low S in the soil.

Table 16. Grain yield response of some rice cultivars to applied S in S-deficient soil in the field and in the greenhouse. IRRI, 1986.

Cultivar	Field			Greenhouse		
	Yield (g/hill)		Increase (%)	Yield[a] (g/hill)		Increase or decrease (%)
	No S	40 kg S/ha		No S	10 ppm S	
IR30	15.3	22.7	48	11.2 a	15.8 a	41
IR34	15.0	19.5	30	12.0 b	20.7 a	72
IR36	13.7	21.7	58	5.2 b	15.7 a	202
IR54	11.0	24.0	118	5.2 b	17.8 a	242
IR58	13.0	19.0	46	9.9 a	15.5 a	56
IR60	17.3	21.0	21	5.2 b	15.8 a	204
IR64	10.7	24.0	124	11.1 b	18.3 a	65
IR13540-56-3-2-1	17.0	28.0	65	6.7 b	19.0 a	183
IR21820-154-3-2-2-3	11.3	19.0	68	5.5 a	8.8 a	60
IR28222-9-222	11.0	21.0	91	9.0 b	31.8 a	253
IR29697-65-2-3-3	9.5	21.7	128	15.0 b	23.2 a	55
IR31802-48-2-2-2	14.3	24.0	68	17.3 a	19.6 a	13
IR31917-31-3-2	13.7	19.7	44	19.9 a	16.0 a	-24
IR32429-47-3-2-2	12.3	20.3	65	22.6 a	16.2 ab	-40

[a]In a row, treatment means followed by a common letter are not significantly different at the 5% level by DMRT.

LONG-TERM SULFUR FERTILITY EXPERIMENT

The effects of continuous application of high analysis fertilizers (urea, triple superphosphate, and KCl) on rice grown in a clay soil continued to be studied at the IRRI farm during 1986 DS and WS (8th and 9th crops). *Sesbania rostrata* incorporated into the soil at 45 DAS was added as one of the treatments during the year.

In DS, all treatments receiving N gave significant yield increases over the control (Table 17). NPK alone resulted in a significantly higher yield than NPK + straw + Zn. Moreover, the yield from NPK alone was comparable to those of NPK + Zn, NPK + S, NPK + azolla + Zn, NPK + Zn + S, NP + Zn, NK + Zn, and N + Zn. The same trends had been observed in previous years, indicating

Table 17. Yield of 15 treatments in the long-term S fertility trial with irrigated IR64 rice. IRRI, 1986 DS and WS.

Treatment[a]	Yield[b] (t/ha)		
	Dry season	Wet season	Mean
Control	4.2 c	3.3 ef	3.8
Zn alone	4.4 c	3.0 gh	3.7
N + Zn	5.9 ab	3.8 abc	4.9
P + Zn	3.9 c	3.3 ef	3.6
K + Zn	4.0 c	2.9 h	3.4
NP + Zn	6.1 ab	4.0 a	5.0
NK + Zn	6.0 ab	3.8 abc	4.9
PK + Zn	4.0 c	3.2 fg	3.6
NPK + Zn	6.2 ab	3.8 abc	5.0
NPK only	6.4 a	4.0 a	5.2
NPK + S	6.3 ab	3.5 c-f	4.9
NPK + Zn + S	6.2 ab	3.4 def	4.8
NPK + azolla + Zn	6.3 ab	3.9 ab	5.1
NPK + straw + Zn	5.6 b	3.7 a-d	4.6
S. rostrata incorporated at 45 DAS	4.2 c	3.6 b-e	3.9

[a]Zn as root dip in 4% ZnO solution. S as urea S at 40 kg S/ha. [b]CV = 7.8% in DS and 5.6% in WS.

that N remains limiting. Despite the continuous use of high analysis fertilizers containing almost no S, S deficiency is not yet apparent.

In WS, yields were generally lower than in DS. The highest yield of 4.0 t/ha was obtained from both NPK alone and NP + Zn. There were no significant yield differences observed between Zn alone, Zn + PK, and Zn + K, or between P + Zn and the control. Likewise, the yields with N + Zn, NK + Zn, and NPK + Zn were the same. The yields with Zn alone and PK + Zn were lower than that of the control. The yield increase of NPK alone was comparable to those of NPK + azolla + Zn and NPK + straw + Zn. However, the yield with NPK alone was significantly higher than those obtained from NPK + Zn + S, NPK + S, and *S. rostrata* incorporated at 45 DAS. The application of S during WS appears to depress yield.

Soil and crop management

Rice crop cultural practices

Agronomy, Soils, and Plant Physiology Departments

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CONTINUOUS CROPPING

Agronomy Department

The 69th (dry season [DS]) and 70th (wet season [WS]) croppings in the continuous cropping experiment were planted using 4 test varieties and 2 promising breeding lines. Yield responses of transplanted (TPR) and broadcast seeded (BR) rices were compared over four N rates.

In DS, except for IR8, rices not receiving N fertilizer yielded 4.2-5.4 t/ha (Table 1). Brown planthopper damage slightly reduced the yield of IR8. In BR plots receiving N, IR64 at 150 kg N/ha yielded the highest. With TPR, IR58 and IR64 at 100 kg N/ha yielded the highest.

TPR IR36, IR58, and IR32429-47-3-2-2 at 150 kg N/ha yielded significantly higher than BR. Yields of the other test rices were comparable in both crop establishment methods.

In WS, yields without N fertilizer ranged from 2.5 to 3.2 t/ha in BR and from 2.7 to 3.5 t/ha in TPR (Table 2). Heavy rains during the reproductive stage resulted in low yields. Late occurrence of tungro reduced the yield of IR8.

SEEDING RATE AND WATER MANAGEMENT IN BROADCAST SEEDED FLOODED RICE

Agronomy Department

To evaluate the effects of seeding rate and water management on grain yield, pregerminated seed of IR58, IR64, and IR29723-143-3-2-1 was tested at seeding rates of 100, 150, and 200 kg/ha and 3 water management treatments: Wm1 = BR into 5 cm water; Wm2 = BR onto mud, irrigation at 2 d after seeding (DAS); Wm3 = conventional water management = BR onto mud, irrigation at 4 DAS. N fertilizer at 100 kg N/ha was applied following researchers' split. Weed and insect control were maintained at optimum levels.

Under Wm1, all test rices emerged; however, some seedlings subsequently floated. A similar observation was noted with Wm2, but fewer seedlings floated.

Under any water management practice, DS grain yields of the test rices were not affected by seeding rate. At 100 kg seed/ha, IR58 gave high yields under Wm1. Grain yields of IR64 and

Table 1. Grain yield of transplanted (TPR) and broadcast seeded (BR) rices as affected by N rate and crop establishment method during the 69th cropping. Continuous cropping experiment, IRRI, 1986 DS.

Variety or line	Yield[a] (t/ha)											
	No N			50 kg N			100 kg N			150 kg N		
	TPR	BR	Difference	TPR	BR	Difference	TPR	BR	Difference	TPR	BR	Difference
IR8	4.2 b	3.7 c	0.5^{ns}	4.8 ab	4.4 b	0.4^{ns}	5.0 c	5.4 b	−0.4^{ns}	5.1 b	4.6 c	0.5^{ns}
IR36	4.8 ab	4.2 bc	0.6^{ns}	6.3 ab	5.5 a	0.8**	6.8 a	6.5 a	0.3^{ns}	6.7 a	5.5 b	1.2**
IR58	5.4 a	5.1 a	0.3^{ns}	6.6 a	5.5 a	1.1**	7.0 a	6.3 a	0.7**	6.6 a	5.6 b	1.0**
IR64	4.2 b	4.4 b	−0.2^{ns}	6.0 ab	5.8 a	0.2^{ns}	7.0 a	6.6 a	0.4^{ns}	6.9 a	6.8 a	0.1^{ns}
IR25587-133-3-2-2	4.6 b	4.2 bc	0.4^{ns}	5.1 c	5.4 a	−0.3^{ns}	6.0 b	6.1 a	−0.1^{ns}	6.3 a	5.9 b	0.4^{ns}
IR32429-47-3-2-2	4.5 b	4.5 ab	0.0^{ns}	5.8 b	5.7 a	0.1^{ns}	6.6 a	6.2 a	0.4^{ns}	7.0 a	5.8 b	1.2**

[a]Av of 4 replications. CV = 9% for fertilizer, 9% for variety, and 6% for planting method.

Table 2. Grain yield of transplanted (TPR) and broadcast seeded (BR) rices as affected by N rate and crop establishment method during the 70th cropping. Continuous cropping experiment, IRRI, 1986 WS.

Variety or line[b]	Yield[a] (t/ha)											
	No N			30 kg N			60 kg N			90 kg N		
	TPR	BR	Difference	TPR	BR	Difference	TPR	BR	Difference	TPR	BR	Difference
IR8	2.7 b	2.7 a	0.0^{ns}	3.2 ab	2.7 ab	0.5^{ns}	3.3 a	2.8 c	0.5^{ns}	2.2 c	2.3 b	−0.1^{ns}
IR36	3.5 a	3.0 a	0.5^{ns}	3.9 a	2.9 ab	1.0**	3.9 a	4.0 a	−0.1^{ns}	3.9 ab	3.7 a	0.2^{ns}
IR64	3.0 ab	2.8 a	0.2^{ns}	3.6 a	2.8 ab	0.8**	3.8 a	3.1 bc	0.7*	3.8 ab	3.6 a	0.2^{ns}
IR25587-133-3-2-2-2	2.9 ab	2.5 a	0.4^{ns}	2.9 b	2.4 b	0.5^{ns}	3.3 a	2.8 c	0.5^{ns}	3.3 b	2.1 b	1.2**
IR32429-47-3-2-2	3.4 a	3.2 a	0.2^{ns}	3.4 ab	3.1 a	0.3^{ns}	3.0 a	3.5 ab	0.4^{ns}	4.0 a	3.7 a	0.3^{ns}

[a]Av of 4 replications. CV = 22 % for fertilizer, 16 % for variety, and 12 % for planting method. [b]Rats damaged IR58 yields.

IR29723-143-3-2-1 did not significantly change with change in water management.

Under Wm3, the appropriate seeding rate depended on the cultivar used. For high tillering IR58, 100 kg seed/ha appeared to be high, as indicated by a high yield when crop stand was reduced under Wm1. With medium tillering IR64 and IR29723-143-3-2-1, 100 kg seed/ha was appropriate to obtain high yields.

In WS, pregerminated seed of IR64 and IR29723-143-3-2-1 at seeding rates of 50, 75, and 100 kg/ha was evaluated under 4 water management practices: Wm1 = BR onto mud, irrigation to 5 cm at 4 DAS; Wm2 = BR onto mud, irrigation to 10 cm at 4 DAS; Wm3 = BR into 10 cm water, draining for 5 d starting at 10 DAS; Wm4 = BR into 10 cm water, draining for 1 wk at maximum tillering.

EFFECT OF GROWTH REGULATORS ON LODGING

Agronomy Department

A 1986 DS experiment examined the effect of growth regulators on lodging of lodging-resistant IR8 and IR64 and moderately susceptible IR21820-154-3-2-2-3 and IR36.

A foliar spray of plant growth regulator CCC (2-chloroethyltrimethyl ammonium chloride), applied at 3,000 g/ha at booting and heading, did not significantly reduce lodging of the susceptible varieties. However, Hoe 78784 at 150 kg ai/ha applied to the foliage of IR21820-154-3-2-2-3 only at booting significantly reduced lodging. This effect might be attributed to the lower stem elongation in treated IR21820-154-3-2-2-3 than in the control, which was significant from the 1st to the 5th internodes. CCC treatment had no effect on internode elongation in all varieties.

The growth regulators did not significantly affect the tiller number and leaf area of all test rices. However, plant height decreased in IR8 treated with CCC at heading. Foliar application of Hoe 78784 reduced stem weight, leaf weight, and root dry weight in IR8, and decreased plant height in IR21820-154-3-2-2-3.

Yield components of IR8 and IR21820-154-3-2-2-3 were likewise not affected by CCC application, but IR8 straw dry weight, IR36 spikelet ripening

percentage, and IR64 panicle length were reduced with Hoe 78784 applied at booting.

The plant growth regulators did not significantly affect the panicle length, panicle number, and 100-grain weight of the test varieties. CCC and Hoe 78784 application did little to increase bending index.

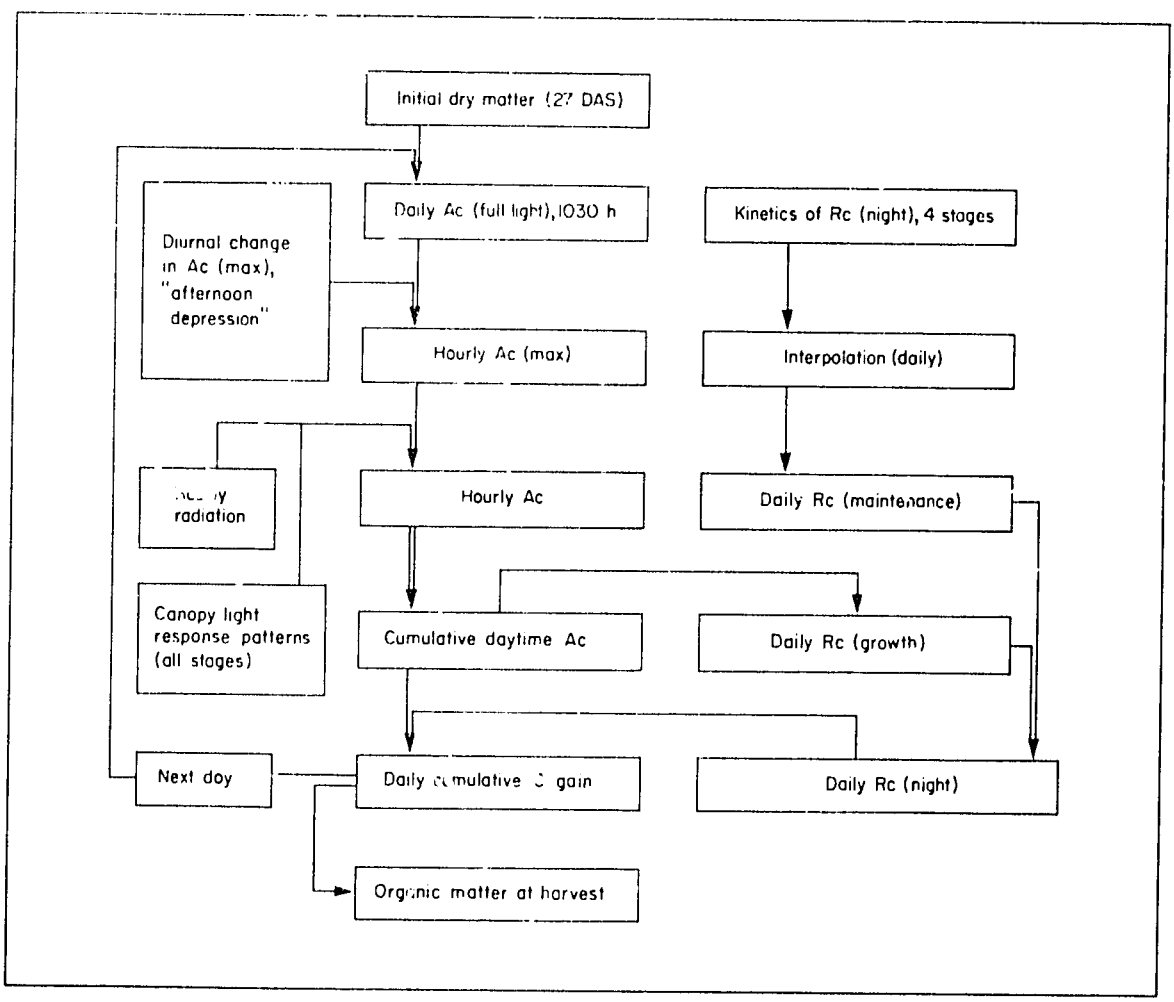
CANOPY PHOTOSYNTHESIS OF DIRECT SEEDED AND TRANSPLANTED RICE

Agronomy Department

In a cooperative project with the University of Hamburg, Federal Republic of Germany, canopy photosynthesis and respiration measurements were used as diagnostic tools to modify cultural practices for increased rice yield.

In 1986, research activities focused on direct seeded and lowland TPR IR64. Wet seed dibbling at 20- × 20-cm hill spacing provided for the direct seeded treatment planting density equal to the TPR treatment. Figure 1 shows the modeling process relating canopy gas exchange to growth. Micrometeorological and agronomic growth parameters were recorded.

The studies revealed marked differences in growth kinetics and plant development between the two stand establishment techniques. In direct seeded IR64, canopy establishment was considerably faster than in TPR, where growth was delayed



1. The modeling process relating canopy gas exchange in IR46 to growth, IRRI, 1986. Ac = canopy net photosynthesis, RC = canopy respiration, DAS = days after sowing.

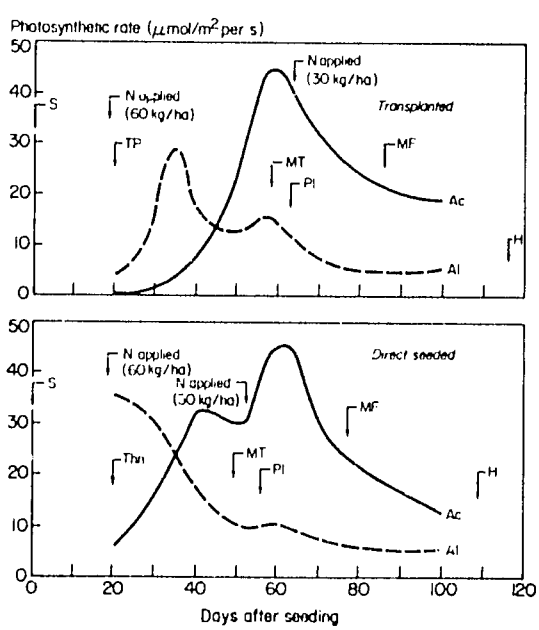
by the physiological shock induced by transplanting.

Inhibition of net photosynthesis per unit of leaf area during the initial 2 wk after transplanting (Fig. 2) led to a retardation in leaf area production and a 4- to 5-wk lag until canopy photosynthesis in TPR caught up with that in direct seeded rice.

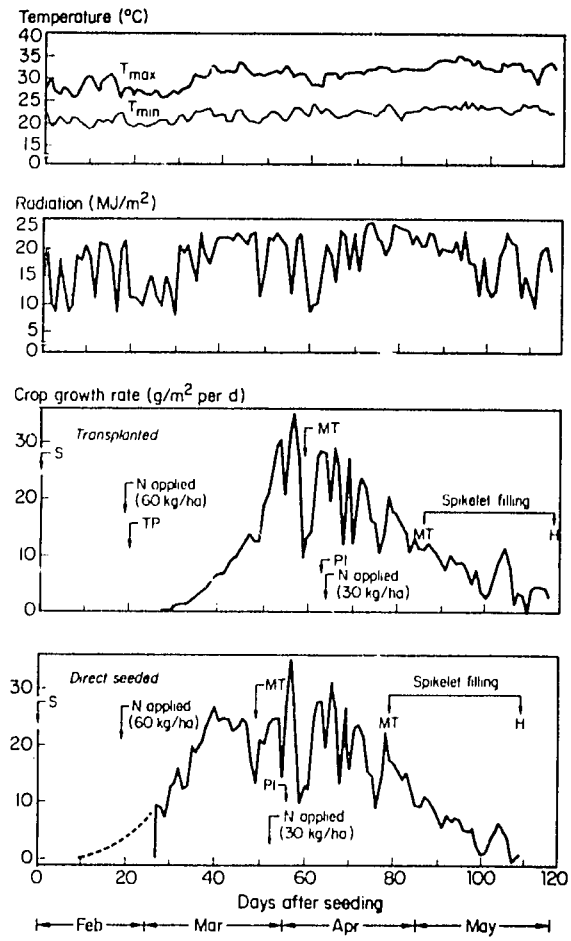
The kinetics of crop growth rate, calculated from canopy gas exchange, were superior in direct seeded rice throughout the vegetative phase (Fig. 3). Peak growth rates occurred at the early reproductive phase and were identical in both treatments.

Direct seeded IR64, therefore, produced 30% more biomass than TPR during the vegetative phase, increasing its biomass by 2.0 t/ha at maturity (Fig. 4). Growth duration was longer by 10-20 d in TPR, depending on the season.

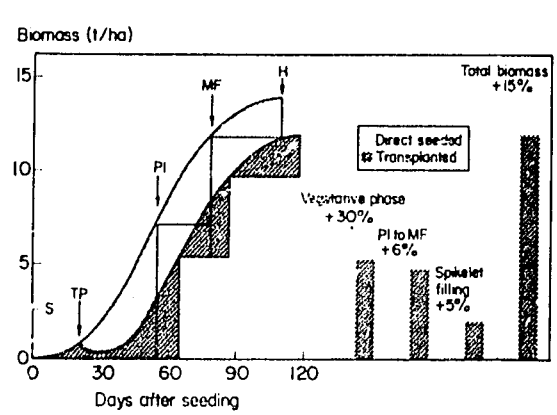
IR64 yielded 6.0 t/ha in DS and 4.0 t/ha in WS, regardless of planting method. Direct seeded IR64, therefore, did not achieve its superior vegetative growth, indicating limiting suboptimal panicle sink size.



2. Maximum midday canopy photosynthesis (Ac) and leaf photosynthesis (Al) in transplanted and direct seeded IR64, IRRI, 1986 DS. DAS = days after seeding, S = seeding, TP = transplanting, Thn = thinning, MT = maximum tillering, PI = panicle initiation, MF = maximum flowering, H = harvest.

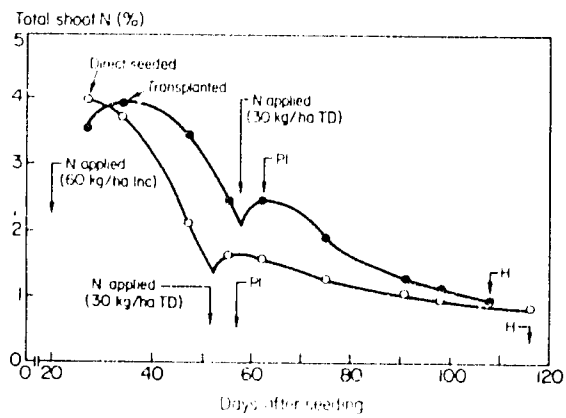


3. Meteorological data and crop growth rate as calculated from canopy gas exchange in transplanted and direct seeded IR64. IRRI, 1986 DS.

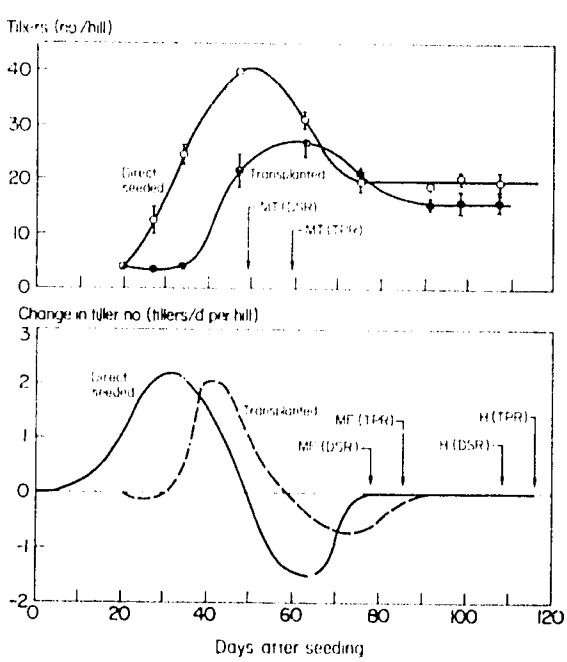


4. Biomass production in direct seeded and transplanted IR64 as calculated from a canopy gas exchange, specified for 3 growth stages. IRRI, 1986 DS.

In direct seeded rice, the reduced panicle sink size and spikelet number can be attributed to low tissue-N concentration (Fig. 5). Although total N uptake was identical in both planting methods, absorbed N underwent a dilution effect in the fast-growing direct seeded plants, particularly at PI, unlike in TPR. Profuse tillering with subsequent tiller abortion may have also reduced production in direct seeded rice (Fig. 6). In contrast, TPR exhibited moderate tillering due to the inhibitory action of the transplanting shock.



5. Total shoot N content in direct seeded and transplanted IR64, IRRI, 1986 DS. Inc = incorporated, TD = topdressed.



6. Tiller number and change in tiller number in direct seeded (DSR) and transplanted (TPR) IR64, IRRI, 1986 DS.

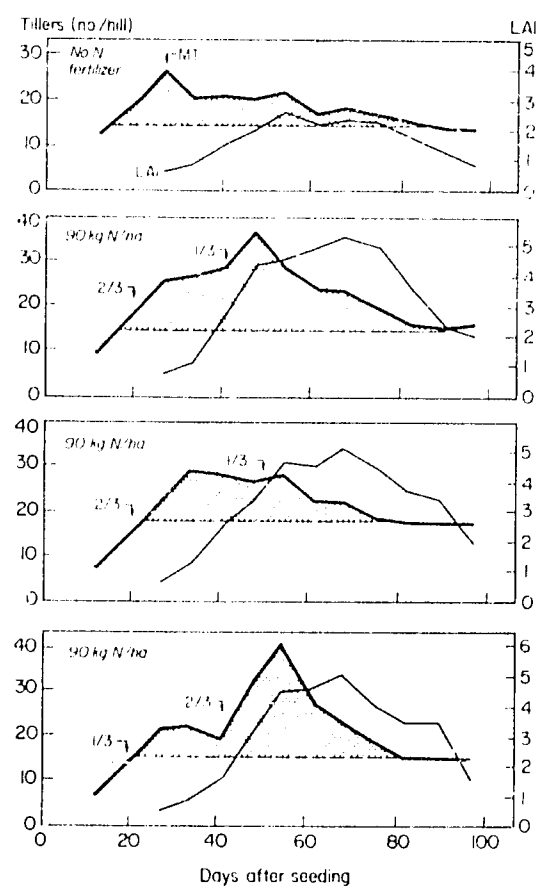
Figure 7 shows that careful timing of N application may determine optimum tiller management in direct seeded rice, particularly between 25 and 45 DAS, which is a period of active N uptake.

EFFECT OF ROW SPACING ON GROWTH AND YIELD OF UPLAND RICE

Soils Department

Two row spacings — 20 and 40 cm — were tested in 4 replications in a randomized complete block design using UPLRi-5 in an acid upland soil in Iloilo, Philippines. The seeds in both treatments were drilled at 3-cm depth and covered with soil. Both treatments were fertilized with 40 kg N/ha and 13 kg P/ha.

The 20-cm row spacing produced slightly taller plants and grain yield significantly higher by about



7. Kinetics of tiller number and leaf area index (LAI) in direct seeded IR64 using 4 fertilizer regimes, IRRI, 1986 WS. Urea application at 40 DAS induced tillering while application at 50 DAS did not. Dotted areas indicate excessive tillering.

100 g/m^2, mainly because of higher plant population (Table 3).

The roots in both cases were concentrated (95%) in the immediate 125 cm^2 soil in the furrow and were rarely more than 5 cm farther laterally from the furrow. Weed growth in the close row spacing treatment was less.

Under limited fertility, maintaining higher plant population by closer row spacing or intrarow spacing is desirable for economic production. Fertilizers should be applied close to the plants because under limited fertility the roots do not grow much laterally.

INTERCROPPING EARLY MATURING AND DEEPWATER RICE

Agronomy Department

Deepwater rices (DWRs) of different plant types were compared to determine whether some are better suited to an intercropping system. Collaborative experiments were conducted in Thailand at both Huntra and Prachinburi. Rows were 20 cm apart, with 2 rows of DWR alternating with 3 rows of early variety (EV) rice. Drought, bird damage, and early flood affected EVs, and data in Table 4 are for DWRs only.

Four DWRs — Pin Gaew 56, SPR7270-18, LMN111, and BKNFR76042-18-1-1 — showed equal or less than 10% decline in yield for the intercrop compared with monoculture. For these rices the yield per meter of row in the intercrop, where there was a gap of 80 cm left after harvest of the EV, was more than double that from rows in the monoculture.

For RD19 and SPR'76 COM3-5-2, compensation for the gap was much less, and consequently the yield of DWR in the intercrop was only 60-70% of the monoculture. These two DWRs are less likely to be successful in intercropping.

Results of two experiments testing different row combinations are given in Table 5. The rows were 20 cm apart, and the seeding rate was 120 kg/ha. At Huntra, alternating two rows of DWR Pin Gaew 56 with two rows of EV IR22097-41-4-3 (2DWR+2EV) gave the best total production, even though EV had negligible yield because of drought and bird damage. At Prachinburi, EV IR15429-268-1-2-1 had slightly better yields

Table 3. Effect of row spacing on the growth and yield of upland rice in acid soils. Iloilo, Philippines, 1986.

Row spacing (cm)	Plant height (cm)	Yield (g/m^2)	Unfilled grains (%)
20 (drilled)	114.5	255.4	12.1
40 (drilled)	110.0	149.3	15.8

Table 4. Yields, weight of grain/meter of row, and ratio of intercrop yield[a] to monoculture yield for 4 deepwater rices at Huntra (HTA) and Prachinburi (PCR), Thailand, 1985 WS.

Item	Yield (t/ha)		Grain (g/m of row)		Ratio of DWR yield from intercrop to monocrop	
	HTA	PCR	HTA	PCR	HTA	PCR
Pin Gaew 56 in intercrop	3.38 a		169 a		1.03 a	
Pin Gaew 56 monoculture	3.31 a		66 d			
SPR7270-18 in intercrop	3.30 a		165 a		0.92 a	
SPR7270-18 monoculture	3.60 a		72 d			
RD19 in intercrop	2.05 c	1.31 c	103 c	66 ab	0.64 b	0.62 a
RD19 monoculture	3.21 a	2.18 ab	64 d	44 bc		
LMN111 in intercrop	2.51 bc	1.14 c	126 b	57 bc	0.95 a	0.90 a
LMN111 monoculture	2.56 b	1.29 c	53 d	26 c		
SPR'76COM3-5-2 in intercrop		1.77 bc		88 a		0.70 a
SPR'76COM3-5-2 monoculture		2.53 a		51 bc		
BKNFR76042-18-1-1 in intercrop		1.80 bc		90 a		1.04 a
BKNFR76042-18-1-1 monoculture		1.78 bc		36 bc		

[a]2 rows of deepwater rice (DWR) + 3 rows of early rice.

Table 5. Grain yield of early maturing rices (EV), deepwater rice (DWR), and total production from intercrop row combinations at Huntra and Prachinburi, Thailand, 1985 WS.

Treatment	Grain yield (t/ha)					
	Huntra			Prachinburi		
	EV	DWR	Total	EV	DWR	Total
2DWR+4EV	0.36 b	3.35 ab	3.71 ab	0.66 b	1.19 c	1.85 a
2DWR+3EV	0.14 c	3.12 b	3.26 b	0.52 b	1.53 bc	2.01 a
2DWR+2EV	0.19 c	3.90 a	4.08 a	0.44 b	1.87 ab	2.30 a
Monoculture DWR	–	3.43 ab	3.43 b	–	2.22 a	2.22 a
Monoculture EV	0.64 a	–	0.64 c	1.23 a	–	1.22 b

Table 6. Grain weight per 1-m row, number of panicles per 1-m row, and grain weight per panicle of deepwater rice from intercrop row combinations at Huntra and Prachinburi, Thailand, 1985 WS.

Treatment	Huntra (Pin Gaew 56)			Prachinburi (RD19)		
	Grain weight (g/m row)	Panicles (no./m row)	Grain weight (g/panicle)	Grain weight (g/m row)	Panicles (no./m row)	Grain weight (g/panicle)
2DWR+4EV	136.3 a	58.3 a	2.35 a	71.5 a	48.8	1.52 ab
2DWR+3EV	128.4 a	58.2 a	2.19 a	76.8 a	49.8	1.62 a
2DWR+2EV	107.9 a	52.7 a	2.05 a	74.6 a	43.6	1.71 a
Monoculture DWR	64.5 b	39.7 b	1.62 b	44.3 b	46.5	0.98 b

than at Huntra, but DWR RD19 is shorter and more upright than Pin Gaew 56, and did not spread out after harvest of the EV; thus, there was less compensation. Nevertheless, total yields of 2DWR+3EV and 2DWR+2EV were similar to the monoculture.

In DWR, compensation occurred in both number of panicles per meter of row and in weight of grain per panicle (Table 6). Both yield components increased as the number of EV rows was increased.

Intercrops with one to three rows of DWR alternating with two to four rows of an EV can give DWR component yields as high as that of a monoculture (all rows DWR) because, after harvest of the EV, the remaining DWR compensates by its relatively better survival of stems and its larger panicles than the monoculture.

DEEPWATER RICE FOR HERBAGE

Plant Physiology Department

Rice herbage can be an important forage in crop-livestock farming systems in DWR areas where rice is the only crop grown during the monsoon and growth duration is long. Two field experiments studied plant growth and yield as affected by herbage removal in a 160-d rice breeding line B4259-148-1-3-1-3. Herbage was harvested manually with scythes. Cutting heights and dates varied. In the second experiment, 2 cuttings were made: first at 33, 40, or 50 d after transplanting (DT), and again after 30 d.

Single cutting. *Herbage production.* Cutting low, combined with cutting late, gave the greatest amount of forage (Table 7). Delaying herbage harvest until maximum tillering (>80 DT) resulted in a sizable gain in forage yield.

Pruning at the collar of the first or the third leaf eliminated the need for exact height measurements while ensuring that no growing points were severed. Pruning at 15 cm comes to within 4 cm of the growing point at 80 DT and may damage it. Injury to the growing point affects tiller and panicle development.

Leaves comprised the major portion of the forage. Pruning at the collar of the first leaf gave forage composed of 100% leaf tissue. Cutting lower gave more culm tissue.

Table 7. Standing biomass and forage yield of B4259-148-1-3-1-3. IRRI, 1985 WS.

Cutting date[a] (DT)	Standing biomass (t/ha)	Forage yield[b] (t/ha)			
		Cut at 1st leaf[c]	Cut at 3d leaf[c]	Cut at 15 cm[d]	Cut at 30 cm[d]
40	2.4	0.7 ghi	0.9 f-h	0.8 f-i	0.5 i
50	3.5	0.8 f-i	1.2 de	1.4 d	0.6 hi
60	4.8	1.1 def	1.4 d	1.8 c	1.0 efg
70	6.1	1.4 d	1.7 c	2.6 b	1.3 d
80	6.3	1.4 d	1.8 c	3.2 a	1.9 c

[a]DT = days after transplanting. [b]Forage yields followed by a common letter are not significantly different at the 5% level by DMRT. [c]Collar of 1st or 3d leaf. [d]Distance from soil surface.

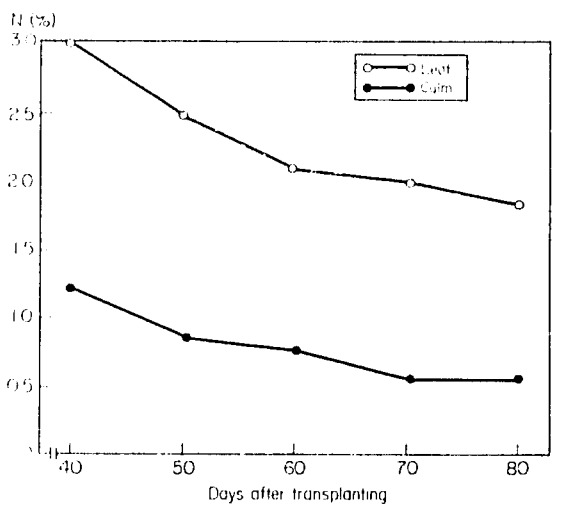
The N content of rice forage was comparable to or even better than that of other forage crops. The crude protein content of forage rice was highest during the early vegetative phase (Table 8). Leaf N was twice as high as culm N and declined with maturity much faster (Fig. 8). The deterioration of forage quality in terms of crude protein was due primarily to leaf maturation and secondarily to increasing the proportion of culm in the forage. The best time to harvest herbage for maximum crude protein yield is during the late vegetative phase when the large bulk of the forage makes up for the lower crude protein content.

Grain yield. Pruned plants suffered 12-62% yield losses, depending largely on cutting date and to a lesser extent on cutting height (Table 9). Herbage

Table 8. Crude protein of rice herbage. IRRI, 1985 WS.

Cutting date[a] (DT)	Crude protein (%)			
	Cut at 1st leaf	Cut at 3d leaf	Cut at 15 cm	Cut at 30 cm
40	17.63	16.13	15.94	19.81
50	14.81	13.19	13.50	15.19
60	11.63	11.00	9.31	12.38
70	11.19	10.56	9.81	12.00
80	11.50	10.56	9.31	10.94

[a]DT = days after transplanting.



8. Trends in leaf and culm N content of B4259 at the vegetative phase. IRRI, 1986.

Table 9. Grain yield of B4259-148-1-3-1-3 cut for herbage during the vegetative phase. IRRI, 1985 WS.

Cutting date[a] (DT)	Grain yield[b] (t/ha)				
	Uncut check	Cut at 1st leaf	Cut at 3d leaf	Cut at 15 cm	Cut at 30 cm
40	4.8 a	4.0 bc	3.8 cd	3.7 cde	4.0 bc
50		3.7 cde	4.2 b	3.9 bcd	4.0 bc
60		3.6 def	3.6 def	3.3 fg	3.6 def
70		3.3 fg	3.0 gh	2.6 ij	3.4 ef
80		2.9 hi	2.4 jk	1.8 l	2.2 k

[a]DT = days after transplanting. [b]Treatment means having a common letter are not significantly different at the 5% level by DMRT.

removal during the early vegetative phase had little adverse effect on grain yield. Treatments cut early showed yield losses ranging from 0.8 to 1.1 t/ha and acceptable grain yields of 3.7-4.2 t/ha. Given a higher market value for herbage or for the resulting animal product, pruning can be profitable and can compensate for the loss in grain yield.

Although pruning improved tiller production and increased the number of panicles per m^2, the differences in number of panicles were small and were not observed to increase yield. Pruning only slightly affected spikelet fertility, and changes in 1,000-grain weight showed no particular pattern.

The number of spikelets was mainly responsible for differences in grain yield resulting from cutting. This yield component was associated with time rather than height of cutting and declined progressively with lateness of cutting, following a trend similar to grain yield.

Dry matter production. Herbage harvesting did not improve total biomass (herbage + grain + straw + roots) production (Table 10). Early pruning was not detrimental to total dry matter production. However, plant dry matter at harvest was reduced by as much as 38% in one treatment as compared with the intact plants, the decline in plant weight occurring mostly in the culms.

Early removal of herbage increased the economically useful fraction of the rice crop. At late cutting, greater herbage removal gave low grain yield, resulting in lower harvest index. A rice crop could be cut or grazed to derive feed and later on still produce grain.

Double cutting. *Herbage production.* The herbage yield of rice when cut 33, 40, or 50 DT and subsequently cut again after 30 d ranged from 1.6 to 4.0 t dry weight/ha (Table 11). The maximum forage from 2 cuts was obtained from a 15-cm pruning at 50+80 DT. The highest forage yield under a single pruning came from late cutting and short cutting height. A double cut at 40+70 DT or 50+80 DT can provide the equivalent amount of herbage harvested from a single cut at either 60 or 70 DT.

Two cuts can spread herbage harvest throughout the crop season. It is possible to divide the herbage harvest by a 30-d interval depending on the need for green biomass. This practice would be applicable where the crop duration is more than 150 d.

Grain yield. Removal of leaves by 2 cuts reduced grain yield, and late double pruning — 50+80 DT — caused the greatest yield loss (Table 12).

Double pruning significantly reduced the number of spikelets per panicle. The number of panicles per m^2, filled spikelet percentage, and 1,000-grain weight were generally not affected by pruning.

Dry matter production. Growth was set back more severely by two cuts rather than by a single cut, and the total amount of plant material produced was generally lower with pruning than without (Table 13). The total plant dry weight decreased as a result of double pruning. Lower total plant weight was associated with lower leaf and culm weights following pruning: 25-70% reduction in the weight of leaves and 5-35% reduction in the weight of culms.

Economics. The economic feasibility of utilizing rice herbage for forage will have to be studied further to derive a range of management options. Diverse and nonconventional use of rice such as for forage may increase economic gains. A dual-purpose crop can increase the profitability of rice

Table 10. Total biomass (herbage + grain + straw + roots) production of B4259-148-1-3-1-3 cut for herbage during the vegetative phase. IRRI, 1985 WS.

Cutting date[a] (DT)	Total biomass[b] (t/ha)				
	Uncut check	Cut at 1st leaf	Cut at 3d leaf	Cut at 15 cm	Cut at 30 cm
40	13.2 abc	12.9 a-d	11.9 bcd	12.5 a-d	13.0 a-d
50		11.9 bcd	13.8 a	13.4 ab	13.8 a
60		13.4 ab	13.7 a	12.9 a-d	13.0 a-d
70		13.3 ab	11.8 b-e	12.4 a-d	12.9 a-d
80		12.3 a-d	11.4 de	11.4 cde	10.2 e

[a]DT = days after transplanting. [b]Treatment means having a common letter are not significantly different at the 5% level by DMRT.

Table 11. Standing biomass and forage yield under double and single cutting of B4259-148-1-3-1-3. IRRI, 1986.

Cutting date[a] (DT)	Standing biomass (t/ha)	Forage yield[b] (t/ha)			
		Cut at 1st leaf	Cut at 3d leaf	Cut at 15 cm	Cut at 30 cm
			First cut		
33	2.1	0.6 ij	0.8 hi	0.8 hi	0.3 j
40	4.0	1.0 ghi	1.2 fgh	1.3 efg	0.6 ij
50	5.2	1.3 efg	1.7 d	2.4 bc	1.5 def
60	6.1	1.6 de	1.7 d	2.7 b	1.7 d
70	7.1	1.7 d	2.1 c	3.4 a	2.5 b
			Second cut		
63	4.0	1.1 ef	1.4 bc	1.5 a	1.3 bcd
70	3.8	1.1 def	1.2 c-f	1.6 a	1.2 c-f
80	6.5	1.0 c-f	1.3 cde	1.7 a	1.6 a
			First cut + second cut		
33+63		1.7 hij	2.2 fgh	2.4 efg	1.6 ij
40+70		2.1 f-i	2.4 efg	2.9 cd	1.9 g-j
50+80		2.4 efg	3.0 bc	4.0 a	3.1 bc
60		1.5 j	1.7 hij	2.7 cde	1.7 hij
70		1.7 hij	2.1 f-i	3.4 b	2.5 def

[a]DT = days after transplanting. [b]Within each order of cut, forage yields having a common letter are not significantly different at the 5% level by DMRT.

Table 12. Grain yield of B4259-148-1-3-1-3 under double and single cutting. IRRI, 1985 WS.

Cutting date[a] (DT)	Grain yield[b] (t/ha)				
	Uncut check	Cut at 1st leaf	Cut at 3d leaf	Cut at 15 cm	Cut at 30 cm
33+63	4.8 a	3.6 cd	3.3 c-f	3.2 def	3.7 bcd
40+70		3.3 c-f	3.3 c-f	2.6 g-i	3.6 cd
50+80		2.9 fgh	2.5 hi	1.8 j	2.5 hi
60		4.1 b	3.5 cde	3.0 efg	3.7 bcd
70		3.5 cde	3.3 c-f	2.2 ij	3.0 efg

[a]DT = days after transplanting. [b]Treatment means having a common letter are not significantly different at the 5% level by DMRT.

Table 13. Total biomass (herbage + grain + straw + roots) production of B4259-148-1-3-1-3 under double and single cutting. IRRI, 1985 WS.

Cutting date[a] (DT)	Biomass[b] (t/ha)				
	Uncut check	Cut at 1st leaf	Cut at 3d leaf	Cut at 15 cm	Cut at 30 cm
33+63	13.3 ab	11.2 cde	11.2 cde	11.5 cde	12.4 abc
40+70		11.5 cde	11.8 cde	12.0 cd	11.6 cde
50+80		10.5 e	10.7 de	11.5 cde	11.3 cde
60		12.0 bcd	13.5 a	12.3 abc	13.3 ab
70		12.3 abc	10.6 de	11.2 cde	12.5 abc

[a]DT = days after transplanting. [b]Treatment means having a common letter are not significantly different at the 5% level by DMRT.

farming, depending on the combined prices of grain and animal products.

Two cuttings to obtain more herbage are possible. Although more labor is needed, two cuttings can provide the feeding interval needed for a better spread of the available herbage and labor. Varieties with longer growth duration such as in DWR areas will have more time to recover from pruning. Pruning rice crops in such areas may have fewer adverse effects on grain yield or may even be beneficial.

Soil and crop management

Tillage and management of soil physical conditions

Soils, Water Management, Agricultural Engineering, and Agronomy Departments

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EFFECTIVE USE OF WATER AND ENERGY IN WETLAND PREPARATION

Soils, Water Management, and Agricultural Engineering Departments

Puddling, soil aggregates, and water percolation. For rototiller puddling using minimal energy, water percolation is affected by the quantity of water applied immediately before cultivation (Annual report for 1985). Using the same soil as in 1985 (Vertic Tropaquept, 43% clay and 39% silt in 0-15 cm depth), we studied the effects of 5 precultivation watering regimes on percolation and on related soil physical properties. The regimes variously applied totals of 100, 200, and 300 mm of water by 100-mm applications during the 3d preceding puddling and on the day itself. Puddling was done at 7 kJ/m^2 of ground area with a floating rototiller. To simulate long-term effects, the puddlings and associated water regimes were imposed 4 times at 4-wk intervals, with soil submerged throughout, except for the 4 d immediately prior to each puddling and for some unavoidable drying between the third and fourth puddlings.

Water-dispersible silt-plus-clay, which measures how effectively puddling creates suspended material that can subsequently settle into pores and thus lessen percolation, was 6% prior to puddling, 19% after 1 puddling, and 31% after 2 or more puddlings. It was unaffected by water treatment. Bulk density at 0-5 cm depth was progressively decreased by the first 3 puddlings from 0.90±0.02 to 0.75±0.02 t/m^3; it was decreased no further by the fourth puddling.

Averaged over all watering treatments, the depth of easily removed soft mud, which was initially zero, was about 6 cm after 1 puddling, and 7.5 cm after 4 puddlings. After the fourth puddling, treatments for which 100 mm of water was applied on the day of puddling — but none on the preceding day — had a soft mud depth of 6.2±0.2 cm, regardless of whether 0, 100, or 200 mm additional water had been applied on earlier days. In contrast, soft mud depth was 7.8±0.3 cm when 200 mm of water was applied as 100 mm on the day of the puddling and 100 mm on the preceding day; it was 8.2±0.3 cm when 300 mm was applied during 3 successive days. Corresponding values (after the fourth puddling) for the depth of soil weaker than 0.4 MPa penetrometer resistance — at which rice root extension is inhibited — were 8.5, 8.8, and 9.7 cm, all ±0.7 cm. Thus, waste of land-soaking water by drainage is manifest as a shallower depth of soft, weakened soil.

The mass of soil aggregates of diameter >2 mm that survived 3 puddlings, as determined by wet sieving and averaged over all water treatments, was 12±1 g/100 ml of soil; it was 19±1 g before the first puddling. The first puddling also decreased the mass of aggregates >8 mm from 12±1 to 7±1 g/100 ml and caused corresponding increases of aggregates of 2-4 and 4-8 mm. These latter increases suggest that no aggregates in the smaller size classes were destroyed, and the puddling energy was used mainly to cut and break the larger aggregates. The second and third puddlings slightly lessened the mass of aggregates in all size classes. After the fourth puddling, however, aggregates >8 mm increased by 4±2 g/100 ml, probably indicating soil reaggregation caused by unavoidable wetting and drying cycles between the third and fourth puddlings. This hypothesis was supported by observations on aggregates subjected to alternate wetting and drying in the laboratory.

When 100 mm of water was applied on the day of puddling, but none on the preceding day, 9±1 g aggregates >2 mm/100 ml soil survived 4 puddlings. For treatments where for each puddling 200 or 300 mm was imposed in 100-mm applications on 2 or 3 successive days, aggregates >2 mm amounted to 14±2 g/100 ml.

Water percolation was affected by both puddling energy input (as determined by the number of puddlings) and puddling water treatment. Percolation rate, as measured by double-ring infiltrometer throughout 3 wk following each puddling and numerically corrected to standard conditions of the water table at ground level, was on average 30 mm/d — much higher than that with normal farmer practice. Such a rate is nonetheless comparable to rates previously recorded on the IRRI farm, where drainage hydrology creates large hydraulic gradients. Percolation would have been less in these experiments had there been a growing rice crop whose roots and associated microorganisms would have blocked some water-transmitting pores. Before the first puddling,

percolation was 40±10 mm/d. Puddling energy of 14 kJ/m^2 (the input of 2 puddlings) lessened percolation to 23±5 mm/d. There was no further decrease for cumulative energies of 21 or 28 kJ/m^2. Thus, 14 kJ/m^2 may have been sufficient to break all the easily breakable bonds between soil aggregates. Even after 4 puddlings, the percolation rate was 40±10 mm/d (the same as for nonpuddled soil) for treatments of 100 or 200 mm, whether or not in the latter there was a 1-d interval between the two 100-mm applications. For 300-mm water application, percolation was 24±7 mm/d when there was 1 d between applications, and 14±6 mm/d when the three 100-mm waterings were made on the day of puddling and on the 2 preceding days. Lessening of percolation by puddling may therefore be more effective if water is maintained between the soil aggregates during the days before puddling. Research needs to determine whether 200 mm or less of puddling water applied in more frequent but smaller applications can decrease percolation to less than 10 mm/d. Such research has relevance also for puddling of rainfed lowlands, where accretions of land-preparation water may be small and spasmodic. Four rototillings of a previously nonpuddled IRRI rainfed soil, using rainwater, lessened percolation from 2,000 to 7 mm/d.

Puddling implements and diurnal percolation patterns. In a separate experiment in the same field that was used for the study of precultivation watering regimes, three puddling implements were compared for their effects on water percolation and on IR60 growth. The implements — a floating rototiller, a skid-supported rototiller, and a plow and harrow — were individually used for such times that each transferred about 7 kJ/m^2 of ground area to soil that, when near-saturated by rain, had a 100-mm application of land-preparation water.

Daytime and nighttime percolations were each fastest on plots puddled by the floating rototiller (Table 1). However, both rice production and weed production were no less on these plots than on plots with much lower infiltration resulting from plowing + harrowing, although rice production was possibly higher following skid-supported rototillage. In supporting experiments, weed mass was higher with floating rototillage. Large differences

Table 1. Effects of puddling implements on water percolation, weed dry mass, and height and yield of IR60. IIRI, 1986 DS.

Implement[a]	Percolation[b] (mm/d)		Weed mass[c] (g/m^2)	Plant height (cm)	Grain yield (t/ha)
	Day	Night			
SRT	25	3	45	60	3.6
FRT	37	10	36	56	2.8
P + H	16	2	39	59	3.0
SED	20	5	13	2	0.3

[a]SRT = skid-supported rototiller, FRT = floating rototiller, P + H = plow and harrow. [b]Corrected for water table at ground surface; geometric mean of 2 replications. [c]At 50 d after transplanting.

between daytime and nighttime percolation were observed in other experiments and are larger than can be explained by temperature effects on water viscosity. They possibly indicate day-night differences in drainage hydrology resulting from daytime irrigation of surrounding areas.

These effects of drainage hydrology were investigated using double-tube infiltrometers with long inner tubes of 30 cm diameter, extending 25 cm into and 125 cm above the soil to allow measurement of percolation under a large hydraulic gradient. Infiltration I (mm/d) depended exponentially on the sum H (cm) of pressure head + water table depth:

$$I = 3.1 \exp(0.039 H)$$

($r = 0.91$, n = 27, day and night observations combined)

This equation should also describe changes in percolation caused by any subsurface changes in hydraulic potential.

Supporting observations showed that infiltrometers in which the inner tubes extend <25 cm into the soil and the outer tubes <20 cm are likely to overestimate percolation.

Bunds and percolation. In nonpuddled soil alongside and beneath bunds, percolation may be more rapid than in puddled soil (Annual report for 1985). A 1986 experiment tested this hypothesis by measuring percolation plus deep lateral seepage (P+DS) and percolation plus total lateral seepage (P+TS) on a 2 × 2 group of four 4.5- × 5.5-m field plots following repuddling immediately after removing the internal bunds. Removing the bunds increased the area-to-perimeter ratio of the

enclosed land from 1.2 to 2.6 m^2/m. For comparison, measurements had been made before removal of the bunds. Two adjacent 4.5- × 5.5-m plots were repuddled at the same time, but their bunds were left unchanged; 6 nearby control plots were left intact (they were needed particularly to correct for effects on percolation and deep seepage of variations in water table depth). All 12 plots were initially puddled, individually and under standing water, using rototiller energy of 5 kJ/m^2 of ground area, about 2 mo before bund removal and repuddling, also at 5 kJ/m^2. P+DS and P+TS could thus be compared among the groups of 2, 4, and 6 plots for periods both before and after bund removal and repuddling.

After repuddling the 2 plots, daytime P+TS, when corrected for changes in the 6 control plots and when standardized to 10 cm water table depth, decreased to 0.45±0.15 of its prepuddling value. On the 4 plots, removal of the internal bunds and subsequent repuddling caused essentially the same decrease to 0.52±0.15 of the prepuddling value. Corresponding ratios for daytime and nighttime P+DS were 0.32±0.12 and 0.33±0.10 for the 2 plots, and 0.17±0.08 and 0.11±0.05 for the 4 plots. Thus, where bunds were removed and the exposed soil repuddled (4 plots), decreases in P+DS were larger than for repuddling alone (2 plots) consistent with the hypothesis that percolation was more rapid through the nonpuddled zone. The hypothesis is further supported by analysis of the daytime percolation ratios: P+TS ratios were larger than P+DS ratios, indicating that repuddling, as expected, lessened DS more than TS. Additionally, the fractional value for daytime conditions of (P+DS ratio)/(P+TS ratio) for the 4 plots (0.17/0.52 = 0.33±0.20) was much smaller than for the 2 plots (0.33/0.45 = 0.73±0.30), confirming that deep seepage was considerably lessened by puddling the nonpuddled soil beneath bunds.

If water is indeed to seep rapidly down unpuddled soil beneath bunds, two requirements must be met: the saturated vertical hydraulic conductivity of soil beneath bunds should be larger than that of puddled soil inside the plots; and within the surface soil inside the plots, the horizontal saturated conductivity should exceed the vertical so that water will move preferentially toward the nonpuddled zone. These requirements were met in part; laboratory measurements showed that, for vertical flow, soil beneath the bunds was considerably more permeable than soil within plots; but within plots, horizontal conductivity exceeded vertical conductivity only at depths below 30 cm (Table 2).

Soil tests for choosing wetland preparation. Soil aggregate stability against dispersion in water has been evaluated as a predictor of the suitability of various rice soils for nonpuddling land preparations to lessen percolation. Stability of aggregates was measured for surface soils from previously puddled fields in Sukamandi (Indonesia), in Cavinti and Guimba (Philippines), and at IRRI, and from a nonpuddled site at IRRI. Puddled and nonpuddled soils from IRRI and puddled soil from Guimba were classified as suitable for lessening of percolation through compaction and smearing at field-capacity moisture using a duckfoot cultivator. On the previously puddled IRRI soil, the force needed to pull the cultivator through field-capacity soil was too large for a hand tractor. Cultivation was therefore made under wetter conditions, on soil that initially had a nighttime percolation rate of 21±12 mm/d; 2 successive duckfoot operations lessened percolation to 7±3 mm/d, and 2 successive plowings and harrowings to 2±1 mm/d. On the nonpuddled IRRI soil, percolation of 900±200 mm/d was decreased to 2±1 mm/d by the duckfoot and to 3±1 mm/d by plowing and harrowing.

Table 2. Vertical and horizontal saturated hydraulic conductivity at various depths within puddled plots and from nonpuddled soil beneath bunds separating those plots.[a] IRRI, 1986.

Depth (cm)	Saturated hydraulic conductivity (mm/d)		
	Beneath bund	Within plot	
	Vertical[b]	Vertical[c]	Horizontal[b]
0-10	600	10	1
10-20	1200	50	1
20-30	900	60	5
30-40	800	30	50
40-50	200	300	400
SE	±20%	±20%	±20%

[a]Laboratory determinations on undisturbed soil cores of 70 mm length and diameter; geometric means of replications. [b]4 replications. [c]6 replications.

Table 3. Effects of tillage on the specific moisture desorption partition and pore size distribution of 2 soils. IRRI, 1985 WS and 1986 DS.

Tillage treatment	Matric potential limits ϕ (MPa)	Specific desorption (1/MPa)	Pore size distribution: Range ($\times 10^{-6}$ m)	Pore size distribution: Relative volume in % total porosity
	Silty clay (Typic Argiudoll), 1985 WS			
Zero tillage	0 to −0.064	0.404	>2.27	37
	−0.064 to −0.229	0.340	2.27-0.63	8
	−0.229 to −0.373	0.062	0.63-0.39	2
	−0.373 to −0.732	0.021	0.39-0.20	3
	−0.732 to −1.500	0.033	0.20-0.10	16
	<−1.50		<0.10	34
Dry plowing	0 to −0.062	0.410	>2.34	45
	−0.062 to −0.826	0.108	2.34-0.18	14
	−0.826 to −1.500	0.080	0.18-0.10	10
	<−1.50		<0.10	31
Puddling	0 to −0.068	0.082	>2.14	18
	−0.068 to −1.500	0.086	2.14-0.10	33
	<−1.50		<0.10	49
	Clay (Andaqueptic Haplaquoll), 1986 DS			
Zero tillage	0 to −0.02		>7.26	12
	−0.02 to −1.50		7.26-0.10	22
	<−1.50		<0.10	66
Puddling	0 to −0.02		>7.26	12
	−0.02 to −1.50		7.26-0.10	22
	<−1.50		<0.10	66

LOWLAND RICE RESPONSE TO TILLAGE

Agronomy Department

The effects of soil type and moisture regime on lowland rice response to wet and dry tillage were tested in greenhouse and field experiments.

Greenhouse studies. Traditional puddling was tested against conventional dry tillage and zero tillage under simulated rainfed conditions on a silty clay soil (Typic Argiudoll) with IR20 as the test crop.

Puddling increased total soil moisture retention capacity (Table 3) and penetration resistance during the drying cycle. Dry tillage had contrary effects, but it nevertheless increased plant available soil moisture. Under alternate wetting and drying, root length density decreased more drastically in puddled than in dry-plowed plots because of increased penetration resistance (Table 4).

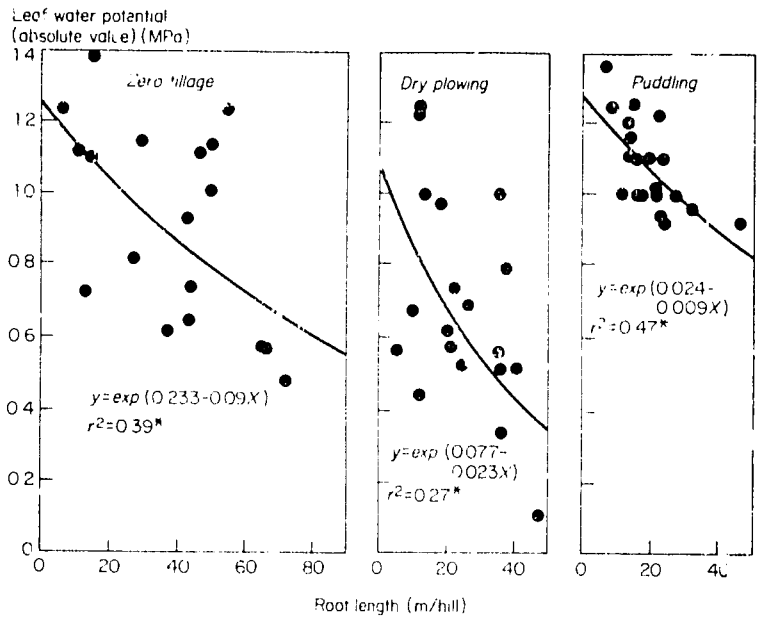
In all treatments, root growth was affected more by differential moisture desorption than by low matric potential *per se*. Tillage also affected the relation of plant water status to root density (Fig. 1). The rooting requirement for high leaf water potential varied from 14 m/hill in zero-tillage plots to 12 m/hill in puddled and 26 m/hill in dry-plowed plots. Despite their contrasting effects on soil physical conditions and root growth, tillage treatments did not significantly affect grain yield, which was very low.

Field studies. Puddling was compared with zero tillage in a clay soil (Andaqueptic Haplaquoll) under transient irrigation in 1986 dry season (DS). The effects of variable intensities of wet and dry tillage on lowland rice (IR20) were studied in a

Table 4. Effect of tillage on root growth of IR20 in a silty clay soil (Typic Argiudoll). IRRI, 1986 WS.

Soil depth (cm)	Root length density[a] (cm/cm³): Zero tillage	Dry plowing	Puddling
0-10	3.10 a	1.39 b	1.32 b
10-20	0.73 a	0.78 a	0.38 b
20-30	0.27 a	0.28 a	0.14 b
30-40	0.17 a	0.09 b	0.05 c
40-50	0.10 a	0.08 a	0.04 b
$\bar{X}$	0.87 a	0.53 b	0.38 c

[a] In a row, treatment means followed by a common letter are not significantly different at the 5% level by DMRT.

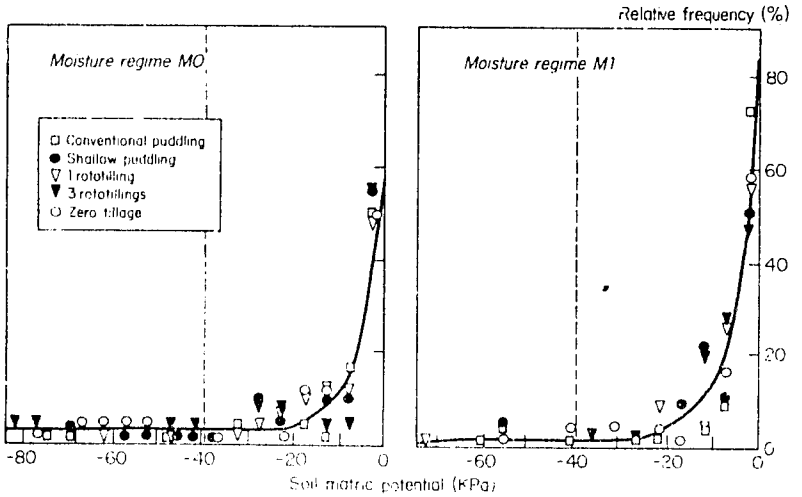


1. Effects of tillage on the relationship between root length and leaf water potential of IR20. IRRI 1985 WS.

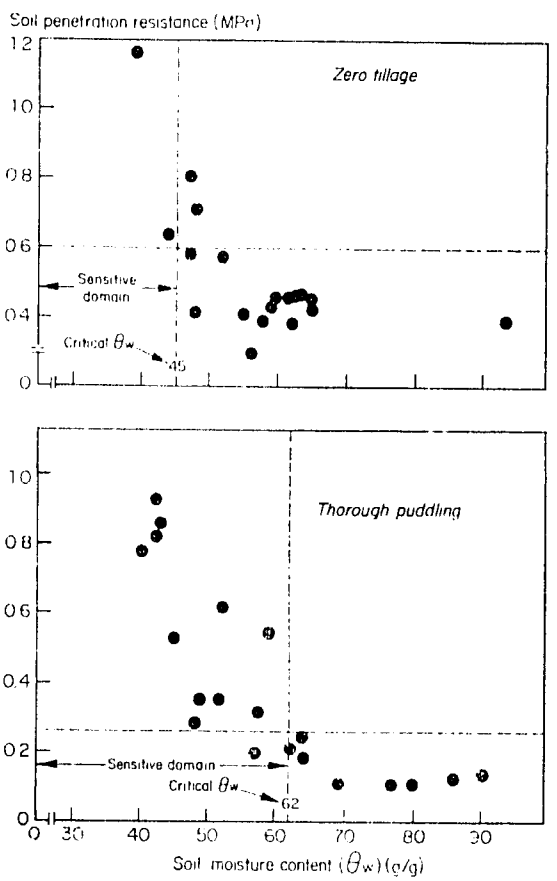
silty clay soil under 2 water regimes (M0 = 3 irrigations, wk at 5 cm above surface for 4 h, M1 = 2 irrigations, wk at 5 cm above surface for 4 h). Wet tillage techniques consisted of traditional and shallow puddling (5-7 cm deep by power weeder). Dry tillage methods consisted of one and three 8-cm-deep rototillings followed by submergence.

Wet tillage in silty clay soil increased moisture retention at matric potential < -0.033 MPa (Table 3). Increasing tillage intensity did not significantly improve soil water retentivity. Tillage did not affect the soil moisture characteristics of the clay soil. At both sites, tillage favored fast moisture depletion near the soil surface during the drying cycles because of cracking, which increased with clay content and tillage intensity. The profile average water stress was, however, less severe in tilled than in untilled soil. It was milder under traditional puddling and shallow puddling than under dry rototilling treatments (Fig. 2). Puddling increased penetration resistance of the silty clay soil under severe moisture stress. On the other hand, all tillage methods lowered soil strength where only mild stress occurred. In heavy-textured soil, however, even mild drought spells increased penetration resistance, more dramatically in puddled than in untilled soil. Within textural types, the responsiveness of soil penetration resistance to changing moisture status varied with soil dispersibility, which increased with tillage intensity. The threshold saturation deficit for significant increase in soil strength was lower with puddling than with other treatments (Fig. 3). Critical moisture status was more variable among tillage methods with clay than with silty clay soil.

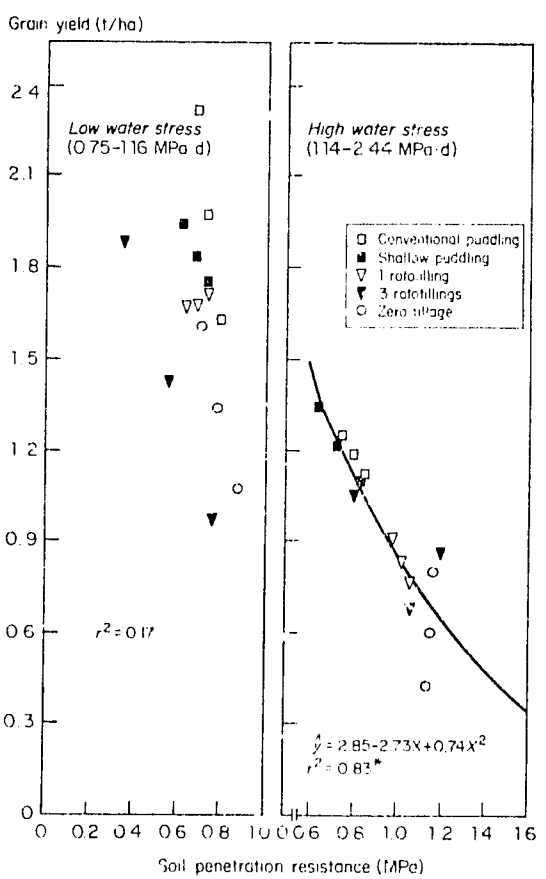
In medium-textured soil, tillage did not affect rice root growth under an adequate moisture regime. Under stress, however, high intensity tillage methods increased root length density, whereas zero tillage and one rototilling produced the contrary effect (Table 5). The root length density and grain yield of IR20 suffered significant decreases at soil penetration resistance >0.75 and >0.81 MPa, respectively, as the soil moisture stress at 15 cm depth fluctuated between 1.14 and 2.44 MPa during the growing season. Plant growth and yield were not correlated with soil strength when the soil water stress varied between 0.75 and 1.16 MPa (Fig. 4). Except for root length density, which was significantly higher in puddled soil than in untilled control (Table 6, 7), IR20 did not respond to tillage in heavy-textured soil, although the soil strength profile contrasted in the puddling and no-puddling treatments.



2. Effects of tillage on soil matric potential frequency distribution in a silty clay soil during drying cycles, IRRI, 1985 DS. M0 = 3 irrigations/wk at 5 cm above surface for 4 h, M1 = 2 irrigations/wk at 5 cm above surface for 4 h.



3. Effect of puddling on the relationship between moisture content and penetration resistance of clay soil. IRRI, 1986 DS.



4. Effects of soil strength on the grain yield of IR20 under 2 moisture regimes in a silty clay soil. IRRI, 1986 DS.

Table 5. Effects of tillage and moisture regime on growth of IR20 in a silty clay soil (Typic Argiudoll). IRRI, 1986 DS.

Soil depth (cm)	Root length density[a] (cm/cm³)									
	Irrigation at 3-d intervals					Irrigation at 6-d intervals				
	ZT	R1	R3	SH	PU	ZT	R1	R3	SH	PU
0-10	0.59 ab	0.89 a	0.42 b	0.40 b	0.85 a	0.34 c	0.60 c	1.05 b	1.04 b	1.73 a
10-20	0.07 a	0.16 a	0.11 a	0.06 a	0.06 a	0.07 a	0.13 a	0.07 a	0.15 a	0.16 a
20-30	0.03 a	0.07 a	0.05 a	0.05 a	0.05 a	0.05 a	0.04 a	0.03 a	0.07 a	0.04 a
30-40	0.03 a	0.07 a	0.03 a	0.04 a	0.05 a	0.02 a	0.04 a	0.04 a	0.03 a	0.01 a
$\bar{X}$	0.18 a	0.30 a	0.15 a	0.14 a	0.25 a	0.12 c	0.20 bc	0.30 ab	0.32 ab	0.49 a

[a]Within a water regime, and in a row, treatment means followed by a common letter are not significantly different at the 5% level by DMRT. ZT = zero tillage, R1 = one rototilling, R3 = 3 rototillings, SH = shallow puddling, PU = traditional puddling.

CULTIVATION OF PUDDLED SOIL FOR RAINFED LEGUMES

Soils and Agricultural Engineering Departments

For DS mungbean grown on previously puddled soil and using soil water remaining after harvest of irrigated rice, experiments in 1985 suggested that high nutrient uptake and yield might be achieved by combining deep and conventional tillage (Annual report for 1985). Those experiments also showed that, although mungbean growth benefits from seeding soon after rice harvest by utilizing seed zone moisture, it also is inhibited by chemically reduced soil conditions that persist after rice harvest.

Research in 1986 at IRRI and in farmers' fields measured the effects of deep (35 cm) winged-tine strip cultivation followed by conventional plowing (10 cm) and harrowing on the yield and rooting of CES 1d-21 mungbean, and measured the yield loss caused by reduced soil conditions. Supporting studies sought to evaluate the benefits to mungbean of seed dressings of calcium peroxide, fungicide, and rhizobia in puddled soil, and to measure the effect of the progressive drying of the compact layer in puddled soil on soil strength and mungbean growth.

The adverse effects of the compact layer might be avoided by relay-planting legumes into drained soil between rice rows at 5 d before rice harvest. Rice transplanted at a nonuniform row spacing that facilitated relay planting gave yield equal to that from uniform spacing, and relay-planted mungbean achieved high emergence and suffered no damage during rice harvest (Annual report for 1985). Trials in 1986 DS compared production from relay-planted soybean and from soybean planted soon after rice harvest into zero-tilled and deep-tilled soil.

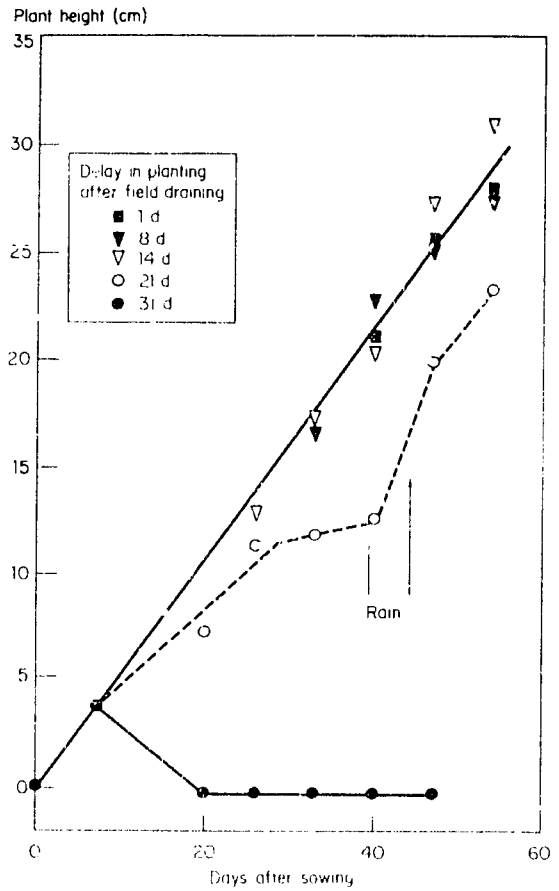
Table 6. Effect of tillage on root growth of IR20 in a clay soil (Andaqueptic Haplaquoll) at 2 growing stages. IRRI, 1986 DS.

Soil depth (cm)	Root length density[a] (cm/cm³)			
	Vegetative stage, 30 DT		Flowering stage	
	Zero tillage	Puddling	Zero tillage	Puddling
0-10	0.96 a	0.77 b	2.56 a	3.25 a
10-20	0.03 b	0.14 a	0.42 b	0.75 a
20-30	0.01 a	0.01 a	0.19 b	0.31 a
30-40	–	–	0.11 b	0.21 a
$\bar{X}$	0.33 a	0.31 a	0.82 b	1.13

[a]Within a growth stage and in a row, treatment means followed by a common letter are not significantly different at the 5% level by DMRT.

Table 7. Effect of tillage and moisture regime on grain yield of IR20 in a silty clay. IRRI, 1986 DS.

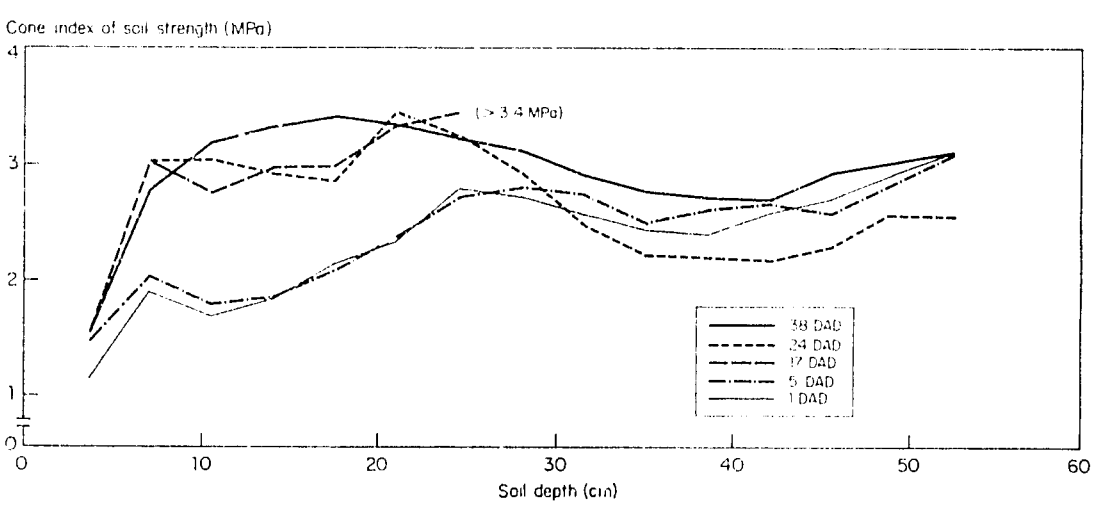
Tillage	Grain yield (t/ha)	
	Moisture regime A (2 irrigations/wk)	Moisture regime B (1 irrigation/wk)
Zero tillage	1.34 b	0.57 c
1 rototilling	1.84 a	0.78 bc
3 rototillings	1.42 b	0.77 bc
Shallow puddling	2.04 a	1.23 a
Traditional puddling	1.88 a	1.08 a



5. Effect on DS mungbean growth of drying of compact layer in previously puddled Vertic Tropaquept clay loam soil, IRRI, 1986. Drying was effected by delay in transplanting of potted seedlings.

Limitation of legume growth by the compact layer and chemically reduced seed zone in puddled soil. Into a Vertic Tropaquept clay loam soil that was puddled and then drained, 7-d-old CES 1d-21 mungbean seedlings were placed at 1, 8, 14, 21, and 31 d after draining (DAD). The seedlings were growing in moist soil in 5-cm-diameter × 10-cm-high nonrigid plastic tubes. The tubes were placed into 10-cm-deep holes with 5 cm diameter made by auger. The tubes had openings in the base to allow the roots to emerge and encounter the drying, strengthening soil at 10-cm depth and below. Plant height, rooting depth, and soil strength were measured weekly; depth to water table daily; and grain mass per plant at harvest. Plant heights (Fig. 5) were similar for placements at 1, 8, and 14 DAD. Growth was markedly less for placement at 21 DAD, but it was subsequently restored by 40 mm rain. With placement at 31 DAD, all plants died because their roots could not penetrate the soil, which by 38 DAD had attained a strength of >3.7 MPa at 25 cm depth, where the moisture content was 0.35 kg/kg; strength below 30 cm may have been less, as shown by curves for 1, 5, 17, and 24 DAD (Fig. 6).

For placements at 1, 8, and 14 DAD, depth and mass of roots at a comparable number of days after seeding (DAS) were equal; root mass for the 21 DAD placement was less, although depth of rooting was equal to that for earlier placements,

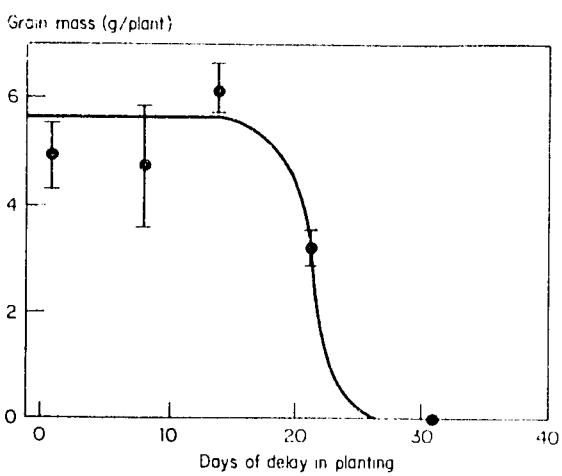


6. Cone index of soil strength at various depths at various days after draining (DAD) of previously puddled Vertic Tropaquept clay loam soil, IRRI, 1986 DS.

probably because of rain and a water table occasionally as shallow as 50 cm. There were no roots for placement at 31 DAD. Grain mass per plant was constant for 1, 8, and 14 DAD, and was less by half for 21 DAD (Fig. 7).

After rice harvest from previously submerged soil, the seed zone for succeeding legumes is chemically reduced. Seeding too soon into such soil can lessen seedling growth, but delaying too long causes soil drying and decreased emergence. CES Id-21 mungbean was sown at 0, 3, 7, 12, 18, and 25 DAD in a long-submerged Vertic Tropaquept clay loam soil. Manual seedings into nontilled (T0) and hoed (T1) topsoil were compared.

For sowings at 0 and 3 DAD, emergence percentage was 83±3 for T0, and 72±3 for T1; for 12 and 25 DAD, percentages for both T0 and T1 were equal, at 25±2 and 2±2. Plants at comparable DAS were highest when planted at 7 DAD into soil of +600 mV Eh, but were about 7% shorter for 0 and 3 DAD when Eh was between -100 and +200 mV. Plants were 15 and 55% shorter for plantings at 12 and 18 DAD, respectively, because of seed zone drying and perhaps shading by older plants. On replicate plots that stayed wet longer because they were adjacent to a flooded ricefield, a larger decrease in height was caused by reduced conditions, but there was less decrease because of drying.



7. Effect on DS mungbean grain of drying of compact layer in previously puddled Vertic Tropaquept clay loam soil, IRRI, 1986. Drying was effected by delay in transplanting of potted seedlings.

Machine-seeding of mungbean using a Massey University-IRRI inverted-T seeder was evaluated for factorial combinations of previously submerged (chemically reduced) and nonsubmerged (reoxidized) soils (each rewetted to 0.4-0.5 volumetric water content) and of tilled and nontilled seed zones cleared of stubble. For all 4 treatment combinations, the emergence percentage was >85; it was highest (94±3) on submerged tilled soil, possibly because submerged soil dried more slowly. The machine left some sectors of rows unplanted; the total length of unplanted sectors was about twice as large on nontilled than on tilled soil. In a trial in soil of only about 0.3 volumetric moisture content, the emergence percentage was only 22±11 in tilled and 8±4 in nontilled soil.

In soil of 0.42 volumetric moisture content, mungbean machine-planted about 4 cm from rows of rice stubble had an emergence percentage of 59±3; that planted midway between rows, at 8 cm from the stubble, had 54±3. The stubble lessened emergence (as compared to stubble-free soil) by mechanical disturbance of the seed-metering mechanism.

Supporting growth-chamber studies at 30/20 °C day/night temperature showed that dressings of calcium peroxide (CaO_2) did not increase germination percentage or seedling height of mungbean sown into previously submerged soil. The direct contact of CaO_2 with the seed may have been unfavorable for mungbean, as it is known to be with soybean. Greenhouse studies in soil tanks quantified the benefits for CES Id-21 mungbean of benomyl fungicidal seed dressing (F) and of rhizobial inoculation (I), and of their combination (IF). For sowing at 1 DAD, emergence percentage was 66±2 for the untreated (C), and 70±2 for F, I, and IF. For 3 DAD, the corresponding percentages were 87±2 and 93±2. Emergence was about 1 d later for untreated seeds. Damping-off affected all plants, but C plants the most. Plants were highest on IF and lowest on C treatments. At maximum height, the differences were about 10% and were greater for 1 than for 3 DAD. Grain yield was 1.5±0.2 t/ha for IF, and 1.3±0.1 t/ha for C.

Effects on rainfed mungbean of preceding submergence, cultivation, and fertilization of puddled soil. Using CES Id-21 mungbean as the test crop, field-scale operations in 1986 DS investigated the

effects of preceding submergence and, in factorial combination, three cultivation treatments and two N treatments. During the preceding wet season, two successive, fully irrigated rice crops were grown at the Vertic Tropaquept clay loam field site: the first over the whole field, the second on half the field only, in six randomized blocks with six complementary blocks repuddled but then kept fallow and nonsubmerged. After harvest of the second rice crop, all 12 blocks were briefly reflooded to equalize moisture. In the randomized block design there were 3 tillage treatments: no tillage (T0), conventional plowing and harrowing (T1), and conventional tillage preceded by deep strip tillage to 35-cm depth at 35-cm row spacings (T6) using a deep-winged tine (Annual report for 1985). On each tillage subplot, one-half received 30 kg N/ha, the other half none. Four blocks each of previously submerged, i.e., after-rice (AR), and nonsubmerged after-fallow (AF) plots were manually seeded during 2-3 Feb. A heavy rain delayed seeding of the remaining blocks until 10 Feb. For all treatments, spacing was 35 cm between rows and 4.5 cm between plants. All seeds received both fungicide and inoculant. Insects and mildew were controlled by appropriate sprays, and weeds by 1 hand weeding at 23 DAS. There was no irrigation after seeding. Although the DS rainfall of 64 mm was unusually large, the crops relied mainly on the profile of soil moisture remaining after the brief reflooding that simulated end-of-rice-season conditions. The water table was maintained under 2.0 m by rain.

Emergence percentage was 88 or more for all treatments, was not affected by preceding submergence, and was slightly lower for T6. A difference in growth between AR and AF plots was evident as early as 17 DAS, when AF plants (average of all tillage) were 13.5 cm high, and AR plants 9.8 cm. At maturity, heights were 61 cm for AF and 44 cm for AR. Correspondingly, maximum leaf area index (LAI) was 3.4±0.1 for AF and 2.5±0.1 for AR. Total dry matter yield (TDMY) at harvest (Table 8) was 5.0±0.1 t/ha for AF and 3.8±0.1 t/ha for AR.

Neither plant height nor LAI showed significant response to either fertilizer or tillage, but TDMY and fresh fodder yield were numerically but not significantly highest on T6 plots (Table 8). Treatment means for grain yield were determined with very high precision; they showed T6 had the numerically highest yield, but not by a sufficient margin to justify the high cost of deep tillage. The yield difference between AR and AF (average of all tillage) was highly significant at 0.35±0.05 t/ha.

In AR plots, plant height at maturity was 40 cm when seeding was delayed for 7 d by the 3 Feb rainfall, and 47 cm in promptly planted plots. In AF plots, the values were 47 cm in delayed plants, and 67 cm in promptly planted plots. Correspondingly, grain yield (average of AR and AF and of tillage) was 0.40±0.04 t/ha less than with prompt

Table 8. Harvest yields of total dry matter, fresh fodder, and grain of CES 1d-21 mungbean as affected by tillage and by preceding cropping.[a] IRRI, 1986 DS.

Tillage	Total dry matter[b] (t/ha)		Fresh fodder[b] (t/ha)		Grain yield (t/ha)			
					Planted 6 d after draining		Planted 13 d after draining	
	AR	AF	AR	AF	AR	AF	AR	AF
None (T0)	3.7	4.8	6.2	8.0	1.80	2.12	1.53	1.75
Conventional (T1)	3.7	4.9	6.0	8.6	1.79	2.17	1.47	1.76
Deep-winged tine + conventional (T6)	4.1	5.1	6.3	9.3	1.84	2.20	1.35	1.67
SE	0.2	0.2	0.3	0.5	0.05	0.05	0.06	0.10
Mean	3.8	5.0	6.2	8.6	1.81	2.16	1.45	1.73
SE	0.1	0.1	0.1	0.4	0.02	0.04	0.05	0.04

[a]AR = after rice, AF = after fallow. [b]From planting at 6 d after draining, and excluding plots located on unrepresentatively shallow soil.

planting. Moreover, because of difficulties associated with tillage operations, yields for delayed planting were lowest for T6 (Table 8). The yield advantage (average of all tillage) for prompt planting AF as compared with delayed planting AR was 2.16–1.45 = 0.71 ± 0.07 t/ha, indicating a potential for improvement of mungbean yields following irrigated or rainfed lowland rice of 0.71/1.45 = 49%. Such an improvement might be attainable through breeding and soil management.

The thermodynamic efficiency with which the yields were produced was determined from continuous measurement of irradiance interception and of plant dry matter increments. The efficiency of using absorbed photosynthetically active radiance (PAR) was about 3% during 20–40 DAS and declined thereafter to about 2% at harvest. Efficiency was slightly higher for AR plants, possibly because their smaller leaf area resulted in a larger proportion of their leaves being fully irradiated. The efficiencies were similar to those reported (see section on Climatic Environment and Rice) for DS mungbean grown on upland soil.

Grain yield Y (t/ha) correlated strongly with the season's total absorbed PAR (MJ/m²); combined results for 1985 and 1986 DS, for 5 types of tillage, and for AR and AF conditions gave:

$$Y = (0.33 \pm 0.11) + (0.0047 \pm 0.0011)\,\mathrm{PAR}$$

$$(r = 0.96,\ n = 15,\ P < 0.01;\ \mathrm{PAR} = 400\text{–}1\,100\ \mathrm{MJ/m^2})$$

In 1984 and 1985 DS, Y also correlated with depth of root-exploitable soil above a horizon of high soil strength. There was no correlation in 1986, possibly because the higher and better distributed rainfall (64 mm) of 1986 DS meant that the plants had less need to exploit the whole profile of soil-matrix water to meet their potential water requirement of 215 mm.

The shear strength of the soil at 0–40 cm depth was higher throughout the season in AF than in AR plots, because AR plots stayed wetter during 0–30 DAS by about 0.03 unit of volumetric moisture; at equal moisture, cohesion C and friction angle ϕ were the same for AF and AR. At 0–20 cm depth, C and ϕ at a specific moisture were slightly less than on the same field in 1985, possibly a result of the 2 intervening puddlings. Both T1 and T6 tillage in 1986 decreased C (average of AR and AF, 0–20 cm) from 15 ± 2 to 12 ± 2 kPa, and decreased tan ϕ from 0.68±0.04 to 0.63±0.02. At 10–35 cm depth, C and ϕ were expectedly less for T6 in both AF and AR plots.

Though soil strength was higher in AF plots, bulk density and moisture content at 0–20 cm depth were each lower there than on AR plots during 0–30 DAS. Both total and air-filled porosity were consequently higher on AF than on AR plots and notwithstanding high soil strength promoted more extensive rooting as determined by pinboard exposures at 2, 3, 5, 6, 10, and 11 wk after seeding (WAS). These showed strong correlations of root mass with air-filled porosity at 2 WAS for the 0–5 and 5–10 cm soil layers, and at 3 WAS for 10–20 cm; the respective soil layers were those where active root growth would be expected. Pinboards also showed that total root mass (0–100 cm depth, average of all tillage) at harvest was about 0.4 t/ha on AF plots, and about 0.3 t/ha on AR plots; moreover, root mass at 10–100 cm (i.e., excluding the thick primary roots) was about 0.23 t/ha on AF plots, compared with 0.16 t/ha on AR plots. The relative root growth rate did correlate significantly and negatively with the cone index of soil strength at 0–20 cm and throughout the growing season. Nonetheless, root mass was affected only slightly by tillage, possibly because 1986 DS rain kept the soil strength relatively low.

Higher root mass R (t/ha) was positively associated with grain yield Y (t/ha):

$$Y = (0.43 \pm 0.25) + (2.84 \pm 0.20)\,R$$

$$(r = 0.88,\ n = 9,\ 0.2\ \mathrm{t/ha} < R < 0.6\ \mathrm{t/ha})$$

although we may not yet conclude that higher R causes higher Y. Despite mungbean's lack of response to deep tillage in 1986, our experiments did provide direct evidence that extensive deep-soil loosening can promote a large increase in shoot growth. Parts of the field had been excavated in 1985 DS to sample root distribution (to 100 cm) and shear strength (to 40 cm). The pits were subsequently backfilled, but were of less compact structure. In 1986 DS, mungbean plants with roots exploiting the backfilled pits were significantly (10 cm) higher at the pit sites for delayed plantings in both AF and AR plots; the effects were much less for prompt planting.

In 1985 DS, the uptake of N, P, and K was higher during 0–28 DAS in plowed soil than in soil deep-tilled along strips only; during 28–57 DAS,

uptake was higher with deep-strip tillage. In 1986, uptake of N, P, and K from AF plots was highest in T6 during 0-22 and 43-58 DAS, and was equal for all tillage during 22-43 DAS; uptake from AR plots was at all stages similar for all tillage, and was about one-fourth lower than from AF plots, but was nonetheless much higher than in 1985.

Grain yields (Table 9) and nutrient uptake were larger in 1986 than in 1985 because of seed inoculation, better control of leaffolders and

Table 9. Grain yield of DS CES 1d-21 mungbean for various years and sites as affected by tillage and duration of possible reoxidation of the previously submerged rice soils. 1984-86.

Tillage	IRRI, 1984	IRRI, 1985[a]		IRRI, 1986[ab]		Santa Rosa, 1986
	AF	AR	AF	AR[bc]	AF[b]	AR
			Days of possible reoxidation			
	406	20	70	16	146	7
			Grain yield[c] (t/ha)			
None				1.8	2.1	0.9
Conventional	1.9	1.2	1.4	1.8	2.2	0.7
Narrow tine and tractor	1.9					
Narrow tine and winch	2.1					
Deep-winged tine		1.3	1.5			0.4
Deep + shallow tines		1.3	1.5			
Deep-winged + conventional				1.8	2.2	
			Rainfall (mm)			
	33	47		64		na[d]

[a]Excluding plots located on unrepresentatively shallow soil. AF = after fallow, AR = after rice. [b]For plantings at 6 d after draining. [c]From 2 primings; standard error of differences = 0.1 t/ha. [d]Not available.

Table 10. Effects of relay planting and through-the-crop tillage on emergence, survival, growth, and yield of UPL SJ2 soybean in previously puddled clay loam soil (Vertic Tropaquept).[a] IRRI, 1986 DS.

Planting and tillage	Emergence (%)	Plant deaths (%)	Root extension rate at 0 DAS-48 DAD (cm depth/d)	Root-mass growth rate at 0 DAS-harvest (kg/ha·d)	Shoot growth rate at 0 DAS-41 DAD (cm/d)	Maximum plant height (cm)	Grain yield (t/ha)
Relay planting at 12 DAD, no tillage (RT0)	52	9	1.8	2.4	0.96	48	1.09
Relay planting at 12 DAD, deep tillage at 14 DAS (RTC14)	52	11	1.5	3.3	0.86	42	0.78
Relay planting at 12 DAD, deep tillage at 21 DAS (RTC21)	52	9	1.6	4.5	0.79	37	0.63
Planting 18 DAD, no tillage (T0)	70	8	2.2	6.0	1.05	48	1.11
Planting 18 DAD, conventional + deep wingless tine (T6)	65	7	2.0	6.6	1.14	52	1.25
SE	2	2	0.2	0.5	0.04	2	0.10

[a]DAD = days after draining.

weeds, more rainfall, and longer growing season. Yields were also high in 1984, when both rainfall and potential evaporation were lower than in 1985 (Table 9). Table 9 also includes data for mungbean grown immediately after rice harvest in a Philippine farmer's field and shows the number of days for possible reoxidation of rice soils in both AF and AR treatments at both sites. The farmer's yields were much less than at IRRI, mainly because seedlings were submerged by very heavy rain soon after emergence; T0 plots were able to shed the floodwater more quickly, and consequently had higher yields.

Relay planting and through-the-crop deep tillage for soybean. In 1986 DS, UPL SJ2 soybean was planted in a clay loam (Vertic Tropaquept) at 60-cm row spacing between lines of rice stubble at 12 DAD. Three subsequent treatments were compared: no further treatment (RT0) and through-the-crop tillage to 35 cm (using a wingless narrow tine) at 14 DAS (RTC14) and at 21 DAS (RTC21). Two control treatments were T0 and T6, with tillage and seeding at 18 DAD.

Emergence was lower for relay planting, and TC14 and TC21 killed no more plants than died naturally on other treatments (Table 10). Shoots and roots grew fastest on T6 and T0; plants subjected to through-the-crop tillage showed definite slowing of shoot and root extension, and yielded less; the tillage possibly induced root drying and water stress. The yield for RT0 (1.09 t/ha) was equal to that for T0, notwithstanding that emergence and initial shoot and root growth were lessened by the wetter conditions during relay planting. Moreover, the RT0 yield was similar to that achieved for UPL SJ2 at comparable plant population but with thorough seedbed preparation and post-seeding irrigation in upland soil in 1986 DS (see section on Climatic Environment and Rice). Relay planting of soybean, but at 30 or 40 cm row spacing, may therefore have strong potential for achieving high production in a system convenient for farmers.

Climatic environment and rice

International Rice Testing Program and Multiple Cropping, Soils, Agricultural Engineering, and Entomology Departments

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VARIETAL RESPONSES TO CLIMATIC STRESSES IN IRTP TRIALS

International Rice Testing Program

The 1985-86 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 nursery reports of IRTP. Some of the entries that performed well across locations against various stresses are as follows:

- *Drought tolerance*

  From rainfed lowland nurseries: BH2, BKN6721-5-7-4, BRB11-448-1-4, BRB32-75-4, BRB34-74-3, GFU77042-0-4K-28, IR13259-153-5F-P2-3, IR13358-16-3-2, IR21586-R-31-1, IR26716-12-2-1-3, IR26724-246-1-1, IR4422-480-2-3-3-1E-P1, MRC48337-3144, RTN90-4, TCA178, TCA180-4

  From upland nurseries: B3622f-Tb-14-4, BR160-2B-4-8-HR16, Farox 298, Farox 302, INIAP415, IRAT111, IRAT140, IRAT170, ITA186, M55, TOX475-NIB1-NK1-LS3-B1, TOX906-67-1-1

  From deepwater nurseries: BKN6986-1, BKNFR76024-100-1-5-1, BKNFR76026-3-2-2-3, BKNFR76035-112-1, BKNFR76045-85, BKNFR76055-166-4-1, DWCT114-140-1-1-140-1, DWCT156-1-2-0-1, HTA7463-110-1-1-3-0, IR11185-R-0-7, Jalamagna, RD19

- *Submergence tolerance*

  BKNFR76026-3-2-2-3, BKNFR76042-18-1-1, CN506-147-2-1, FR13A, RD19, IR11185-R-0-7 IR11185-RRR-88-2, IR21038-77-P2-5-2-3-1-1, IR6370-K23-1, SPR7295 53-2-1-3, Tilakkachari

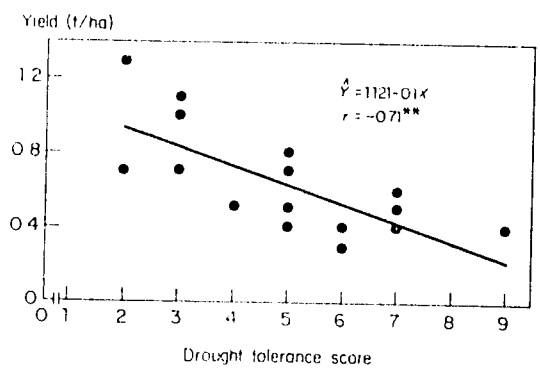
- *Low temperature tolerance*

  Barkat, Cheolweon 29, Cheolweon 31, Cheolweon 32, China 1039, Diamante-Inia, K333, K335, K39-96-1-1-1-2t, Lien-chan-ze-thou, Quella-Inia, Reinei, Stejaree 45, Ta-Mao-Tao, Wasetoramochi

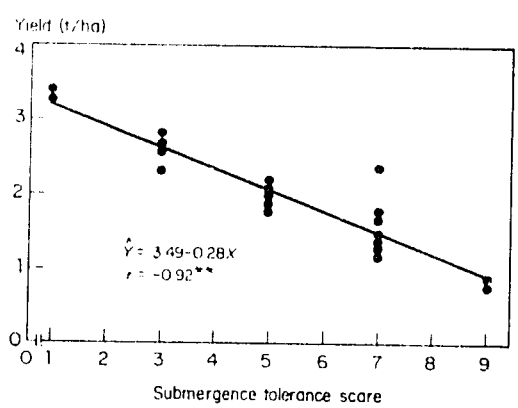
- *Drought and low temperature tolerance*

  B3619c-Tb-8-1-4

The importance of varietal tolerance for drought under upland conditions is well illustrated by the results from the IRTP Upland Rice Yield Nursery conducted in Santo Tomas, Batangas, Philippines, where severe moisture stress occurred during the reproductive phase. The yields obtained in that trial were negatively correlated with the drought tolerance score or, in other words, positively associated with the level of tolerance for drought (Fig. 1). The local check Dinalaga and IRAT144 produced the highest yields of 1.3 and 1.1 t/ha, and most entries yielded less than 0.5 t/ha. The IRTP Rainfed Lowland Yield Nursery conducted in Phitsanulok, Thailand, showed a similar relationship between yield performance and level of varietal tolerance for submergence (Fig. 2). The trial was completely submerged in water exceeding 1 m depth during booting and flowering. The mean yield was 2.0 t/ha. The tolerant varieties RP1057-



1. Regression of grain yield on drought tolerance score (0 = most tolerant, 9 = most susceptible) in the 1985 International Rice Testing Program (IRTP) upland yield nursery conducted in Santo Tomas, Batangas, Philippines.

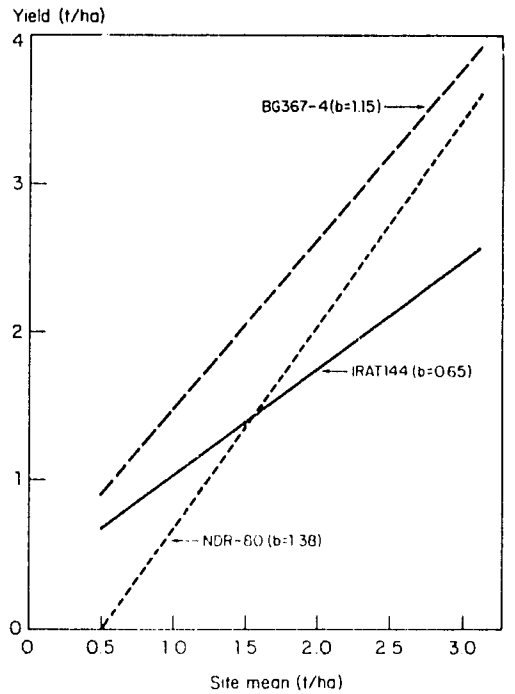


2. Regression of grain yield on submergence tolerance score (0 = most tolerant, 9 = most susceptible) in the 1985 IRTP rainfed lowland yield nursery conducted in Phitsanulok, Thailand.

184-5-3-2 and Mat Candu produced yields of more than 3.0 t/ha, and the susceptible lines IR19431-72-2 and IR14753-86-2 yielded less than 1.0 t/ha.

Regression analysis of the varietal yields on the site means in the IRTP upland yield trials conducted at 16 sites representing various degrees of moisture stress showed stable performance by the drought-tolerant variety IRAT144 (stability index = 0.65). However, BG367-4 from Sri Lanka outyielded IRAT144 at all site mean levels (Fig. 3).

In the IRTP International Rice Cold Tolerance Nursery, a comparison of the flowering durations of entries at selected sites in tropical, subtropical, and temperate regions and at different elevations showed that the breeding line K335 has a remarkable degree of stability in duration to flowering (Table 1).



3. Regression of yield of 3 selected varieties on site means (23 varieties, 16 sites). IRTP upland yield trials, 1985.

SIMULATION OF POTENTIAL RICE PRODUCTION UNDER DIFFERENT WEATHER CONDITIONS USING LORICE

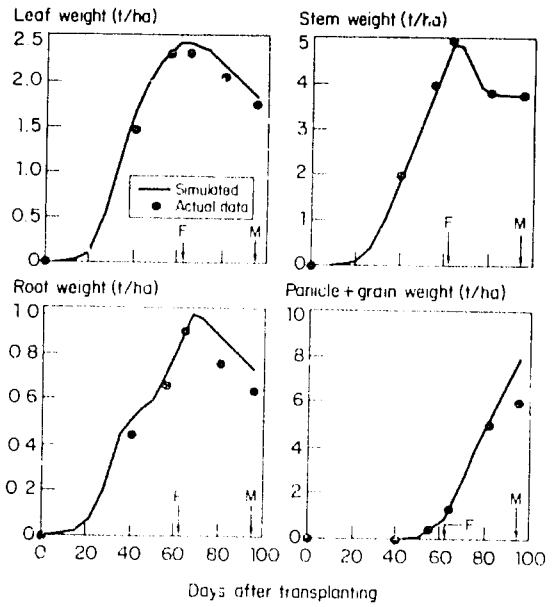
Multiple Cropping Department

A simulation model, LORICE, developed by the Centre for Agrobiological Research, The Netherlands, was used to calculate potential rice production under different weather conditions. The model assumes optimum conditions of water and nutrients and negligible influence of pests and diseases. The only variables affecting crop performance are weather, crop management, and the characteristics of the cultivar; these factors comprise the input data requirements of the model. The model considers the processes affecting the growth and development of the crop, such as photosynthesis, respiration, partitioning of assimilates to organs, translocation of reserves, losses and

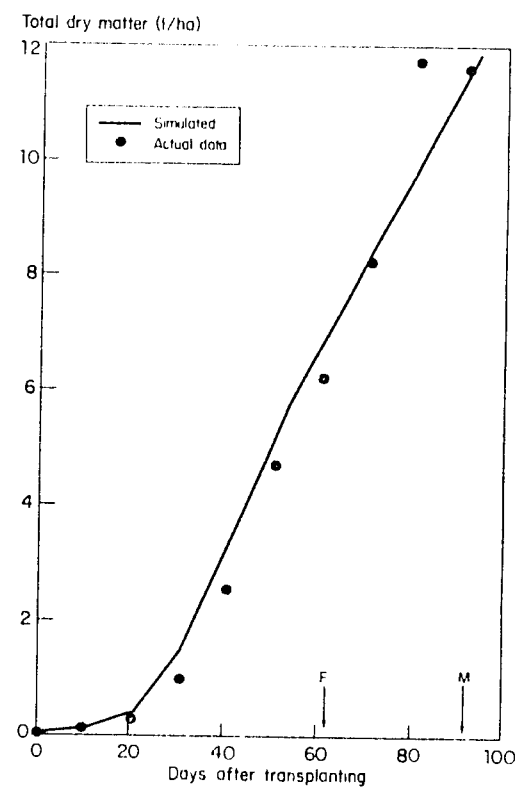
Table 1. Varietal differences in stability of days to flowering, IRTP International Rice Cold Tolerance Nursery.

Variety	Days to flowering at different sites[a]					
	Temperate		Subtropical		Tropical	
	(1)	(2)	High altitude (3)	Plain (4)	High altitude (5)	Plain (6)
			Tolerant entries			
Stejaree 45	138	110	95	90	98	75
Ching-shi 5	149	118	94	93	108	71
Barkat	131	96	88	89	96	78
K335	116	88	80	77	84	73
China 1039	138	110	85	88	96	69
			Nontolerant entry			
IR19746-26-2-3-3	NF	NF	96	94	105	73

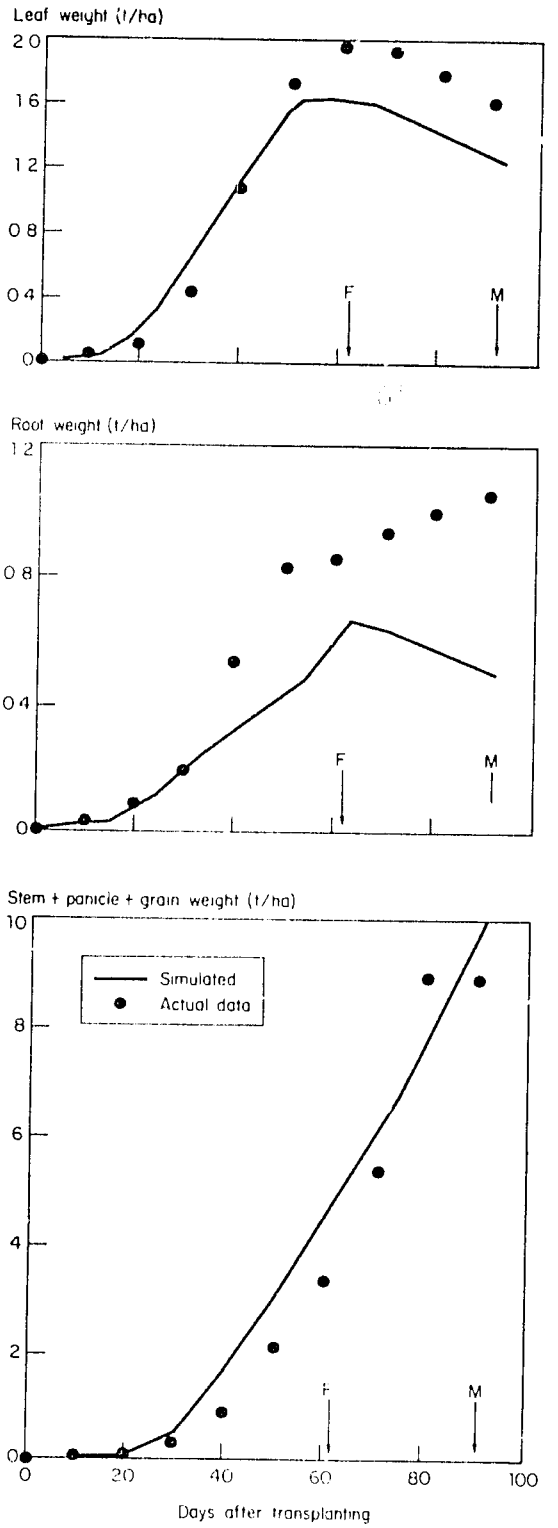
[a] 1 = Szarvas, Hungary (latitude 47°N, elevation 85 m), 2 = Vercelli, Italy (45°N, 132 m), 3 = Wangdiphodrang, Bhutan (37°N, 1500 m), 4 = Changsha, China (37°N, 30 m), 5 = Banaue, Philippines (17°N, 1200 m), and 6 = Joydebpur, Bangladesh (23°N, 8 m). NF = did not flower.



4. Simulated and actual distribution of total dry matter to different plant organs of IR36, Plant Physiology Department, IRRI, 1986 DS. F = flowering, M = maturity.



5. Simulated and actual total dry matter of IR36. Model parameters from Plant Physiology Department, IRRI, 1986 DS; actual data from the International Rice Weather Yield Nursery, IRRI, Nov 1984.



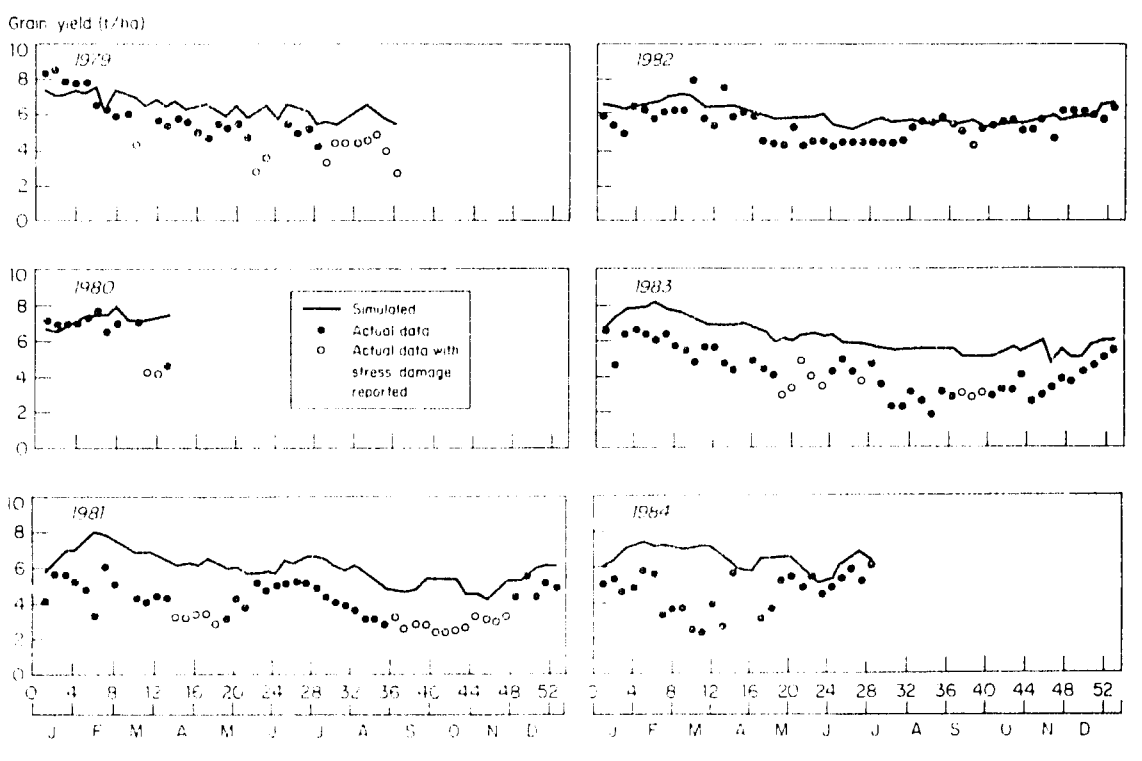
6. Simulated and actual distribution of total dry matter to plant organs of IR36. Model parameters from 1986 DS experiment, Plant Physiology Department, IRRI; actual data from Nov 1984 International Rice Weather Yield Nursery, IRRI.

reallocations of carbohydrates from dying organs, increase in leaf area, and sink limitation.

When the model was adapted to a dry season (DS) experiment of IRRI's Plant Physiology Department on the growth characteristics of IR36, there was good agreement in trend and amount between the simulated and actual dry weights (Fig. 4). However, the grain yield was overestimated because of the higher leaf area index (LAI) estimated by the model. The LAI actually measured was lower because of a high rate of leaf senescence, which was apparently a function of the high temperatures experienced in May 1986. High temperature effects on leaf area were not incorporated in the model.

The model was validated using the 1984 DS International Rice Weather Yield Nursery at IRRI. Initial conditions in the experiment were entered, and a change was made in the initial partitioning of the assimilates to the leaves and stems. Results of the validation are given in Figures 5 and 6. The model overestimated the total dry matter from 20 d after transplanting to flowering (Fig. 5). After this period, it generally approximated the actual values. Overestimation of the total dry weight before flowering was caused primarily by an overestimation of stem and panicle weight (Fig. 6). The grain yields predicted by the model were close to the actual yields, and the harvest indexes were about the same.

The model was used to estimate grain yield for different planting dates in 1979-84 (Fig 7). The yields of rice crops planted in January and February were estimated to be the highest during the year. Such plantings enable the crop to be at the reproductive phase during periods of high solar radiation and high diurnal temperature range. The actual yields from the Rice Garden experiments of 1979-84 followed a similar trend, although they were often lower than the estimated yield (Fig. 7). The variability of the model yields over time was low, whereas the variability in the actual yields was



7. Simulated and actual grain yield for weekly transplantings of IR36 seedlings. Model parameters from 1984 DS experiment, Plant Physiology Department, IRRI; actual data from Rice Garden experiments, Training and Technology Transfer Department, IRRI.

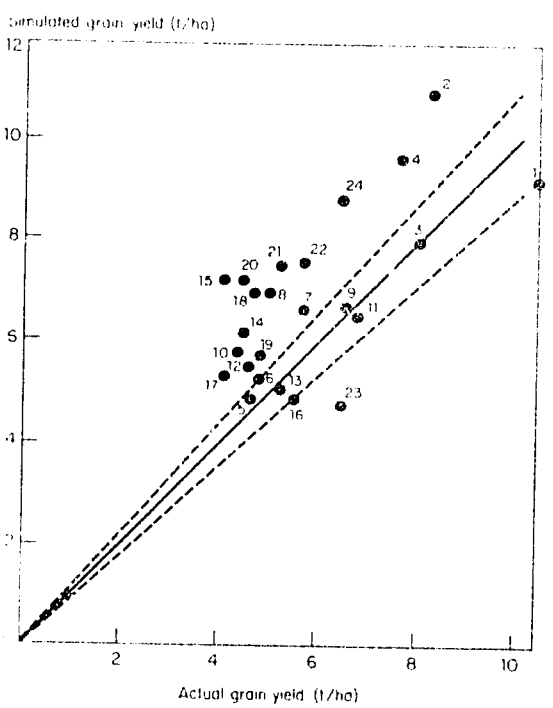
high. Some nonweather factor (or factors) influencing yield was responsible for the variability in actual yields.

Model predictions corresponded well with actual grain yields for 24 trials in the International Rice Weather Project covering 13 sites in 9 countries (Fig. 8): 21% of the trials were close to the 1:1 yield correspondence line. Differences in simulated and actual yields may have been caused by inaccuracy in the estimation of the initial weights of the seedlings, among other factors. It was only in one trial at IRRI that data on the initial weight at transplanting and periodic measurements were available; the initial weights at transplanting for the other trials were interpolated using the IRRI data. Also, some nonweather and weather stresses and nonoptimal management conditions reported in the trials were responsible for differences in the estimated and actual grain yields.

A higher total accumulation of radiation during the postflowering phase was generally associated with higher yields, in both the model and experimental results. The model overestimated all wet season (WS) plantings. The adverse effects of intense rain — such as lodging, pest and disease incidence, and other physiological effects — may have caused the actual yields to be lower.

The model was tested for sensitivity to changes in some of its variables. Changes in the initial weight of the crop and the initial development stage were found to affect grain yield significantly. The model is also sensitive to changes in some of the parameters of maximum specific leaf weight, reference specific leaf weight during the time of maximum leaf photosynthesis, and maximum leaf photosynthesis. Runs of the model with different assimilate partitioning tables indicated that varieties have unique partitioning patterns. Management practices may also cause differences in the partitioning pattern. Also, the actual temperature sum from transplanting to flowering is a better predictor of phenology at different locations than a constant temperature sum.

The model as a whole reasonably estimated actual yields. Improvements can be made if more accurate data on variables that significantly affect yield are available and if low or high temperature stress effects are incorporated in the model.



8. Simulated and actual grain yield for 24 trials at 13 locations, International Rice Weather Project, IRRI, 1986. $R = 0.66$. Numbers represent individual trials.

TOPOSEQUENCE WATER BALANCE, SOIL SUBMERGENCE, YIELDS, AND SIMULATIONS FOR UPLAND RICE

Soils and Entomology Departments

For upland rice grown along a gently sloping hill toposequence, 1983-85 WS experiments determined the conditions under which uptake of shallow groundwater can increase growth and yield. They also indicated that hydrological effects may in part be mediated chemically, as by Fe:Mn balance, or biologically, as through weeds and rice blast. Research in 1986 WS sought to confirm these findings and to evaluate a numerical simulation (UPRICE) for growth, yield, and water relations of upland rice on a toposequence. One component of UPRICE simulates irradiance interception and photosynthesis by rice leaves. The defoliation of rice, as by yellow stem borer, and its effect on photosynthesis and yield may therefore be simulated by a variant of UPRICE coded UPRIPE. The 1986 WS experiments tested UPRIPE by imitating stem borer damage through mechanical defoliation (detillering) of chosen

proportions of rice plants on designated plots at specific growth stages.

In the field of Typic Hapludoll soil that was used in 1985 WS, measurements in 1986 were made at 3 elevations along the toposequence. From 1985 results, average depths to the water table were predicted to differ by about 30 cm between lower and intermediate and between intermediate and upper elevations. At each elevation there were 5 replicate 9- × 11-m plots, in each of which were monitored the soil and crop (IR36) variables that are needed to operate and evaluate the UPRICE simulation. The variables included plant height; leaf area; root density; dry matter, straw, and grain yields; soil-water content and pressure; hydraulic conductivity; water-retention characteristics by the soil horizon in 0-1.0 m depth; and depth to groundwater. Intercepted photosynthetically active radiance (PAR) was measured on selected plots by tube solarimeters, and standard agrometeorological recordings were made at a nearby observatory.

For the UPRIPE evaluation, 9 additional 9- × 11-m plots were established, all at the same (lower) elevation so that the effects of defoliation would not be confounded by variations in depth to groundwater. In these 9 plots, defoliation of IR36 at 3 growth stages (maximum tillering, panicle initiation, and grain filling) at each of 3 intensities involved cutting at just above ground level 0, 15, and 30% of the tillers in 1.0-m square subplots.

The UPRIPE plots were located among and alongside the lower-elevation UPRICE plots in such a manner that at this lower elevation 10 plots were available for evaluating UPRICE. The plots were arranged in 2 blocks of 5 replications, with average soil-surface elevation differing within blocks by <3 cm and between blocks by only 12 cm. The lower blocks were designated 1A and 1B, and the blocks at the intermediate and upper elevations as 2 and 3. All plots at all elevations received appropriate fertilization and were regularly monitored for plant health and incidence of weeds and insects.

The hydrology of 1986 WS was similar to that of 1984 WS: rainfall of 5 mm or more occurred on 55 d, and rainfall of 1 mm or more on nearly two-thirds of the growing season days, with no rainless period longer than 2 d. Total WS rainfall (1,689 mm) was 65% higher than the long-term mean (Table 2). In consequence of this total amount and distribution of rainfall, soil drying at 0-20 cm proceeded only to −0.02 MPa and did not affect rice growth, and maximum depth to groundwater — attained during 8-10 wk after seeding (WAS) and again just before harvest (Fig. 9) — was no larger than 70 cm at the lower elevation and 120 cm at the upper. Conclusions from the 1983-85 experiments indicate that such hydrological conditions should not cause a rice yield response to elevation along the toposequence, and 1986 measurements of high precision (Fig. 10, lower curve) confirm that yield variation along the toposequence was not caused by variation in depth to water table. The upper curve in Figure 10 shows that 1985 yield dependence on toposequence position was very similar to that of 1986. Both curves show lower production at the intermediate elevation, in part because of less favorable profiles of soil strength. At all elevations, these profiles contained in their top 1.0 m 2 horizons of increased soil strength — the first rather weakly developed,

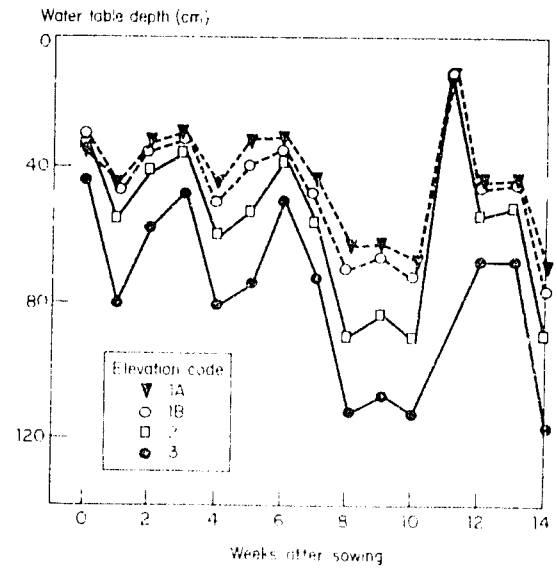
Table 2. Hydrological features, IRRI wet seasons.

Year and crop season	Season's total rainfall (mm)	Season's number of days of rain >1 mm (d)	Season's number of days of rain >5 mm (d)	Driest soil-water potential at 0-20 cm depth (MPa)
1983, 1 Jun-30 Sep	1158	64	39	−0.10
1984, 1 Jun-30 Sep	910	72	48	−0.06
1985, 1 Jun-31 Oct	1616	68	48	−0.10
1986, 18 Jul-3 Nov	1689	73	55	−0.02
1975, 1 Jul-31 Oct	894	60	38	—[a]
1960-64, 1 Jun-30 Sep	1034	67	42	—[a]

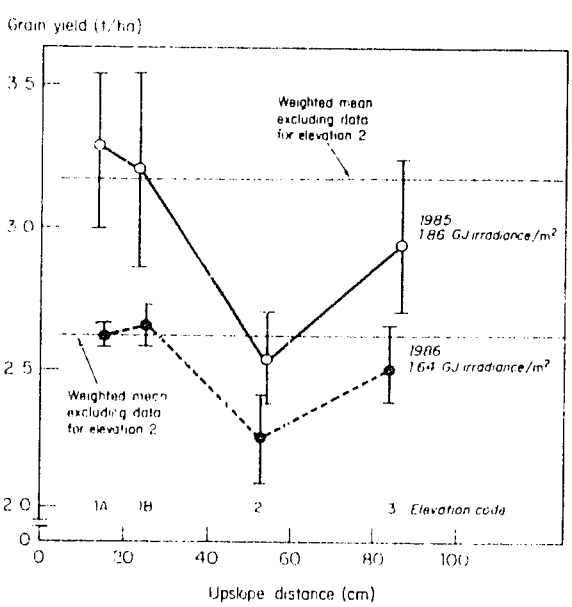
[a]Not measured.

the second more strongly. For plots at elevations 1A, 1B, and 3, grain yield Y (t/ha) related to depth D_1 (cm) to the first (shallower) strong horizon as:

$$Y = (2.37 \pm 0.18) + (0.005 \pm 0.004) D_1 \quad (r = 0.32,\ n = 15;\ 25\ \text{cm} < D_1 < 55\ \text{cm}) \qquad (1)$$



9. Seasonal progression of depth to water table at 4 toposequence elevations. IRRI, 1986 WS.



10. Grain yield of upland IR36 at 4 upslope distances along a toposequence, IRRI 1985 and 1986 WS. Bars indicate ± SE.

The coefficient (0.005±0.004), though nonsignificant, is useful for subsequent comparison. At elevation 2, depth D_1 varied little between replicate plots; it generally was shallower than at other elevations, as was depth D_2 to the second strong horizon. Yield at elevation 2 did not conform to eq. 1 but did relate to D_2 through:

$$Y = (0.21 \pm 0.22) + (0.026 \pm 0.010) D_2 \quad (r = 0.84,\ n = 5;\ 60\ \text{cm} < D_2 < 85\ \text{cm}) \qquad (2)$$

Y is related to D_2 rather than to D_1 because the first strong horizon was less developed and the vertical separation $D_2 - D_1$ of strong horizons much less at elevation 2 than elsewhere.

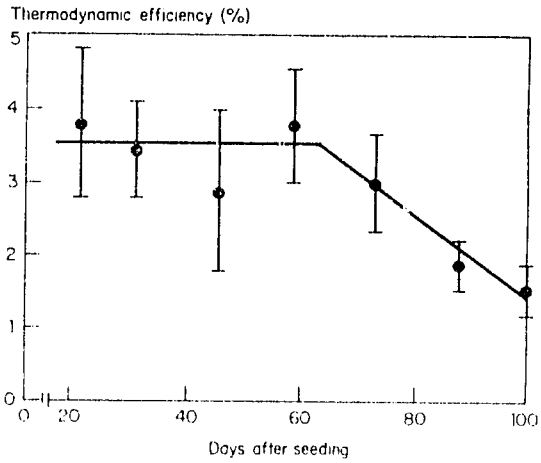
For elevations 1A, 1B, and 3, as for elevation 2, Y correlated with D_2 more significantly than with D_1:

$$Y = (1.66 \pm 0.15) + (0.010 \pm 0.004) D_2 \quad (r = 0.62,\ n = 15;\ 69\ \text{cm} < D_2 < 95\ \text{cm}) \qquad (3)$$

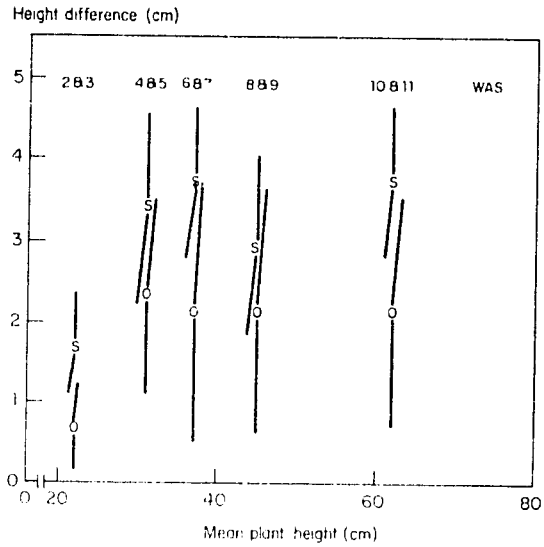
Eq. 1, 2, and 3 each indicate that rice yield increased with depth of root-exploitable soil; the highly significant eq. 3 is consistent with our 1985 findings for mungbean on a neighboring upland soil.

Rice yields were lower in 1986 than in 1985 (Fig. 10) partly because the 1986 season's total solar irradiance was less and LAI was lower — 2.7±0.3 at 8 WAS in 1986 compared with 3.3±0.2 in 1985. The photosynthetic efficiency with which the yields were produced was determined from measurements of the seasonal progression of plant-mass increment and of total and absorbed PAR. For 1986, efficiency of use of PAR averaged over the growing season was 2.7%. For elevations (1A, 1B, 3) with approximately equal yields, Figure 11 shows that the thermodynamic efficiency of using absorbed PAR was roughly constant (~3.5%) during 0-60 d after seeding (DAS), and declined after 60 DAS to about 1.5% at 100 DAS. These efficiencies are generally less than, and their seasonal progressions different from, those in 1985, possibly because of differences in leaf concentrations of N and other elements.

Within individual plots in 1986, variation in rice growth had both hydrological and chemical causes. The intense and persistent 1986 rainfall during 0-8 WAS resulted in several days' submergence of the soil immediately upslope of the terrace boards.



11. Seasonal progression for thermodynamic efficiency of upland IR36 in using absorbed photosynthetically active radiance. Elevations 1A, 1B, 3, IRRI, 1986 WS.



12. Difference within plots in upland IR36 height between plants near upper and lower plot boundary boards as related to mean plant height, WAS, and whether plots were substantially submerged (S) or not submerged (0) after prolonged heavy rain, IRRI, 1986 WS. Data points all indicate that plants were taller near the upper boundary; bars indicate ± SE.

Although IR36 was bred for lowland conditions, this submergence lessened growth, as we determined by comparing heights of plants near the upper (less submerged) and lower (more submerged) boundaries within individual plots, and by classifying all plots according to the proportion of their areas that during daytime in 0-2 WAS remained submerged for 4-8 h after 3- or 4-d rainfall totals >50 mm. Figure 12 shows the average difference, within plots, in height of plants near the upper and lower boundaries in relation to mean plant height, WAS, and whether plots were substantially submerged (S) or not (0). Differences were apparent as early as 2 WAS following heavy rain during germination and emergence at 0-5 DAS; they increased until 4 WAS, and thereafter were constant until crop maturity. From 4 WAS, plants near the upper boundaries on S-plots were higher than lower-boundary plants by 3.3 cm. Moreover, among the S-plots, differences were larger, though not significantly so, for plots with more extensive or prolonged submergence. For 0-plots, mean difference after 4 WAS was 2.1 cm, consistently less than for S-plots. However, the fact that for 0-plots the average was significantly positive suggests that 0-plots may also have suffered some unobserved (perhaps nighttime) submergence that lessened seedling and plant growth near the lower boundaries. Aboveground dry matter confirmed this effect of submergence samplings at 6 WAS were by chance near lower plot boundaries — and showed that plant mass in more submerged plots was 22±12% (1.5±0.8 t/ha) lower than in less submerged plots.

Shoot concentrations of nutrients and potentially toxic elements were also compared for regions within individual plots that showed contrasts of poor and good growth. Such contrasting regions usually but not always coincided with submerged and nonsubmerged regions. Concentrations (as total for each element) differed most for Al, Fe, and Mn. Table 3 shows that the concentration of Al in poor growth regions at elevation 2 was toxic, and that in good growth regions was highest at elevation 2, where yield was lowest. For Mn and Fe, concentrations in regions of both good and poor growth were within tolerable limits, although Fe in poor growth regions at elevation 2 was nearly toxic. But the Fe-to-Mn ratios varied more: in good growth regions they were all below the growth-limiting lower limit of 1.5, and in poor growth regions at elevation 2 they were markedly higher than the upper limit of 2.5.

Because the total elemental concentration of Fe is not a good indicator of Fe available for plant

Table 3. Plant concentrations of potentially toxic elements in poor and good growth regions of IR36 upland rice on a toposequence hill slope at 77 DAS.[a] IRRI, 1986 WS.

Elevation code	Good growth region	Poor growth region[b]
	Al (ppm)	
1A	115	–
1B	115	–
2	170	362
3	158	172
	Mn (ppm)	
1A	106	–
1B	103	–
2	220	65
3	233	62
	Fe (ppm)	
1A	107	–
1B	104	–
2	172	269
3	158	127
	Fe:Mn	
1A	1.0	–
1B	1.0	–
2	0.8	4.3
3	0.7	2.0

[a]DAS = days after sowing. [b]Poor growth regions occurred only at elevations 2 and 3.

growth, measurements were also made in 1986 of active iron Fe^{+2}. Leaf samples were taken on all plots at 27, 56, and 70 DAS, and Fe^{+2} was extracted with 1.5% orthophenanthroline solution at pH 3. Concentrations were above the deficiency limit of 45 ppm at 27 DAS, but below that at 56 and 70 DAS (Table 4). The concentration was no less at elevation 2, where grain yield was lower. The accumulation of Fe^{+2} in aboveground plant tissue (Table 4) was about 13 g/ha at 27 DAS, 80 g/ha at 56 DAS, and 130 g/ha at 70 DAS, which was probably sufficient for rice growth. The low yields in 1986 were not caused by lack of active Fe.

The spatial variability in growth and yield of upland IR36 in 1986 WS was determined on two areas of newly cleared land adjacent to the IRRI upland farm. The areas were roughly rectangular (45 × 100 and 50 × 130 m) and had a 2% slope. The smaller area received no fertilizer, and the average yield from 26 harvest plots of 2.0 × 2.5 m was 2.2 t/ha, with a range of 1.2-3.4 t/ha. The larger area had 90-30-30 kg NPK/ha. The average yield from 45 harvest plots was 3.3 t/ha, and the range

Table 4. Leaf concentration and accumulated shoot content of Fe^{+2} in upland IR36 at 27, 56, and 70 DAS and at various elevations along a toposequence. IRRI, 1986 WS.

Elevation code	Fe^{+2} concentration (ppm) at			Fe^{+2} total shoot content (g/ha) at		
	27 DAS	56 DAS	70 DAS	27 DAS	56 DAS	70 DAS
1A	60	32	37	12	76	126
1B	66	33	39	16	99	145
2	62	31	37	13	64	125
3	58	35	36	13	79	148
SE	3	2	2	2	12	16

was 2.4-4.3 t/ha. The average yield in the fertilized area was thus larger than the 2.5 t/ha obtained for fertilized IR36 in the toposequence study (Fig. 10), where individual plot yields ranged less widely (1.9-2.9 t/ha). For the new areas, the higher variability of growth was confirmed by the measured coefficients of variation for plot yield along 50-m transects. The patterns of variation across the new areas were complex and were not related to the equally complex variations in depth to groundwater and in drainage hydrology (as in the toposequence study, rice was not expected to benefit from groundwater uptake in 1986 WS). Soil profiles to 100 cm depth at 22 locations on the larger of the new areas each contained 1 layer of high strength, at depths between 20 and 35 cm. The toposequence field generally had 2 strong layers in 0-100 cm. The smaller of the new areas has not yet been surveyed. For the larger area, grain yield correlated ($P < 0.10$) with soil depth above the strong layer:

$$Y = (2.25 \pm 0.42) + (0.040 \pm 0.018)D_1 \quad (r = 0.29,\ n = 45;\ 20\ \text{cm} < D_1 < 35\ \text{cm}) \qquad (4)$$

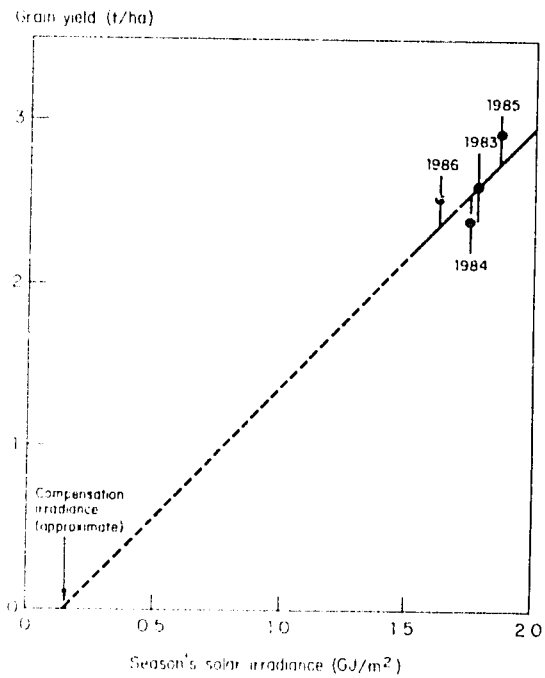
Within the large uncertainties, the parameters of eq. 4 are consistent with those of eq. 1. If the yield-depth relation is real, increased availability of soil-water deriving from extra soil depth is *not* likely to have been the reason, because surface soil stayed persistently moist in 1986 WS. Whether the mechanism is nutritional — through increase of cation exchange sites — or physical — through improved aeration or another process — is yet to be determined.

SIMULATIONS FOR GROWTH AND DEFOLIATION OF UPLAND RICE

Soils and Entomology Departments

Average toposequence yields differed between 1985 and 1986 in part because of solar irradiance (Fig. 10). Totals of WS irradiance also explained some of the IR36 yield variation during 1983-86 (Fig. 13). However, correlations such as in Figure 13 cannot explain the absolute magnitudes either of the grain yields or of the regression coefficients in eq. 1-4. Predictions for grain yields in different years and on different soils should therefore be sought in deterministic crop-growth simulations, such as the IRRI-Centre for Agrobiological Research (Netherlands) UPRICE, which synthesize the interactive effects of weather, soil, and physiological processes.

This model was used to simulate IR36 growth at upper and lower elevations on three IRRI toposequences in 1983, 1985, and 1986. The crop-water balance component of the simulation requires water retention and water transmission characteristics and measured initial soil-water content for the distinct soil layers within crop rooting depth, as well as daily measured values for depth to water table and weather variables. Water retention and transmission characteristics may sometimes be estimated through correlations with soil texture; however, the characteristics of IRRI volcanic soils are beyond the valid range of these correlations and need therefore to be measured for the IRRI toposequences. Comparisons of simulated and measured yields (Table 5) show that, at upper and lower elevations, the measured mean yields were much less than simulated values, indicating perhaps that actual yields were constrained by processes not included in the simulations. If the severity of the influence of such processes was



13. Measured mean grain yield of upland IR36 in relation to season's total solar irradiance. IRRI, 1983-86 WS.

Table 5. Simulated and measured IR36 grain yield in upland rice WS toposequence experiments at IRRI fields UO1 (1983), UQ2 (1985 and 1986), and RF34 (1986).

Year and field	Yield (t/ha)			Irradiance (GJ/m²)
	Measured mean	Measured largest	Simulated	
		Lower elevation		
1983 UO1	3.3	3.6	4.5[a]	1.79
1985 UQ2	3.6	4.2	4.7[b]	1.86
1986 UQ2	2.6	2.9	4.9[b]	1.64
1986 RF34	3.2	3.9	4.9[a]	1.64
		Upper elevation		
1983 UO1	1.8	2.3	3.9[a]	1.79
1985 UQ2	2.4	3.3	4.8[b]	1.86
1986 UQ2	2.5	2.8	4.9[b]	1.64
1986 RF34	3.3	4.2	4.9[a]	1.64

[a]Estimated soils data. [b]Measured soils data.

random across sites, then some individual measured plot yields might approach simulated values more closely, as indeed occurred (Table 5, "measured largest"). In 1986, the measured mean and largest yields were lower (and further from simulated yields) for the longer-used field UQ2 than for the newly cleared RF34, possibly because of nutritional factors as suggested in Table 3. Moreover, 1985 UQ2 predictions indicate a need for modifications in the simulations of initial growth and of ripening-phase phenology.

However, the simulations of soil-water processes were acceptably close to reality. Measured and predicted soil-water contents for various UQ2 soil layers during the dry period within 1985 WS usually agreed to within 0.05 unit of volumetric water content.

Simulations by UPRIPE of rice growth under conditions of mechanical defoliation must await the further development of UPRICE. The effects on IR36 yield of mechanical defoliation (detillering) in 1986 WS are shown in Table 6. Yield was hardly affected by defoliation at maximum tillering. With defoliation at panicle initiation or at grain filling, percentage yield loss was equal to the percentage (15 or 30) of tillers removed.

Table 6. Decrease of upland IR36 grain yield resulting from mechanical defoliation (detillering). IRRI, 1986 WS.

Time of defoliation	Grain yield decrease[a] for defoliation intensity of			
	15%		30%	
	t/ha	%	t/ha	%
Maximum tillering	0.19	7	0.06	2
Panicle initiation	0.35	13	0.74	28
Grain filling	0.43	16	0.74	28
SE	0.12	5	0.12	5

[a]Grain yield with no defoliation = 2.62 ± 0.04 t/ha.

MEASUREMENT OF SOIL-WATER RETENTION CHARACTERISTICS

Soils Department

Simulation of upland rice growth requires water retention characteristics for the distinct soil layers at each specific field plot. Within-plot variability of these characteristics requires that replicate samples be measured, usually on a pressure-plate extractor using vertical cylindrical samples. However, each sample requires many days to achieve equilibrium at the driest (−1500 kPa) water potential. Because the time to attain equilibrium is proportional to the square of sample height, tests were made to determine whether for IRRI upland soil valid water-retention data can be obtained if the equilibrium time is shortened by decreasing sample height from 5 to 3 or 2 cm. Lessening of sample height also allows more samples to be equilibrated concurrently in one pressure extractor chamber, because more layers of extractor plates and samples can be accommodated. Measurements on 3-cm- and 2-cm-high samples of 5 cm diameter were made for 5 depths in 0-50 cm on 5 plots of field UQ2. Water retention curves showed no systematic bias among sample sizes and showed variation due to sample size comparable to that between replications. Values for the quantity of water retained (between −3 and −300 kPa as calculated from the retention curves) were in close agreement at all soil depths (Table 7). We conclude that valid data may be derived from the 2-cm cores, but at least 3 replications should be measured. From such 2-cm-high samples, we determined (Table 7) that the plant-available water-holding capacity (−3 to −1500 kPa) was almost constant at 11 mm water/10 cm soil for all depths in 0-50 cm.

Table 7. Effect of sample height on moisture retention as measured by pressure extractor for various depths on IRRI Typic Hapludoll upland soil.[a] 1986.

Soil layer depth (cm)	Retained water[b] (mm) per layer from samples of indicated height		Available water holding capacity[c] (mm) per layer from 2-cm-high samples
	3 cm	2 cm	
0-10	7.0 ± 0.3	6.4 ± 0.6	11.6 ± 1.2
10-20	6.7 ± 0.5	5.4 ± 0.5	10.2 ± 1.9
20-30	6.5 ± 0.9	7.0 ± 0.8	10.7 ± 0.8
30-40	5.7 ± 0.1	6.4 ± 0.4	11.6 ± 0.7
40-50	6.6 ± 0.3	6.3 ± 0.4	10.9 ± 0.8
0-50	32.5 ± 1.1	31.5 ± 1.2	55.0 ± 2.6

[a]Average of 5 plots dispersed among 3 elevations, field UQ2. [b]Between −3 and −300 kPa. [c]Between −3 and −1500 kPa.

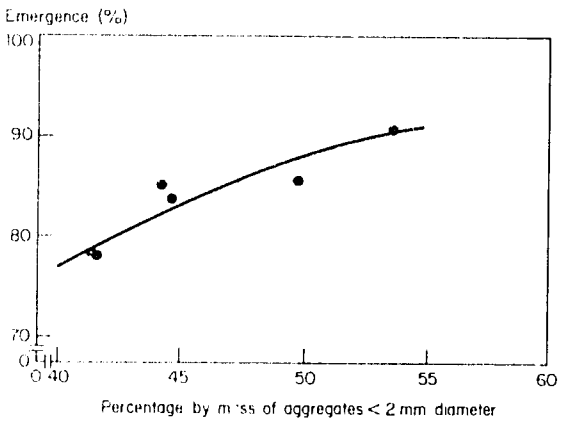
MACHINE-SEEDING OF RICE, MAIZE, AND MUNGBEAN INTO UPLAND SOIL

Soils and Agricultural Engineering Departments

Initial trials for upland rice of the Massey University/IRRI inverted-T seeder were promising (Annual report for 1985). Trials in 1986 showed that machine planting of larger-seeded (IRAT13) and smaller-seeded (N22) varieties gave acceptably high rates of emergence (although lower than with manual seeding), provided that the volumetric soil-water content exceeded 0.30. The machine was less effective in planting the larger-seeded variety, despite the fact that the distribution of soil aggregate sizes should favor the germination of larger seeds. We studied the effect of aggregate sizes on seed emergence for manually planted N22 seeds only. Emergence increased with the proportion of aggregates that were small in relation to seed width and thickness (Fig. 14).

Inverted-T seeding into upland soil was also evaluated for maize and mungbean. In a sandy clay loam, machine seeding into untilled or conventionally tilled soil gave emergence rates of 1.7 (maize) and 4.0 (mungbean) times higher than for manual seeding into tilled soil. With manual sowing, many seeds did not germinate, despite the wetter seed zone soil (−11 kPa potential) at sowing than in the machine-seeded plots (−14 kPa for tilled and −19 kPa for nontilled plots). The soil structure created by the machine's soil opener was better able to supply water for seed imbibition than the manually created structure. (The performance of the inverted-T seeder in previously puddled soils is reported in the section on Tillage and Management of Soil Physical Conditions.)

Seed zone temperature also was affected by soil structure. Midday temperature at 3-5 cm depth was 35 °C on nontilled machine-seeded plots and 34 °C on manually sown tilled plots. Interactions of temperature with soil-water potential are also important for legume germination. Growth chamber studies of such interactions, using 7-cm-deep beds of 2 mm sterilized upland soil crumbs, were made for soybean varieties UPL SJ2 and UPL SY2. The optimal temperature was 30 °C, at which both varieties achieved 70% emergence (Table 8) in soil between −3 and −40 kPa. The



14. Relation of percentage emergence of hand-sown N22 upland rice to percentage by mass of seed zone soil aggregates smaller than 2 mm in diameter. Typic Hapludoll silty clay loam of volumetric water content 0.32-0.35, IRRI, 1986.

Table 8. Maximum percentage of emergence and range of soil-water potential within which emergence exceeds one-half maximum for 2 soybean varieties at 4 temperatures.[a] IRRI, 1986.

Temperature (°C)	UPL SJ2 Maximum emergence rate (%)	UPL SJ2 Water potential limits for half maximum emergence: Lower (kPa)	UPL SJ2 Water potential limits for half maximum emergence: Upper (kPa)	UPL SY2 Maximum emergence rate (%)	UPL SY2 Water potential limits for half maximum emergence: Lower (kPa)	UPL SY2 Water potential limits for half maximum emergence: Upper (kPa)
20	35	nd	−2	60	nd	nd
25	45	−300	−2	65	−300	−1
30	70	−300	−3	70	−300	−3
35	55	−100	−1	50	−100	−1

[a]Seeds were sown dry into beds of 2 mm crumbs of IRRI upland soil. Growth chamber had 50% relative humidity. nd = not determined.

ranges of soil-water potential suitable for soybean emergence were less easily determined than for mungbean (Annual report for 1985), but Table 8 does indicate interaction of temperature with the dry and wet potentials corresponding to one-half of maximum emergence. The decline of emergence in wet soil was caused by fungal attacks despite sterilization treatments. At 20 and 25 °C, UPL SY2 germinated more effectively than UPL SJ2.

AGROHYDROLOGY OF DRY SEASON LEGUMES FOLLOWING UPLAND RICE

Soils Department

At the upper elevation of the toposequence field, mungbean CES 1d-21 and soybean UPL SJ2 were each grown at three row spacings during 1986 DS in a collaborative experiment with the University of Reading, England, the International Fertilizer Development Center, and the International Institute of Tropical Agriculture. The row spacings of 25, 50, and 75 cm generated plant populations of about 0.6, 0.3, and 0.2 million plants/ha, respectively. Effective seedling emergence was achieved by a 20-mm irrigation. The mungbean and soybean also received 50 and 54 mm of rain between seeding on 8 Jan and respective harvests on 19 Mar and 9 Apr. Potential transpiration averaged 3 mm/d, and depth to water table varied between 1.0 and 2.0 m. By 45 DAS, soil-water potential throughout the 0-50 cm depth was less (more negative) than −50 kPa for 25-cm row spacing and less than −40 kPa for 75-cm spacing. From 60 DAS, narrow-spaced soybean dried the soil at 80-cm depth to potentials below −30 kPa.

Maximum total dry matter and forage yield (Table 9) were higher for mungbean [illegible] which accumulated matter until maturity [illegible] than for soybean. Because of water stress and leaf senescence, soybean accumulated little between 61 DAS and maturity at 89 DAS. Maximum LAI was higher for soybean, and grain yields (averaged over row spacings) were equal. Although larger plant populations increased maximum dry matter, they did not cause consequent increases in grain yield (Table 9).

The season's average extinction coefficient for absorption of total solar irradiance was higher for mungbean (0.67±0.03 m^2/m^2) than for soybean

Table 9. Effect of row spacing and plant population density on growth, photosynthetic efficiency, and yield of dry season CES 1d-21 mungbean and UPL SJ2 soybean in upland soil,[a] IRRI, 1986.

Row spacing (cm)	Plant density (no. × 10^6/ha)	Maximum leaf area index (m^2/m^2)	PAR absorbed during 0-61 DAS (MJ/m^2)	Thermodynamic efficiency of using PAR during 0-61 DAS (%)	Maximum total dry matter (t/ha)	Forage yield (t/ha)	Pods (no./plant)	Grains (no./pod)	Mean grain mass (mg)	Grain yield (t/ha)
				Mungbean						
25	0.64	1.9	197	2.3	3.6	1.88	5.4	7.5	58	1.50
50	0.31	1.3	145	2.6	2.5	0.95	7.9	6.2	57	0.95
75	0.22	0.8	112	2.6	2.1	0.97	8.6	8.2	59	1.04
SED	0.04	0.3	12	0.2	0.4	0.14	0.8	1.9	2	0.16
				Soybean						
25	0.58	2.6	192	2.1	3.0	0.69	8.9	1.8	108	1.22
50	0.31	2.1	163	2.2	2.7	0.63	19.8	1.7	118	1.42
75	0.23	1.6	124	2.0	2.1	0.36	18.4	1.7	119	0.96
SED	0.04	0.2	12	0.2	0.4	0.03	2.6	0.1	4	0.11

[a]PAR = photosynthetically active radiance.

(0.51 ± 0.02 m^2/m^2). Totals of absorbed PAR calculated from these coefficients for 0-61 DAS were similar for mungbean and soybean, and increased with plant population density, although less rapidly beyond 0.3 million plants/ha (Table 9). The thermodynamic efficiency of using absorbed PAR during 0-61 DAS was, as expected, the same for all plant population densities (Table 9); it was, however, a significant 16% lower for soybean (2.1 ± 0.1%) than for mungbean (2.5 ± 0.3%). The contrast was greater for seasonal average efficiencies. During its longer growing season, soybean absorbed more PAR than mungbean, but because of water stress after 61 DAS, its seasonal average efficiency of using PAR was only half that of mungbean (1.3% compared with 2.3%). The mungbean efficiency was similar to that recorded in DS experiments on previously puddled soil. Mungbean attained higher efficiency because its shorter growing season allowed it to escape severe water stress. Soybean was stressed from 61 DAS despite having roots at 0.8 m depth — close to the water table. But calculations indicated that the measured soybean root density below 0.7 m was too small to take up sufficient water to satisfy potential transpiration.

Water stress may have also been the reason that in both species Fe-to-Mn ratio in plant tissue at 40 DAS was, at 3.5, outside the range (1.5-2.5) optimal for legume growth.

Shoot concentrations of N, P, and K were similar for soybean and mungbean at all growth stages and for all population densities. Grain N concentration was higher in soybean (6.0%) than in mungbean (4.1%), as was total of harvested grain N (average for wide and narrow row spacings) at 57 compared to 44 kg N/ha. However, the seasonal average daily rate of accumulation of grain N was the same for both species: 0.64 kg N/ha·d for soybean and 0.65 kg N/ha·d for mungbean.

Soil N accumulation beneath these legume crops is described in the section on Management of Soil and Fertilizer Nitrogen.

For both species, roots in some plots extended to 1.0 m depth. In all plots, however, the maximum depth of rooting was constrained by the deeper of the two horizons of high soil strength. For both species, the relation of grain yield Y to depth D_2 to the second strong horizon was consistent with eq. 5 derived by combining all data and normalizing to 0.50 million plants/ha:

$$Y = (0.62 \pm 0.18) + (0.006 \pm 0.003)D_2 \quad (r = 0.42, n = 18, 75\ \text{cm} < D_2 < 120\ \text{cm}) \tag{5}$$

Eq. 5 has statistical significance at the 10% level and is similar to relations found for mungbean in our previous DS experiments in both upland and puddled soils.

Constraints on rice yields

Agronomy and Agricultural Economics Departments

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MANAGEMENT CONSTRAINTS

Agronomy Department

Yield constraints on direct seeded irrigated rice in dry season. The relative contributions of fertilizer, weed control, and insect control to the yield gap between farmers' and researchers' inputs were measured on seven farms each in Nueva Ecija and Camarines Sur, Philippines. Yield data from two farms in Nueva Ecija were not reported because of significant farm-treatment interaction. Yield responses to applied N, P, and K, and to four insect control levels, were also measured. In a separate experiment, the optimum seeding rate for direct seeded rice was determined under four N and two weed control levels in Nueva Ecija.

Soil analyses of test sites are summarized in Table 1. All sites were predominantly clay. In Nueva Ecija, all sites had low organic matter and were deficient in N and Zn; six sites were deficient in P, and five contained adequate K. In Camarines Sur, the area was generally rich in soil N and K but deficient in P and Zn; five of seven sites had pH values below the critical limit.

Farmers' N rates in Nueva Ecija averaged 108 kg/ha, about 60% of which was applied from 17 to 32 d after seeding (DAS) and the rest at 31-55 DAS. The farmers in Camarines Sur applied 75 kg N/ha, also in 2 split doses: 2-3 wk after seeding and the rest at 40-65 DAS. Farmers in both areas used herbicides, particularly liquid butachlor, to control weeds, and foliar insecticides to control insects. Table 2 summarizes input levels used by the farmers and researchers.

Yields with farmers' inputs across 12 sites averaged 5.0 t/ha; researchers' inputs raised the yield further by 0.7 t/ha. Improved fertilizer management accounted for 62% of the yield gap, improved insect control for 25%, and weed control for 13%. Among the three factors studied, inefficient fertilizer management was the major constraint to high yield in both study areas, followed by poor weed control in Nueva Ecija and poor insect control in Camarines Sur.

In Nueva Ecija in the dry season (DS), yield response to applied N (90 kg/ha) with or without P or K was significant. Yields with N averaged 6.3 t/ha, similar to yields with NP and NPK (Table 3). Hence, N was limiting. The crop showed no P or Zn deficiency symptoms despite low levels of these soil nutrients in the area. In Camarines Sur, response to 90 kg N/ha was significant although the test sites were rich in soil N. Applying 13 kg P/ha in combination with N increased the yield further but the addition of K did not, indicating that the area requires only N and P application to increase yield.

The integrated pest management (IPM) concept and a cost-efficient pest management system designed to give high benefit-to-cost ratio

Table 1. Soil characteristics of experimental sites in 2 Philippine provinces, 1986 DS.

Soil property	Range	Mean	Critical limit	Sites (no.) below critical limit
	Nueva Ecija (7 sites)			
pH	5.1 -7.2	6.0	5.5 -6.5[a]	4[b]
Organic C (%)	0.8 -1.4	1.1	2.0	7
Total N (%)	0.07-0.12	0.1	0.2	7
Olsen P (mg/kg)	1.7 -9.8	4.3	5.0	6
Exchangeable K (meq/100 g)	0.12-0.27	0.2	0.2	2
Available Zn (mg/kg)	0.2 -0.9	0.4	1.0	7
	Camarines Sur (7 sites)			
pH	4.9 -5.9	5.3	5.5-6.5	5[b]
Organic C (%)	1.8 -2.7	2.2	2.0	1
Total N (%)	0.15-0.29	0.2	0.2	0
Olsen P (mg/kg)	3.1 -5.6	4.7	5.0	4
Exchangeable K (meq/100 g)	0.12-0.53	0.2	0.2	2
Available Zn (mg/kg)	0.3 -1.2	0.5	1.0	6

[a]Optimum range. [b]Outside optimum range.

Table 2. Input levels in yield constraints experiments on direct seeded, irrigated rice farms in 2 Philippine provinces, 1986 DS.

Input level	Fertilizer (kg/ha)			Weed control[a]		Insect control[b]	
	N	P	K	M	C	F	G
Nueva Ecija (5 sites)							
Farmers'	108	10	0	0	1.4	2.4	0.2
Researchers'	90	13	25	1.0	1.0	3.4	2.0
Camarines Sur (7 sites)							
Farmers'	75	7	11	0.4	1.3	1.6	0
Researchers'	90	13	25	0.6	1.0	2.3	2.7

[a]Av. no. of mechanical (M) weedings by hand and chemical (C) applications. [b]Av. no. of foliar (F) sprays (monocrotophos, chlorpyrifos, azinphos ethyl, etc.) and granular (G) applications (carbofuran, diazinon, etc.) to floodwater.

(B:C) were evaluated and compared with current farmers' and researchers' insect control. In both study areas, no significant yield differences were found among the four insect control practices, suggesting that the high dosage and frequency of insecticide application currently practiced by researchers do not affect yield.

An experiment involving 3 seeding rates (100, 150, and 200 kg seeds/ha), 2 weed control levels, and 4 N levels in 1985 DS was repeated in 1986 DS on 5 farms in Nueva Ecija. All seeding rates produced similar yields, regardless of weed control and N level. The optimum yield was obtained at 80 kg N/ha with either farmers' or researchers' weed control. Researchers' weed control (granular butachlor at 1.0 kg ai/ha applied at 3 d before seeding + spot hand weeding at 20-25 DAS) outyielded the farmers' method by 0.4 t/ha, duplicating previous findings.

Yield constraints on transplanted rice. *Irrigated sites in dry season.* Four application methods involving prilled urea (PU) and urea supergranules (USG) were compared on four farms in Nueva Ecija and eight farms in Camarines Sur. In Nueva Ecija, the researchers' split-applied PU at 58 kg N/ha was as efficient as deep hand-placed USG and deep-placed PU by plunger-auger but superior to deep-placed USG by press wedge (Table 4); the researchers' split was also superior to the farmers' split at 58 or 87 kg N/ha. In Camarines Sur, deep hand-placed USG was as efficient as the researchers' split but superior to other application methods; the researchers' split outyielded the farmers' method by 0.2 t/ha, but the yield difference was not significant.

In Nueva Ecija, floodwater analyses 1 d after the first fertilizer application showed that the farmers' method gave the highest total N concentration (15.5 kg/ha), followed by USG deep-placed by press wedge (11.3 kg/ha) and PU deep-placed by plunger-auger (7.4 kg/ha). The researchers' split-applied PU and hand-placed USG plots contained lower total floodwater N concentrations at 1-5 d after fertilizer application than plots with other application methods. Total floodwater N concentrations in Camarines Sur were lower, but the pattern was similar to that observed in Nueva Ecija (Fig. 1). Total floodwater N concentrations from researchers' and farmers' splits after topdressing were similar and followed the same pattern, regardless of site.

Table 3. Yield responses to N, P, and K on rainfed and irrigated farms in 3 areas in the Philippines, 1986.

Province	Sites (no.)	Water regime	Crop establishment method	Yield[a] (t/ha)			
				No fertilizer	N	NP	NPK
			Dry season				
Nueva Ecija	5	Irrigated	Direct seeded	3.9 b	6.3 a	6.5 a	6.5 a
Camarines Sur	7	Irrigated	Direct seeded	3.3 c	4.7 b	5.2 a	5.2 a
			Wet season				
Tarlac	7	Rainfed	Transplanted	3.6 b	4.8 a	4.8 a	5.0 a
Camarines Sur	8	Rainfed	Transplanted	4.1 b	5.2 a	5.6 a	5.5 a
Nueva Ecija	2	Irrigated	Transplanted	4.5 b	5.5 a	5.6 a	5.8 a
Camarines Sur	3	Irrigated	Transplanted	3.9 b	5.0 a	5.1 a	5.1 a

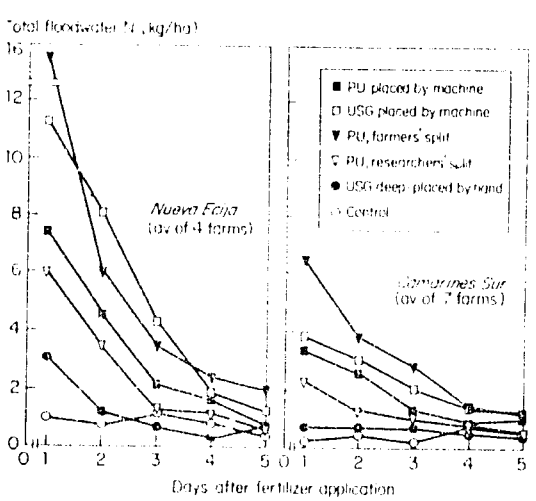
[a]In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. Fertilizer level was 90-13-25 kg NPK/ha in DS, and 60-13-25 kg NPK/ha in WS.

Table 4. Effect of N source and application method on grain yield of transplanted irrigated rice at high levels of cultural practices in 2 areas in the Philippines, 1986 DS.

N source[a]	Application method	N applied (kg/ha)	Yield (t/ha)	
			Nueva Ecija (4 sites)	Camarines Sur (3 sites)
–	–	0	4.2 g	3.8 e
PU	Farmers' split[b]	58	5.3 ef	5.1 bc
PU	Researchers' split[c]	58	5.8 bc	5.3 ab
PU	Plunger-auger[d]	58	5.6 cd	4.8 d
USG	Deep point placement[e]	58	6.0 ab	5.4 a
USG	Press wedge[d]	58	5.2 f	4.9 cd
PU	Farmers' split[b]	87	5.5 de	–
PU	Researchers' split[c]	87	6.2 a	–

[a]PU = prilled urea, USG = urea supergranules. [b]N applied at 15 d after transplanting (DT) and after panicle initiation (PI) in Nueva Ecija, and at 15 and 45 DT in Camarines Sur. [c]2/3 basal broadcast and incorporated without standing water + 1/3 at 5-7 d before panicle initiation. [d]Machine placement at 2-4 DT. [e]10-12 cm soil depth, hand-placed at 2-4 DT.

A separate experiment on three farms in Camarines Sur tested the suitability of the traditional *laplap* and root-wash seedling preparation methods for the IRRI-designed mechanical transplanter. Manual and mechanical transplanting, using either the *laplap* or root-wash method of seedling preparation, had no definite advantage over direct seeding (Table 5). The performance of the mechanical transplanter depended on how the seedlings were prepared. The density of the seedling mat for the *laplap* method determined the number of seedlings planted per hill. In the root-wash method, tangled roots resulted in excessive seedlings being picked with every stroke of the transplanter.



1. Total floodwater N (NH_4^+-N + urea-N) concentrations at 1400 h with various N application methods on irrigated farms in 2 Philippine provinces, 1986 DS.

Rainfed sites in wet season. The yield gap between farmers' and researchers' inputs was measured on seven drought-prone farms in Tarlac and eight in Camarines Sur. Tarlac farmers' N rates were substantially higher than those of Camarines Sur farmers and those of researchers in both study areas (Table 6).

Yields with researchers' inputs averaged 5.0 t/ha in Tarlac and 5.1 t/ha in Camarines Sur. Farmers' yields at both sites averaged 4.2 t/ha. The fertilizer contribution to the yield gap was the highest — 50% in Tarlac and 78% in Camarines Sur. In Tarlac, improved insect control contributed 30%, and improved weed control 20%. In Camarines Sur, insect control and weed control each contributed 11%. Results suggest that the Tarlac farmers' practice of applying N fertilizer was inefficient. In Camarines Sur, the farmers' N rate

Table 5. Grain yields with direct seeding and different ways of preparing seedlings for manual and mechanical transplanting. Camarines Sur, Philippines, 1986 DS.

Treatment	Yield (t/ha)			
	Sabater	Boreta	Falabi	Mean
Direct seeded	5.1 a	4.5 b	3.6 b	4.4
Transplanted				
Manual, root-wash	4.6 b	4.9 ab	4.2 a	4.6
Manual, *laplap*	4.9 ab	5.5 a	3.7 b	4.7
Mechanical, root-wash	4.9 ab	4.8 ab	3.5 b	4.4
Mechanical, *laplap*	4.8 ab	4.8 ab	3.4 b	4.3

should be increased and applied with P to increase rice yield.

The promising drought-tolerant breeding line IR32307-107-3-2-2 with growth duration similar to those of farmers' dominant varieties (IR60 and IR64 in Tarlac; IR36, IR60, and IR64 in Camarines Sur) was tested on drought-prone farms. The test rice significantly outyielded the farmers' varieties in both study areas (Table 7), but its tolerance for drought stress was not tested because of adequate rainfall evenly distributed in the wet season (WS).

In a separate experiment, five other promising early-maturing and drought-tolerant breeding lines were tested under farmers' and researchers' cultural practices. Generally, the test rices performed better with researchers' than with farmer's practices (Table 8). In both areas, IR13240-108-2-

Table 6. Input levels in yield constraints experiments on transplanted rice in 3 areas in the Philippines, 1986 WS.

Province	Sites (no.)	Input level	Fertilizer (kg/ha)			Weed control[a]		Insect control[b]	
			N	P	K	M	C	F	G
			Rainfed sites						
Tarlac	7	Farmers'	74	8	10	0	0.4	1.3	0.1
Tarlac	7	Researchers'	60	13	25	1.0	1.0	4.3	1.0
Camarines Sur	8	Farmers'	19	0	0	0.5	1.4	2.8	0
Camarines Sur	8	Researchers'	30	13	25	1.5	1.3	4.6	1.0
			Irrigated sites						
Nueva Ecija	2	Farmers'	88	18	13	0	1.0	2.5	0
Nueva Ecija	2	Researchers'	60	13	25	1.0	1.0	4.0	1.0
Camarines Sur	3	Farmers'	15	0	0	0.4	1.5	2.7	0
Camarines Sur	3	Researchers'	30	13	25	1.5	1.2	4.9	1.0

[a]Av no. of mechanical (M) weedings by hand and chemical (C) applications. [b]Av no. of foliar (F) sprays (monocrotophos, chlorpyrifos, azinphos-ethyl, etc.) and granular (G) applications (carbofuran, diazinon, etc.) to floodwater.

Table 7. Yields of farmers' varieties and test varieties of transplanted rice at researchers' levels on rainfed and irrigated farms in 3 areas in the Philippines, 1986 WS.

Province	Sites (no.)	Water regime	Yield[a] (t/ha)		
			Farmers' variety	Test variety	Difference
Tarlac	7	Rainfed	5.0	5.4	0.4*
Camarines Sur	8	Rainfed	5.1	5.8	0.7*
Nueva Ecija	2	Irrigated	5.8	6.0	0.2ns
Camarines Sur	3	Irrigated	4.7	4.5	−0.2ns

[a]Dominant farmers' varieties were IR60 and IR64 in Tarlac, and IR64 in Nueva Ecija. In Camarines Sur, farmers' varieties were IR36, IR60, and IR64 on rainfed farms and IR64 on irrigated farms. Test varieties were IR32307-107-3-2-2 for rainfed farms and IR64 for irrigated farms.

Table 8. Yields of drought-tolerant promising breeding lines at farmers' (FCP) and researchers' (RCP) cultural practices on rainfed farms in 2 areas in the Philippines, 1986 WS.

Breeding line	Duration (d)	Yield (t/ha)			
		Tarlac (4 sites)		Camarines Sur (3 sites)	
		FCP	RCP	FCP	RCP
IR11418-15-2	109	4.3 b	5.1 b	2.7 ab	4.1 b
IR21015-80-3-3-1-2	114	3.6 c	4.9 c	2.5 b	3.5 c
IR13240-108-2-2-3	109	4.6 a	5.7 a	3.0 a	4.7 a
IR21567-18-3-1	117	4.3 b	5.6 a	2.5 b	3.4 c
IR26894-37-2-1-3	107	2.8 d	2.6 d	2.8 ab	4.1 b

2-3 yielded the highest regardless of cultural practice. In Tarlac, however, the 5.6 t yield/ha of IR21567-18-3-1 with researchers' practices did not significantly differ from that of IR13240-108-2-2-3. IR11418-15-2 also performed well in both areas. IR26894-37-2-1-3 performed well in Camarines Sur but yielded the lowest in Tarlac because of its susceptibility to brown spot and neck blast. Sheath blight (ShB) and bacterial leaf streak infections on IR21015-80-3-3-1-2 and IR21567-18-3-1 in Camarines Sur also caused low yields.

Yield responses to applied N, P, and K in Tarlac and Camarines Sur were similar (Table 3). Application of 60 kg N/ha significantly increased yield. However, applying P or PK in addition to N did not further increase yield. This suggests that only N was necessary to obtain high yield at the test sites. Yields with applied Zn averaged 5.1 t/ha in Tarlac and 5.6 t/ha in Camarines Sur. Yields with no Zn were 0.1 t/ha lower in both areas.

In both study areas, the cost-efficient pest management system and IPM insect control levels were as effective as the farmers' and researchers' insect control. Whorl maggot, caseworm, leaf-folder, and stem borer were prevalent in rainfed rice in Tarlac and Camarines Sur.

The effect of fungicide was tested at high input level. Foliar spraying with a broad-spectrum systemic fungicide, propiconazole, at 250 g ai/ha during the early booting and soft dough stages did not significantly increase yield over the untreated check (Table 9). Rice was infected with ShB, brown spot, bacterial leaf blight, and leaf streak in Tarlac, and by helminthosporium leaf spot and cercospora leaf streak in Camarines Sur.

Soil incorporation of dried chicken manure (3 t/ha) before transplanting, in addition to 90-13-25 kg NPK/ha, significantly reduced the yield in Tarlac because of severe lodging. Application of 90 kg N/ha as PU appeared excessive. With reduced N rate (60 kg/ha), chicken manure application on 8 farms in Camarines Sur increased yield by 0.4 t/ha over the check plot (Table 10).

Methods of applying PU and USG were evaluated on five farms in Nueva Ecija and four farms in Camarines Sur. In Nueva Ecija, yields with researchers' split-applied PU and deep hand-placed USG were comparable, regardless of N rate.

Table 9. Effect of fungicide on grain yield of transplanted rice on rainfed and irrigated farms in 3 areas in the Philippines, 1986 WS.

Province	Sites (no.)	Water regime	Yield (t/ha)		
			Without fungicide	With fungicide[a]	Difference
Tarlac	7	Rainfed	5.0	5.1	0.1^{ns}
Camarines Sur	8	Rainfed	5.1	5.3	0.2^{ns}
Nueva Ecija	2	Irrigated	5.8	5.9	0.1^{ns}
Camarines Sur	3	Irrigated	4.7	5.2	0.5*

[a]Propiconazole was applied as foliar spray at early booting and early heading or soft dough stages at 250 g ai/ha. At irrigated sites in Camarines Sur, additional treatment was made during the dough stage.

Table 10. Grain yield as influenced by application of 3 t chicken manure/ha to rainfed and irrigated transplanted rice in 3 areas in the Philippines, 1986 WS.

Province	Sites (no.)	Water regime	Yield (t/ha)		
			Without chicken manure	With chicken manure[a]	Difference
Tarlac	7	Rainfed	5.0	4.4	−0.6*
Camarines Sur	8	Rainfed	5.5	5.9	0.4*
Nueva Ecija	2	Irrigated	5.4	4.5	−0.9*
Camarines Sur	3	Irrigated	5.1	5.2	0.1^{ns}

[a]Chicken manure was soil incorporated before transplanting in addition to 90 kg N/ha as researchers' split-applied PU at Nueva Ecija and Tarlac sites. In Camarines Sur, N rate from PU was 60 kg/ha.

Both application methods were superior to deep-placed PU by plunger-auger and deep-placed USG by press wedge. Compared with the farmers' method, deep hand-placed USG gave significantly higher yields at both N rates, while the researchers' split was superior only at 58 kg N/ha (Table 11). In Camarines Sur, the researchers' split PU and deep hand-placed USG gave similar yields at both 29 and 58 kg N/ha. Both methods were superior to the farmers' method. The researchers' method was also more efficient than deep-placed USG by machine.

Irrigated sites in wet season. The N rates used by the 2 cooperating farmers in Nueva Ecija averaged 88 kg/ha, higher than the researchers' rate. In Camarines Sur, farmers' N rate was only half the researchers' rate.

Researchers' yields in Nueva Ecija averaged 5.8 t/ha, higher by 0.6 t/ha than the farmers' yield. Improved insect control and weed control gave equal contributions (37.5%) to the yield gap, while improved fertilizer management accounted for 25%. In Camarines Sur, farmers' yields averaged 4.0 t/ha, lower by 0.7 t/ha than the researchers' yield. Improved application of 30-13-25 kg NPK/ha accounted for 64% of the 0.7 t yield gap/ha, whereas improved insect control contributed 27% and weed control 9%.

All cooperating farmers in Nueva Ecija and Camarines Sur planted IR64. The test variety (IR64 from IRRI) and farmers' varieties produced similar yields regardless of site (Table 7), suggesting that the farmers obtained their seeds from a reliable source.

Yields with NPK averaged 5.8 t/ha in Nueva Ecija and 5.1 t/ha in Camarines Sur, similar to yields with N alone or NP. In both areas, yields responded significantly only to applied N (Table 3). Yields with and without applied Zn were similar: 5.4 t/ha in Nueva Ecija and 5.1 t/ha in Camarines Sur.

As in rainfed rice, yields from four insect control levels tested on irrigated rice were comparable. Two foliar sprays with fungicide gave an additional yield of 0.5 t/ha in Camarines Sur, while no significant effect was observed in Nueva Ecija (Table 9). In Nueva Ecija, soil incorporation of 3 t chicken manure/ha, in addition to 90 kg N/ha, hastened crop lodging at ripening, which resulted in substantial yield reduction. Experiments in Camarines Sur also showed no benefit from chicken manure application (Table 10). Further tests with various N fertilizer and chicken manure rates are needed.

In 3 trials in Nueva Ecija, researchers' split and deep hand-placed USG yielded 4.7 t/ha at 29 kg N/ha, significantly higher than the yields from deep-placed PU and USG by machine (Table 11). Lodging during ripening significantly reduced the

Table 11. Effect of N source and application method on grain yield of transplanted rice on rainfed and irrigated farms at researchers' level of cultural practices in 2 areas in the Philippines, 1986 WS.

N source	Application method	N applied (kg/ha)	Yield (t/ha)			
			Rainfed		Irrigated	
			Nueva Ecija (5 sites)	Camarines Sur (4 sites)	Nueva Ecija (3 sites)	Camarines Sur (3 sites)
–	–	0	3.9 e	4.0 e	3.7 d	4.2 e
PU	Farmers' split[a]	29	4.9 cd	4.6 d	4.5 bc	5.1 d
PU	Researchers' split[b]	29	5.1 bc	5.1 b	4.7 ab	5.2 cd
PU	Plunger-auger[c]	29	4.7 d	5.1 b	4.2 c	5.2 cd
USG	Deep point placement[d]	29	5.2 ab	4.9 bc	4.7 ab	5.2 cd
USG	Press wedge[c]	29	4.8 d	4.7 cd	4.2 c	4.8 d
PU	Farmers' split[a]	58	5.0 c	4.8 bcd	4.6 bc	5.2 cd
PU	Researchers' split[b]	58	5.3 ab	5.6 a	5.1 a	5.7 bc
USG	Deep point placement[d]	58	5.4 a	5.6 a	4.6 bc	5.9 ab
PU	Researchers' split[b]	87	5.4 a	5.6 a	4.7 ab	6.2 a

[a]N applied at 15 d after transplanting (DT) and past panicle initiation in Nueva Ecija and at 15 and 50 DT in Camarines Sur. [b]N applied as 2/3 basal broadcast and incorporated without standing water + 1/3 at 5-7 d before panicle initiation. [c]Machine placement at 2-4 DT. [d]10-12 cm soil depth, hand-placed at 2-4 DT.

yield with USG hand-placed at a higher N rate than the researchers' split. The researchers' split also outyielded the farmers' method at both N rates. But at low N rate, its advantage was not significant. In Camarines Sur, all application methods gave similar yields at 29 kg N/ha. The researchers' split was also as efficient as deep-placed USG at 58 kg N/ha, but the latter was superior to the farmers' method.

Yield constraints on upland rice. The yield gap in upland rice in WS was determined on five farms in Santo Tomas and three farms in Cuenca, Batangas, and on three farms in General Trias, Cavite. Another experiment on the same farms evaluated five input management packages of fertilizer, weed control, and insect control using farmers' and modern varieties. A separate experiment evaluated the performance of six rice cultivars grown with and without weed control.

Table 12 lists the soil properties of the test sites. The rainfall distribution in Santo Tomas and General Trias was fairly even, which resulted in low soil moisture tension (SMT) at the test sites (Fig. 2). In Cuenca, very low rainfall after seeding raised SMT to 58 cb twice, resulting in poor crop establishment and ineffective chemical weed control.

Santo Tomas farmers' fertilizer rates averaged 73-3-3 kg NPK/ha. Weed control was done twice with the use of animal-drawn farm implements and twice by hand. One of five farmers used herbicide. All farmers planted traditional upland varieties.

In Cuenca, farmers' fertilizer rates averaged 22 kg N/ha. No farmer applied P or K. Mechanical weed control was done twice and hand weeding once. No farmer used herbicide. All farmers planted the traditional upland variety Kinandang Patong.

General Trias farmers' fertilizer rates averaged 77 kg N/ha. No farmer applied P or K. Mechanical weed control was done twice and hand weeding once. Two of three farmers planted traditional upland varieties.

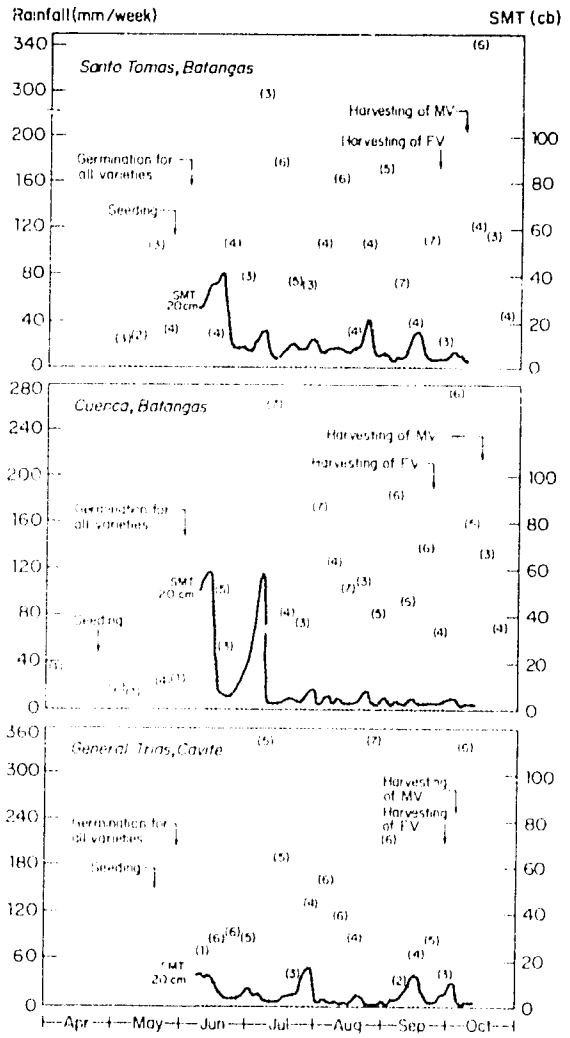
Yield with farmers' inputs was lowest in Cuenca (Fig. 3) where fertilizer applied averaged 22 kg N/ha and SMT reached 58 cb twice during the season and highest in General Trias, where fertilizer applied averaged 77 kg N/ha and SMT reached only 17 cb. In Santo Tomas, rice variety accounted for almost the entire yield gap of 1.8 t/ha on 2 farms (Fig. 4). In Cuenca, fertilizer, rice variety, and weed control accounted equally for the yield gap of 1.8 t/ha on 2 farms. In General Trias, variety accounted for much of the 0.9 t/ha yield gap.

Performance of management packages. Another experiment on the same farms showed that no farmer at the three locations applied insecticides (Table 13). Treatment M5 gave the highest average grain yield; M1 and M4 produced comparable yields (Table 14). M2 produced low grain yield because of poor weed control.

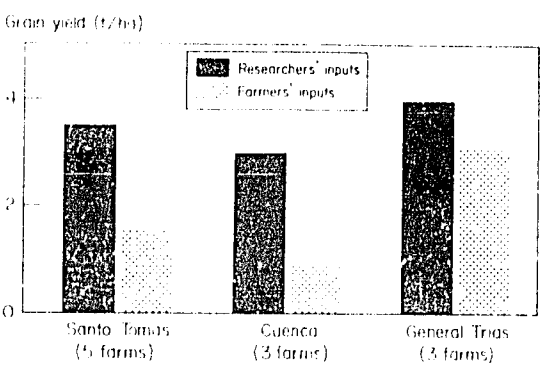
Performance of rice cultivars. A separate experiment on a farm in Santo Tomas showed

Table 12. Chemical properties of 3 Cuenca, 5 Santo Tomas, and 3 General Trias soils where yield constraints trials in upland rice were conducted. Batangas and Cavite, Philippines, 1986 WS.

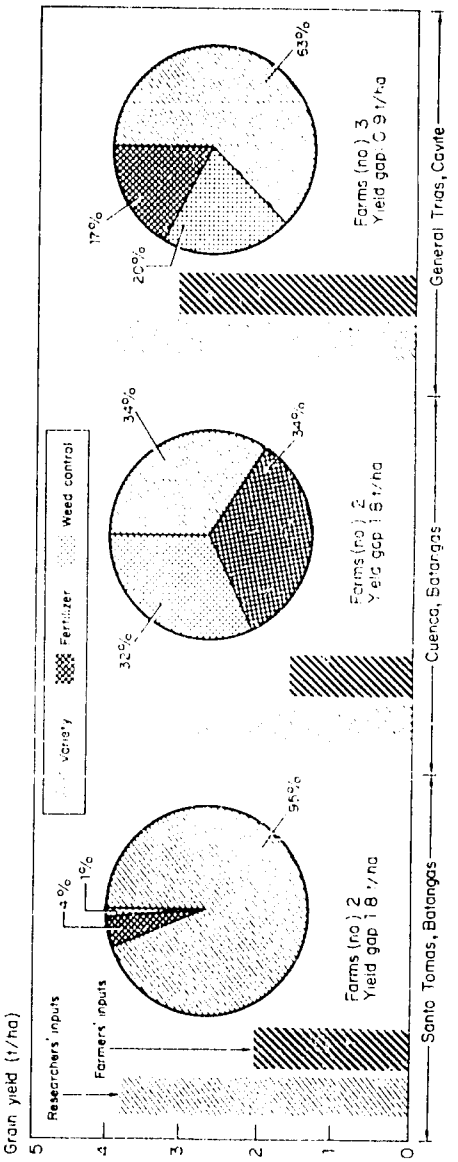
Soil characteristic	Range			Mean		
	Santo Tomas	Cuenca	General Trias	Santo Tomas	Cuenca	General Trias
pH	4.9 - 5.9	5.6 - 5.7	5.1 - 5.5	5.4	5.6	5.3
Organic C (%)	0.6 - 1.1	0.8 - 0.9	0.9 - 1.0	0.8	0.8	0.9
Total N (%)	0.07- 0.11	0.09- 0.10	0.09- 0.11	0.09	0.10	0.10
Exchangeable K (meq/100 g)	0.82- 1.28	1.06- 1.38	0.81- 1.80	1.05	1.26	1.33
Exchangeable Mg (meq/100 g)	5.0 - 5.5	5.5 - 6.7	5.7 - 7.1	5.2	6.3	6.2
Exchangeable Ca (meq/100 g)	11 -13	13 18	14 -19	12	17	16
CEC (meq/100 g)	23 -24	25 -30	27 -31	23	28	30
Olsen P (mg/kg)	27 -49	6 -17	12 -56	35	12	27
Active Fe (%)	2.67- 3.22	2.30- 2.49	2.64- 2.69	2.86	2.39	2.66
Active Mn (%)	0.17- 0.18	0.13- 0.18	0.24- 0.25	0.17	0.15	0.24
Exchangeable acidity (meq/100 g)	0.06- 0.86	0.19- 0.24	0.10- 0.62	0.36	0.21	0.35
Exchangeable Al (meq/100 g)	0.04- 0.68	0.14- 0.18	0.60- 0.46	0.28	0.17	0.25



2. Total weekly rainfall and daily (3-point moving) soil moisture tension (SMT) at constraints experiment sites in 2 Philippine provinces, 1986 WS. MV = modern variety, FV = farmers' variety. Numbers in parentheses are weekly days of rainfall.



3. Average yield of upland rice with farmers' and researchers' inputs in 2 Philippine provinces, 1986 WS.



4. 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, 1986 WS.

that, without weed control, UPLRi-5 and IR12979-24-1 yielded best (Table 15). With some degree of weed control, IR43 outyielded all other test cultivars but was statistically similar to UPLRi-5 and IR12979-24-1. On a farm in General Trias, no test cultivars produced grain yield without weed control. With some degree of weed control, IR12979-24-1 yielded best, but at a level statistically the same as IR43, UPLRi-5, and the farmer's variety.

Table 13. Farmers' inputs and 4 input management package levels. Batangas and Cavite, Philippines, 1986 WS.

Location	Sites (no.)	Package level	Fertilizer N[a] (kg/ha)	Weed control[b] (no.)			Insect control[c]
				C	M	HW	F
Santo Tomas	5	M1	77	0.2	2.4	1.6	0
Cuenca	3	M1	22	0	2.3	1.0	0
General Trias	3	M1	77	0	2.3	1	0
All	11	M2	20	0	2	0	0
		M3	40	1	0	0	0
		M4	60	0	1	1	0.2
		M5	80	1	1	1	2

[a]No P or K application except for 1 kg P and 1 kg K per hectare at Santo Tomas, Batangas. [b]C = chemical, M = mechanical, HW = hand weeding. [c]F = foliar. No granular insecticide was applied.

Table 14. Average yields of farmers' and 2 modern varieties with 5 input management packages in farmers' fields. Batangas and Cavite, Philippines, 1986 WS.

Package level	Grain yield[a] (t/ha)											
	Santo Tomas (5 sites)				Cuenca (3 sites)				General Trias (3 sites)			
	Farmers' variety	IR43	UPLRi-5	Av	Farmers' variety	IR43	UPLRi-5	Av	Farmers' variety	IR43	UPLRi-5	Av
M1	1.6 b	2.5 b	2.7 c	2.3	0.8	1.1	1.5	1.1	3.0	2.9	3.3	3.1
M2	0.8 c	0.8 d	1.1 e	0.9	0.2	0	0.2	0.1	1.0	0.4	0.8	0.7
M3	1.5 b	2.0 c	2.1 d	1.9	0.2	0	0.1	0.1	1.6	2.0	2.8	2.1
M4	1.8 ab	3.1 a	3.1 b	2.7	1.1	2.2	2.3	1.2	3.0	3.3	3.7	3.3
M5	2.0 a	3.2 a	3.7 a	3.0	2.0	2.7	3.0	2.6	2.9	4.2	4.0	3.7

[a]No DMRT values for Cuenca and General Trias because of site-to-site variability.

Table 15. Yield performance of rice cultivars with[a] and without weed control in upland farmers' fields. Batangas and Cavite, Philippines, 1986 WS.

Variety or line	Yield (t/ha)			
	Santo Tomas			General Trias[b]
	With weed control	Without weed control	Difference	With weed control
IR43	4.3 a	0.7 bc	3.6	4.1 a
UPLRi-5	3.7 a	2.7 a	1.0	3.5 a
IR12979-24-1	3.6 a	2.3 a	1.3	4.3 a
IR9782-111-1	2.9 b	0.2 c	2.7	2.3 b
IR36	2.4 bc	0 c	2.4	1.9 b
Farmer's[c]	1.9 c	1.2 b	0.7	4.0 a

[a]One chemical spray (butachlor for Santo Tomas and pendimethalin for General Trias), 1 mechanical method, and 1 hand weeding. [b]Without weed control, no cultivar produced any yield. [c]Kinandang Patong for Santo Tomas, C22 for General Trias.

SOCIOECONOMIC CONSTRAINTS

Agricultural Economics Department

Farmers' and researchers' technologies. The comparative profitability of the researchers' practice and that used by farmers was evaluated, using partial budgeting of costs and returns. The researchers' technology package was marginally profitable in most areas; exceptions were irrigated Camarines Sur in DS and upland Cavite in WS, where the increase in the value of the output was not sufficient to cover added costs.

The weak profitability of the researchers' technology was due to some costly components; the separate profitabilities of fertilizers and insect, weed, and disease control were therefore analyzed (Table 16). The researchers' fertilizer practice was economically viable at all locations, with increased

Table 16. Economic performance of high levels of inputs and farmers' current practices[a] in 4 Philippine provinces, 1986.

Location, water regime, season	Sites (no.)	Package profit (S/ha)	Fertilizer[b]		Insect control						Weed control[g]		Disease control[h]	
			Profit[c] (S/ha)	MBCR	High[d]		IPM[e]		Intermediate[f]		Profit (S/ha)	MBCR	Profit (S/ha)	MBCR
					Profit (S/ha)	MBCR	Profit (S/ha)	MBCR	Profit (S/ha)	MBCR				
Camarines Sur														
Irrigated, WS	3	4	24	1.6	−3	0.92	15	0.24	16	0.32	2	1.45	44	3.5
Rainfed, WS	8	24	42	2.18	−28	0.36	−4	1.23	−3	1.14	11	3.26	11	1.61
Irrigated, DS	7	−77	28	2.55	−93	0.25	7	−0.9	28	n.e.	7.7	n.e.	n.e.	n.e.
Nueva Ecija														
Irrigated, WS	12	48	43	n.e.	−2	0.96	18	0	−2	1.13	32	4.72	−10	0.45
Rainfed, WS	7	12	90	9.8	−25	0.53	2	1.17	26	3.59	12	1.79	5	1.29
Irrigated, DS	5	83	69	10.58	−13	0.67	26	n.e.	3.85	0.43	42	n.e.	n.e.	n.e.
Batangas														
Upland, WS	8	65	21	3.75	44	3.02	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
Cavite														
Upland, WS	3	−43	38	40.13	−81	−1.93	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.

[a] n.e. = not estimated because the negative MBCR owing to decrease in cost is misleading. [b] Researchers' fertilizer levels in WS were 30-30-30 kg NPK/ha in Camarines Sur, 60-30-30 kg NPK/ha in Nueva Ecija. In DS, they were 90-30-30 kg NPK/ha in Nueva Ecija and Camarines Sur, and 80-0-0 kg NPK/ha in Batangas and Cavite. [c] At rough rice price of $165/t in Nueva Ecija and $150/t in Camarines Sur, Batangas, and Cavite. [d] Researchers' cost of insect control were $70/ha in WS in Nueva Ecija and $59/ha in DS, and $85/ha in WS in Camarines Sur and $151/ha in DS. [e] IPM = integrated pest management. Researchers' costs were $19/ha in WS in Nueva Ecija and $13/ha in DS, and $26/ha in WS in Camarines Sur and $24/ha in DS. [f] Researchers' costs were $12/ha in WS in Nueva Ecija and $13/ha in DS, and $21/ha in Camarines Sur in WS and $17/ha in DS. [g] Researchers' costs were $20/ha in Nueva Ecija in WS and $15/ha in DS, $23/ha in Camarines Sur in WS and $15/ha in DS, and $57/ha in Batangas and Cavite. [h] Researchers' cost was $18/ha.

profits ranging from $21 to $90/ha and generally acceptable marginal benefit-cost ratios (MBCR). In general, the increase in revenue from the researchers' insect control (high) was not sufficient to cover the increased costs of insecticides. The IPM practice and the intermediate level yielded marginal improvements in profits that are probably not sufficient to attract farmers to adopt them.

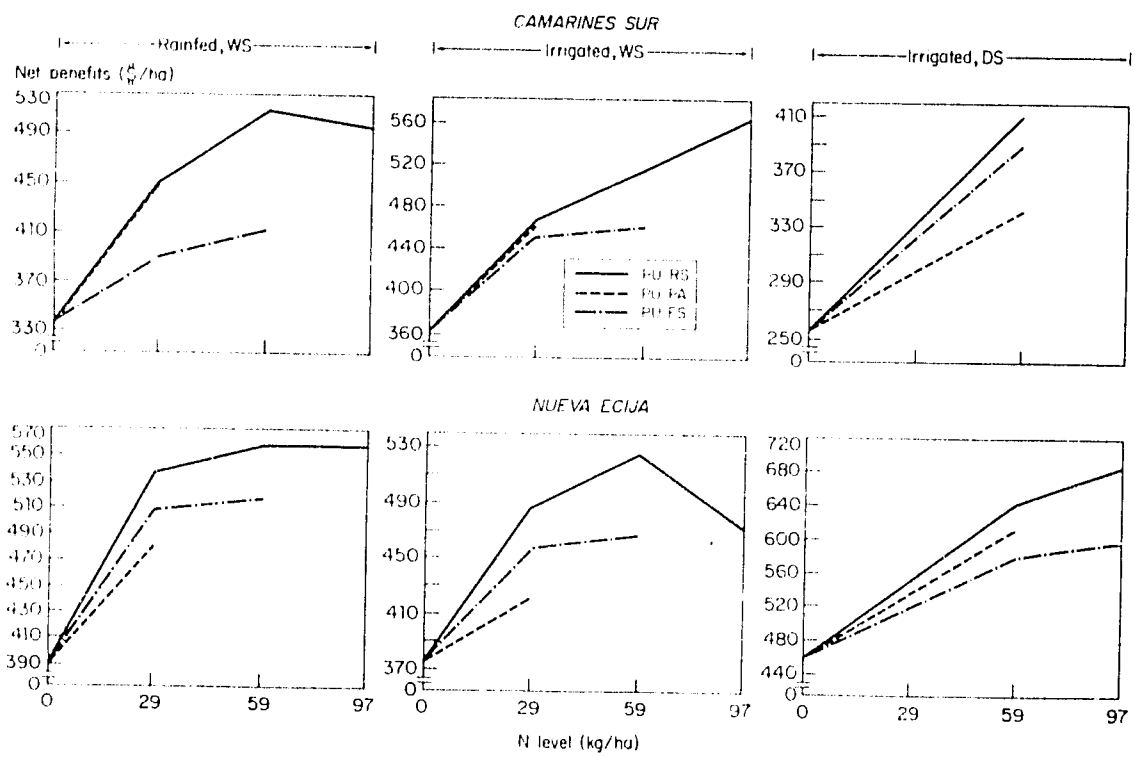
The researchers' weed control practice sufficiently increased profits in rainfed Camarines Sur during WS and in irrigated Nueva Ecija during both seasons. The researchers' disease control technology was profitable only in irrigated Camarines Sur during WS, increasing profits by $44/ha.

Profitability of soil nutrients. Fertilizer N application was profitable up to 90 kg/ha at the

Table 17. Profitability of N, P, K, Zn, and chicken manure application in farmers' fields, Philippines, 1986.

Location, water regime, season	Marginal benefit-cost ratio[a]				
	N at 90 kg/ha	P at 30 kg/ha	K at 30 kg/ha	Zn at 20 kg/ha	Chicken manure at 3 t/ha
Camarines Sur					
Irrigated, WS	6.95	0.47	−1.29	−1.29	0.2
Rainfed, WS	6.67	1.84	−1.18	−1.18	0.41
Irrigated, DS	5.71	2.42	n.i.	n.i.	n.i.
Nueva Ecija					
Irrigated, WS	2.52	1.23	4.35	−0.43	1.15
Rainfed, WS	7.17	0	1.76	0.44	0.76
Irrigated, DS	13.61	1.11	n.i.	n.i.	n.i.

[a] n.i. = not included.



5. Profitability of various N forms and methods of application compared with farmers' practices, Philippines, 1986 WS and DS. PU = prilled urea, PA = plunger-auger, RS = researchers' split, FS = farmers' split.

Table 18. Profitability of farmers' and researchers' management packages in upland rice production. Philippines, 1986 WS.

Variety	Management package 1[a]		Management package 2[b]		Management package 3[c]		Management package 4[d]		Management package 5[e]	
	Net benefit ($/ha)	B:C	Net benefit ($/ha)	B:C	Net benefit ($/ha)	B:C	Net benefit ($/ha)	B:C	Net benefit ($/ha)	B:C
					Batangas					
Farmers'	198	5.6	70	3.8	113	3.2	219	6.0	209	2.5
IR43	192	5.0	26	2.1	83	2.6	227	6.1	229	2.7
UPLRi-5	237	6.0	52	3.1	100	2.9	294	7.6	283	3.1
					Cavite					
Farmers'	499	12.1	159	7.4	230	5.6	505	14.5	383	3.8
IR43	305	7.8	25	2.0	186	4.7	362	10.7	372	3.8
UPLRi-5	355	8.9	245	10.9	290	6.8	419	12.2	347	3.6

[a]Farmers' level of fertilizer, insect, and weed control. [b]20 kg N, 2 mechanical weedings (MW) by kalmot/lithao, no insect control (IC). [c]40 kg N, 1 chemical weeding (CW), benefit cost consideration (BC) for IC. [d]60 kg N, 1 MW, 1 hand weeding (HW), 0.4 × IC [e]80 kg N, 1 CW, 1 MW, 1 HW, 2 IC.

irrigated and rainfed test sites in Camarines Sur and Nueva Ecija during both seasons (Table 17). The application of 30 kg P/ha was profitable only in rainfed Camarines Sur during WS and irrigated areas during DS. Application of 30 kg K/ha was profitable only in irrigated Nueva Ecija during WS. There was no response to Zn. The increase in output value from application of chicken manure was not enough to cover the increased cost of the input.

Forms and application methods of urea. The researchers' split of PU consistently gave higher net benefits than the farmers' practice at both 29 and 58 kg N/ha during both seasons across sites in Camarines Sur and Nueva Ecija (Fig. 5). USG deep-placed by hand or by machine (press wedge) and PU deep-placed by machine (plunger-auger) were not as efficient as the researchers' split.

Management packages. Table 18 gives the economic evaluation of the four input packages compared with the farmers' input in upland Batangas and Cavite. In Batangas, management package (MP) 4 and MP5 were both somewhat more profitable, while MP2 and MP3 were less profitable than the farmers' practices. UPLRi-5 yielded higher net benefits than the farmer's variety (Kinandang Patong) and IR43 with farmers' practices (MP4 and MP5). In Cavite, MP4 yielded consistently higher net benefits on the average than farmers' practices, while MP5 had higher net benefits than farmers' practice with IR43 only. In general, MP4 yielded B:C's that exceeded the generally accepted level of 2.5:1 for upland conditions.

EVALUATION OF ON-FARM MANAGEMENT OF RICE IN SIND, PAKISTAN

Agricultural Economics Department

The Dokri Rice Research Institute (DRRI), Sind, Pakistan, in collaboration with the Pakistan Agricultural Research Council (PARC) and an IRRI economist, compared the productivity and profitability of recommended rice production practices with those of farmers in Upper Sind. Crop management factors examined were fertilizer rate, tillage level, seedling management (seedling age and transplanting density), and Zn application.

Results from 42 on-farm trials conducted over 3 seasons (1983-85) were consistent. The adoption of recommended practices increased farm yields by 2.5 t/ha on the average, from a simulated farmer's yield of 6.2 t/ha to a yield of 8.7 t/ha with recommended practices. The factors that contributed most to the yield difference were fertilizer and tillage level.

Economic analysis showed that it was profitable to adopt the recommendations in a sequential manner — first the low-cost practices of Zn and seedling management, and then the more costly practices of higher fertilizer rate and tillage level. Tillage and fertilizer were highly complementary, the benefits of one factor being conditional on the other. Sensitivity analysis suggests that these findings are stable over the range of prices farmers are likely to face in the short-run in Upper Sind. See the section on Cooperative Country Projects for details.

Consequences of new technology

Agricultural Economics Department

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DIFFERENTIAL IMPACT OF TECHNICAL CHANGE IN FAVORABLE AND UNFAVORABLE AREAS

Accumulated evidence indicates that farm size, tenure, and other social and institutional factors have not significantly affected the diffusion rate of modern varieties (MVs). Because of imperfect credit markets and the higher cash requirements of the new technologies, adoption rates by larger and owner-operated farms have been initially more rapid in areas where the distribution of land ownership is highly skewed. In many areas, however, this was soon mitigated by government credit programs and the interlinking of credit and output markets, which lowered the cost of credit to farmers.

Environmental factors, especially the degree of water control, are crucial in explaining the differential adoption of new technology. Agricultural technologies are highly location-specific, and the scope for technology transfer across regions is thus inherently limited. As much as 60% of the rice area in South and Southeast Asia was still planted to traditional varieties (TVs) in the early 1980s.

Intercountry comparisons. *MVs and environmental conditions.* Intercountry differences in adoption rate are clearly related to the proportion of area irrigated, as shown in Table 1. Countries with low adoption rates are those where less than 30% of the rice area is irrigated. In Thailand and Bangladesh, rice is cultivated in large deltaic areas, where the cost of developing an effective water control system is high. In Nepal, a significant part of the rice area is in the hills and mountainous regions; even in the terai (lowland areas) only 30% of the rice area is irrigated. Both Thailand and Nepal have traditionally exported rice owing to their relatively high land-man ratios and natural comparative advantage in producing rice relative to other crops.

Conversely, countries with high adoption rates are those where the cost of irrigation is relatively less and therefore the ratio of irrigated area to total area is higher. Yet the Philippines, where the proportion of irrigated area is comparable to that of India, has a much higher rate of MV adoption because a large part of Philippine rainfed land is characterized by favorable lowland conditions, where the short-statured MVs also have a yield advantage. In India, there are relatively more rainfed areas that either have deep water conditions or are drought-prone, and where MVs show little advantage over TVs.

The contrast in production and yield performance among the six Asian countries with varying rates of irrigation and MV adoption is also shown in Table 1. In Thailand, Nepal, and Bangladesh — where MVs had the lowest adoption rates — growth performance in rice production and yields declined markedly after 1965. Yields stagnated as rice cultivation was extended into the marginal areas, except in Bangladesh, where the boro season crop benefited from modern technology.

In countries where MV adoption was relatively high — India, Indonesia, and the Philippines — growth in yield and production accelerated during the past two decades. Yield increases accounted for more than 50% of output growth compared with less than 40% during the previous period. Until

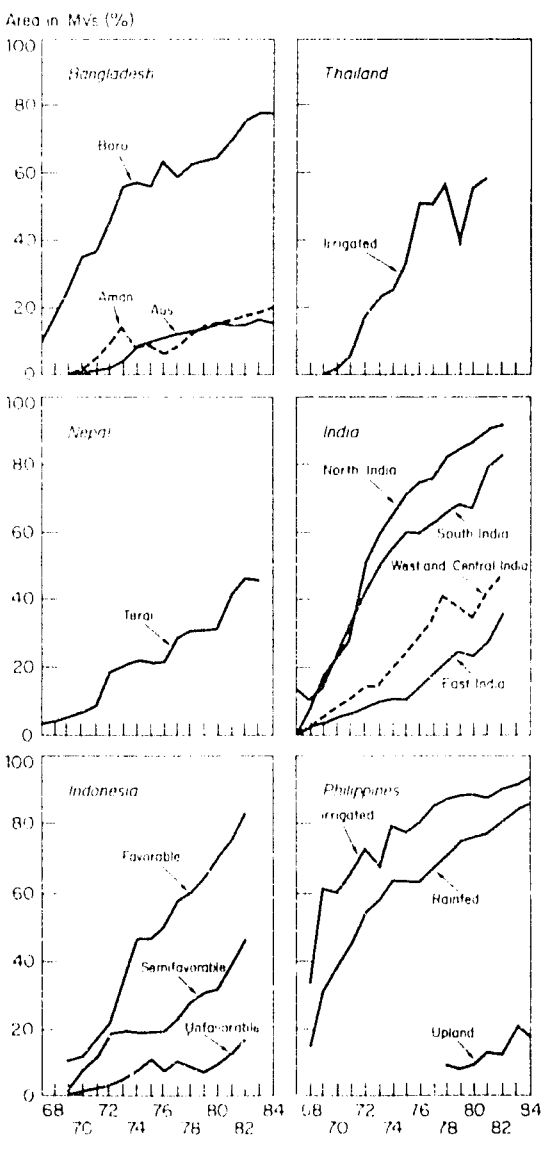
Table 1. Adoption rates of irrigation and modern varieties, and growth rates of rice production, area, and yield in 6 Asian countries, 1955-85.[a]

Country	Area (%) under		Growth rates (%)					
			1955-65			1965-85		
	Irrigation	MVs	Production	Area	Yield	Production	Area	Yield
Bangladesh	13	25	3.1	1.2	1.9	2.0	0.6	1.4
India	42	53	2.1	1.2	0.9	3.0	0.8	2.2
Indonesia	64	64	1.2	1.0	0.2	5.6	1.5	4.1
Nepal	23	36	6.3	1.9	8.2	1.3	1.2	0.1
Philippines	54	85	2.2	1.4	0.8	3.7	0.2	3.5
Thailand	25	13	5.4	2.2	3.2	2.5	2.0	0.5

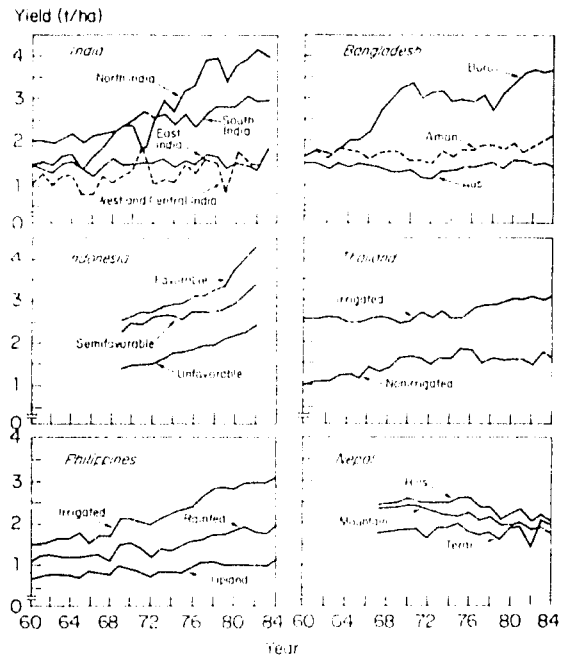
[a] Basic data from IRRI *World rice statistics*, 1985.

recently, the deceleration of growth in rice production in Thailand did not adversely affect rural incomes, since the nonrice agricultural and industrial sectors grew rapidly. In Bangladesh and Nepal, the very limited productivity growth in the rice sector, which provides livelihood to the majority of the population, is an important reason for the stagnation of their economies.

Figures 1 and 2 show the historical trends of MV adoption and rice yields by environmental condition within the countries. The categories differ by



1. Trends in percentage of area planted to modern varieties (MVs) by environmental condition, 1967-84.



2. Trends in rough rice yields by environmental condition, 1960-84.

country because data are not available for a common classification. In Indonesia, provinces are grouped by proportion of irrigated area in lowland rice and proportion of upland to total rice area. Rice data in Bangladesh are classified by season: boro represents the irrigated areas, and aus and aman the unirrigated areas. In Thailand and Nepal, it is assumed that MV adoption is limited to the irrigated areas and to the terai.

The importance of environmental conditions in understanding the variability of adoption rates of MVs across areas is illustrated by Figure 1. High adoption rates in India have been confined to the northern and southern regions, which are almost fully irrigated but account for only about one-fourth of the total rice area. In contrast, eastern India, which has heavy rains during the growing season and poorly developed water control, has the lowest adoption rate.

The gap in adoption rates between categories reflects the degree to which the environment is unfavorable to the MVs. In the Philippines, where MVs were adopted more rapidly than in any other country, the difference in adoption rate is probably least marked. Much of the rainfed lowland area is favorable, since the degree of water control is not

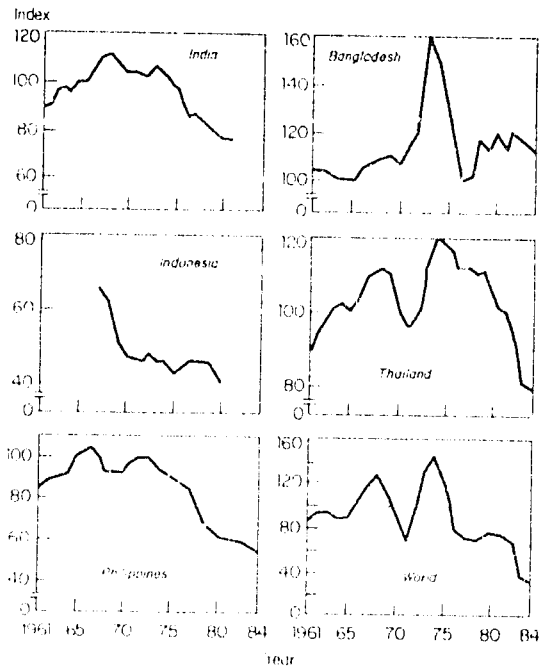
greatly different from that in irrigated areas during the wet season (WS). The introduction of short-duration and more drought-resistant varieties in the mid-1970s pushed the MV adoption rates in the rainfed lowlands closer to those in irrigated areas by the early 1980s. Upland rice areas also began to be planted with MVs in the 1980s.

MVs and productivity. Differential adoption of MVs has widened the disparity in yield between irrigated and unirrigated regions since the mid-1960s (Fig. 2). While yields remained essentially stagnant at 1-1.5 t/ha in the unfavorable areas, average yields reached 3 to more than 4 t/ha in the irrigated areas of all the countries except Nepal, where yields in the terai stayed constant but declined in the unfavorable areas as rice cultivation spread into marginal areas. In Indonesia, there was a modest increase in rice yields in the unfavorable and semifavorable provinces because of greater irrigation investments in the outer islands since the mid-1970s. The new rice technology, therefore, has shifted the comparative advantage of producing rice in favor of irrigated areas within a country and, across countries, in favor of those with a higher proportion of irrigated rice area.

Trends in real price of rice. If the real price of rice declines as yields increase in irrigated areas where modern technology spreads, the incomes of rice producers in unfavorable areas — where yields have not increased — may decline, although the welfare of early adopters and rice consumers is enhanced. The fear has been widely expressed that modern rice technology not only accentuates income disparities between favorable and unfavorable areas but also worsens the absolute poverty of farmers in unfavorable areas.

During the first decade of the Green Revolution, yield increases generally led to higher farm incomes because the real price of rice was maintained and even increased following world price trends during this period. Growth in rice production was substituting for rice imports in countries where MVs were widely adopted. By the mid-1970s, the real price of rice had declined in countries where productivity gains were more rapid and self-sufficiency was achieved — India, the Philippines, and, to a lesser extent, Indonesia (Fig. 3).

Government policies have had a crucial role in balancing producer and consumer interests. In



3. Trends in real price of rice in 5 countries and in the world market, 1961-84. 1964-66 = 100.

Indonesia, the decline has been relatively slight, and rice farmers have benefited from output price supports, less distortionary macro policies, and heavy input price subsidies. Most of the productivity gains in the Philippines and India, however, accrued to consumers, as the real price of rice declined by about 40% (Philippines) and 30% (India) over the past decade.

The domestic prices of rice in Thailand, a major rice exporter, and in Bangladesh, a rice importer, have not followed world price trends as a result of trade and commercial policies. The Thai Government, however, was not able to protect rice farmers from the recent sharp drop in world prices.

The case of Nepal is interesting. Being a small, landlocked economy with long, open borders with India, Nepal's domestic rice price is strongly influenced by the declining price trends in India, but without much benefit from new rice technologies. The falling real price of rice is a major cause of the stagnation of the rice sector in Nepal, a country that is effectively an unfavorable area within the Indian subcontinent. The direct effect of the declining price trend is to reduce incentives to

grow rice and reduce the incomes of rice producers — farm and landless households alike — in unfavorable areas, which often lack alternative employment opportunities.

The accelerated growth in rice productivity in the region has been a major contributor to the decline in world rice price in real terms. Compared to the 1960s, the average real world price from 1976 to 1985 was lower by 16% or, if the unusually high world prices in 1973-75 were excluded, by 30% (Fig. 3). The sharp drop in world rice prices in recent years could be partly a reflection of a short-term trough due to the high investments in irrigation in the late 1970s and the fall in oil prices. Dumping of grain surpluses resulting from rising agricultural protection in the developed countries has exacerbated the decline in world rice prices in recent years. The welfare of countries where productivity has not significantly increased would generally be reduced, particularly the incomes of farmers in exporting countries, as farmer protection could be achieved only by direct subsidies.

Analytical issues. *Growth vs equity.* Early MVs are more suited to irrigated than to unirrigated conditions because the research cost of producing a unit yield increase in irrigated areas is lower. The probabilities of achieving research success and the availability of basic research knowledge on irrigated rice are higher. Most major research stations including IRRI are located in irrigated environments. Moreover, the homogeneous character of irrigated areas across regions facilitates wider technology transfer, hence raising the total benefits derived from a new variety or cultural practice. From the viewpoint of maximizing global rice production, the focus of research on irrigated rice is rational.

The people in the unirrigated areas are generally poorer; and to a large extent, Asian countries with greater proportions of unfavorable areas — such as Bangladesh — are also comparatively poor. In these areas, not only is the degree of water control lower, the soil quality poorer, and climatic conditions harsher, but marketing and social infrastructures are also much less developed.

To evaluate the trade-offs between growth and equity in allocating rice research investments by environmental conditions, one has to consider not only the direct but also the indirect effects of technical change on the livelihood of the people — both farm and landless households — particularly in the unfavorable areas bypassed by new technologies. These indirect effects influence the distributional impact of new technology, initially through market price effects and subsequently through factor market adjustments in labor, land, and other markets.

Factor market adjustments. In terms of the labor market, greater employment opportunities and income in areas where technology has been adopted may induce permanent and seasonal migration from unfavorable to favorable areas, reducing the interregional income disparity initially created by the differential adoption of modern rice technology. Modern technology could also increase the labor supply in favorable areas, particularly among women, or lead to the adoption of mechanical and other labor-saving technology. While these labor market adjustments tend to equalize wages between the favorable and unfavorable areas, they have different implications for the level of wages and employment and, hence, for income distribution.

Land market adjustment can take the form of changing farm size or changing farming systems. With an appropriate land market and tenancy transactions, labor migration may bring about an increase in farm size in unfavorable areas and a decrease in favorable areas so as to equate total farm income across areas and increase the demand for labor in general as farm size declines. The lower profitability of rice farming in unfavorable areas as a result of lower rice price will induce farmers to cultivate other crops, which will mitigate income loss and may have beneficial environmental effects. To the extent that such adjustments in the labor and land market equilibrate returns to land and labor, the worsening of the income inequality between the favored and unfavored areas is minimized.

The overall impact of the new rice technology on the distribution of income within regions as well as between regions with different production environments will depend on the nature of factor use bias and the strength of factor market adjustments, particularly through the labor market, because labor is the most mobile factor and the main asset of the poorest households. In addition, the new rice

technology has mitigating effects on labor demand in the nonfarm sector. Through intersectoral growth linkage effects, rapid growth in farm income will have strong growth and multiplier effects on the rest of the economy, since the bulk of expenditures in the rural sector are spent on food and labor-intensive industrial goods. Moreover, since rice is a basic staple, cheaper rice will lower the price of labor relative to capital and raise the competitive position of the labor-intensive industrial sector vis-à-vis the rest of the world, increasing total employment in the whole economy.

There have been many case studies on the differential rates of adoption and the impact of MVs, but most have been conducted in progressive areas where modern rice technologies were widely adopted. No rigorous statistical analyses have been made with respect to the factor use bias of modern rice technology. Sufficient data are not available to characterize the socioeconomic conditions and the impact of new technology on the incomes of people in unfavorable areas. Neither are they sufficient to broadly identify in the region as a whole how serious the environmental factors are relative to the social and institutional factors in constraining the adoption of, as well as efficient use of, modern rice technology. Moreover, we are essentially ignorant of adjustments in resource allocations in response to modern technology within and among areas with different environmental conditions, and therefore of the ultimate impact of new technology on non-adoptors. We have also ignored the importance of intrahousehold differences in labor allocation, access to resources, and hence the distribution of the benefits of new technology between men and women in the society.

Asian collaborative research. The Agricultural Economics Department is embarking on a collaborative research study among six Asian countries Bangladesh, India, Nepal, Indonesia, Thailand, and the Philippines to shed light on the preceding issues. The ultimate purpose is to draw policy implications for the allocation of rice research expenditures by environmental condition at both the national and international research institution level.

The Philippine component was initiated in 1985 to serve as the prototype study for the Asia-wide project. It is based on an intensive survey of five villages representing different production environments. Three levels of data collection covering both farm and landless households were undertaken. First was a census of all households to determine demographic characteristics, history of migration, land tenure patterns, and selected farm characteristics. This also served as a basis for choosing the 381 sample households intensively surveyed to obtain information on inputs, outputs, factor prices, and all sources of income. Finally, a time allocation survey instrument was administered to 60 households a subsample for the survey.

This report is limited to the analysis of the factors affecting adoption of the new technology and the direct effects of the new technology on productivity. Full analysis of the indirect effects through the labor, land, and credit market adjustments, and the overall impact on income distribution, is in progress.

Two villages (Maragol and Gabaldon) in Nueva Ecija and three villages (Pandan, Rizal, and Signe) in Iloilo, Philippines, were selected. These provinces are the top two rice-growing provinces in the country. Soils in the five villages range from clay loam to clay. Annual mean rainfall is higher and the rainfall distribution more skewed in Nueva Ecija. In Iloilo, the climate is milder, mean rainfall lower, and rainfall more evenly distributed. Maragol and Pandan represent favorable areas, as both are fully irrigated by national gravity systems and have a flat landscape. Maragol farmers plant two consecutive rice crops. Cropping intensity is even higher in Pandan, where half of the rice area is planted to three rice crops throughout the year and the other half to two crops.

Gabaldon is a semifavorable area because its production and input structure are very similar to those of the favorable villages. It is primarily a rainfed village, with 16% of the rice area irrigated by pumps to permit a second rice crop. Otherwise, the dominant cropping pattern is rice - fallow.

Rizal and Signe are classified as unfavorable areas. They are primarily rainfed, and the topography ranges from moderately sloping to mountainous; but all rice is planted on bunded plots. Because of the more even rainfall distribution in

Rizal, only 12% of the crop area lies fallow during the dry season (DS), as sufficient moisture is retained even within the dry months. The introduction of short-duration MVs together with associated cultural practices such as direct seeding and mechanical threshing in the mid-1970s induced the higher cropping intensity on many farms in Rizal. Twenty-eight percent of the rice area is planted to two crops of rice, and half of this is still planted to a third crop of vegetables. Mungbean and other upland crops are planted as the second crop in 40% of the crop area.

Signe also has a varied cropping system. Although only 20% of the rice area is irrigated, 38% is planted to 2 rice crops because some lowland areas are close to the creek and an underground spring. In the mountainous part of the village, maize and legumes are the second crop for more than half of the cultivated area, and the rest lies fallow.

Adoption rates of new technology. Table 2 presents the levels of adoption rates of modern biological technology during WS and DS. The adoption of MVs and fertilizer was virtually complete in the study villages as early as 1975. Even in the unfavorable villages, adoption rates are relatively high. The 20% of rice area planted to TVs in Rizal is located further away from the main road, and transporting of modern inputs is difficult. The TV areas are also in the higher portion of the village, where water is less assured, particularly during DS. The use of MVs in Signe is concentrated in the lowland areas, where water is plentiful. During DS, nearly all rice areas in the unfavorable sites use MVs, because either only irrigated areas are cultivated during DS, as in Signe, or a short-duration variety is critical to get any harvest at all, as in the rainfed village of Rizal.

The Nueva Ecija farms generally used more fertilizer than the Iloilo farms. Fertilizer application in DS was higher because of the greater solar energy, which raises fertilizer productivity. Within Nueva Ecija, fertilizer use in the unfavorable environments was below that in the favorable; the only exception was the higher level of fertilizer application in Gabaldon than in Maragol in DS, which could be explained by the much smaller plots cultivated during this season in Gabaldon.

The proportions of rice area using insecticides and herbicides are also relatively high, at 63 and 99%, respectively. Adoption rates of these inputs were higher in the Nueva Ecija villages than in

Table 2. Adoption rates of modern biological technology in 5 Philippine villages, 1985 WS and DS.[a]

Site	Farms (no.)	Area under MVs (%)	Fertilizer use					Insecticide use		Herbicide use	
			Area (%)	₱/ha	kg N/ha	kg P/ha	kg K/ha	Area (%)	₱/ha	Area (%)	₱/ha
					Wet season						
Favorable											
Maragol	92	100	100	1383	70	32	9	97	324	84	153
Pandan	37	100	100	827	54	12	1	86	220	80	120
Semifavorable											
Gabaldon	54	100	100	1161	59	25	16	93	185	73	71
Unfavorable											
Rizal	63	79	100	961	59	19	16	98	183	83	120
Signe	50	59	79	685	54	4	1	63	45	18	9
					Dry season						
Favorable											
Maragol	92	100	100	1600	84	33	9	98	353	92	159
Pandan	35	100	100	1134	65	14	1	99	236	92	117
Semifavorable											
Gabaldon	24	100	100	2219	109	42	28	75	165	97	155
Unfavorable											
Rizal	40	95	99	1110	57	20	3	95	170	83	50
Signe	22	100	89	1052	76	10	0	89	82	9	16

[a] $1 = ₱18.61.

the Iloilo villages, and higher in irrigated areas than in rainfed areas within each province. But the gap in use of the agricultural chemicals was significantly wider than that in fertilizer application across the environmental conditions.

To discern the relationship between production environment and technology adoption across farmers, a MV adoption and a fertilizer demand function were econometrically estimated (Table 3, 4). The estimated fertilizer demand function had a much better fit (R^2=0.82) than the adoption function (R^2=0.42). Irrigation and village dummy variables were all highly significant factors affecting MV adoption. Despite the low level or absence of irrigation, adoption rates of MVs in Gabaldon and Rizal were significantly higher than in Signe, the reference village. All farms in Gabaldon planted MVs because they have favorable rainfed conditions that do not differ much from the irrigated villages during WS. Rizal, on the other hand, has a relatively even rainfall distribution that allows a second rice crop when short-duration rice varieties and other associated time-saving technologies are available. The level of education of farmers appears to be a more important attribute than age. Tenure and farm size appear to be of minor importance in determining MV adoption. Although one of the tenure variables is significant, the negative coefficient for owner-operators is counter-intuitive and may be capturing the effects of other variables correlated within farm ownership.

Table 3. Adoption function of modern varieties (MVs) based on a farm survey of 5 villages in the Philippines, 1985 WS.[a]

Item	Coefficient	t-value
Irrigation (% of area)	0.139**	2.401
Village 1 (Maragol)	34.718**	5.313
Village 2 (Gabaldon)	47.973**	9.242
Village 3 (Pandan)	35.190**	5.337
Village 4 (Rizal)	33.492**	7.156
Tenure 1 (owner-operator)	−11.361**	−2.817
Tenure 2 (leasehold/CLT)[b]	−1.636	−0.405
Farm size	−0.447	−0.386
Age of farmer	0.106	0.974
Education of farmer (yr)	0.964*	2.021
Intercept	44.026	5.949
R^2	0.42	

[a]Dependent variable is percent of area planted to MVs.
[b]CLT = certificate of land transfer.

Table 4. Estimates of fertilizer demand function based on farm survey data in 5 villages in the Philippines, 1985 WS.[a]

Item	Coefficient	t-value
Fertilizer price (₱/kg NPK)	−0.585**	−5.240
Rice price (₱/kg)	0.072	0.385
Area under MV (%)	0.006**	5.098
Irrigation	0.002*	1.952
Farm size	0.955**	31.677
Village 1	0.171	1.492
Village 2	0.202*	2.194
Village 3	−0.371**	−3.301
Village 4	0.128	0.159
Tenure 1	0.120	1.720
Tenure 2	0.073	1.064
R^2	0.818	

[a]Dependent variable is kg of NPK nutrients. Specification is double-log.

Fertilizer price and the variables shifting the fertilizer response functions (irrigation and MVs) are the important explanatory variables affecting fertilizer use across farms (Table 4). Rice price is insignificant because it is fairly uniform across the observations. The significant unitary coefficient of farm size simply indicates that there is no difference in fertilizer application per hectare between small and large farms. Tenure does not significantly affect the rate of fertilizer use.

Impact on productivity. Table 5 reports the various measures of rice productivity across the study villages. Except for the typhoons that affected the WS harvest in Maragol and Gabaldon, weather conditions in 1985 in both regions were on the whole normal. Production in the 2 villages dropped at least 20% below normal levels because of bad weather. Despite this, the yields in Nueva Ecija were higher than in Iloilo, and higher in the favorable environments than in the unfavorable environments within and across the provinces. As expected, yield differences were much lower during WS than during DS. Except for Rizal, all the villages had significantly higher rates of fertilizer application during DS. In Maragol and Gabaldon, yields were higher in DS than in WS even after considering the 20% drop in production. This was not generally true in the Iloilo villages, as DS yields were lower. In Pandan, average yields for the third season crop were also lower (2.9 t/ha).

Table 5. Measures of rice productivity in 5 Philippine villages, 1985 WS and DS.[a]

Site	Yield (t/ha)		Labor productivity (kg/d)		Net value added[b] (thousand ₱/ha)		Net return[c] (thousand ₱/ha)	
	WS	DS	WS	DS	WS	DS	WS	DS
Favorable								
Maragol	3.5	6.0	41	77	5.5	12.7	2.0	8.0
Pandan	4.0	3.3	46	42	7.6	7.5	3.5	3.5
Semifavorable								
Gabaldon	3.3	4.8	41	61	5.5	8.4	2.9	6.7
Unfavorable								
Rizal	3.2	2.6	52	43	6.9	5.8	4.1	3.7
Signe	1.9	1.9	20	24	3.4	4.3	0.5	1.0

[a]$1 = ₱18.61. [b]Net value added = gross value of output − cost of current inputs and fixed capital. [c]Net return = net value added − paid out land rental and hired labor.

The patterns of labor productivity closely followed yield differences. Labor productivity was lowest in Signe, which had the lowest yields and the lowest level of mechanization, but somewhat higher in Pandan and Rizal in WS because of widespread direct seeding. Because of the very high yields in Maragol and Gabaldon during DS, labor productivity was also high.

Yields and labor productivity are partial measures of productivity, because many other costs of inputs are not taken into account. The cost of other inputs is considered by estimating net value added per hectare, defined as gross revenue minus costs of current inputs and fixed capital. Although costs of current inputs and fixed capital are generally higher in favorable areas, the net value added of rice production is also higher because of its yield advantage. If the yields in Maragol and Gabaldon are assumed to be 20% higher in WS, the average WS and DS net value added per hectare is highest in the irrigated areas Maragol and Gabaldon and lowest in Signe, the most unfavorable area with the lowest adoption rate of modern rice technology. The income derived from rice, however, depends on the proportion of labor that is supplied by the family and the tenure relationship. In terms of net return to the farm household, the difference between favorable and unfavorable areas widens because of the greater proportion of share-tenants in the unfavorable areas.

Differences in the productivity measures observed across villages are influenced not only by production environment and technology but also by other factors. In Table 6, a Cobb-Douglas production function is estimated to distinguish the effects of technology and production environment from the other inputs on production across the sample farms. The goodness of fit is high (R^2=0.876), and the estimated coefficients are all positive and statistically significant. The sum of the coefficients for labor, land, fertilizer, and fixed capital is close to unity, indicating constant returns to scale. Adoption of MVs appears to be more statistically significant than irrigation. The effect of irrigation is somewhat confounded by the village dummy variables, which are all significantly different from Signe, the control village. The lower

Table 6. Estimate of Cobb-Douglas production function based on farm survey of 5 villages in the Philippines, 1985 WS.[a]

Item	Coefficient	t-value
Labor (man-days)	0.431**	5.907
Land (ha)	0.392**	4.992
Fertilizer (kg NPK)	0.522**	2.847
Fixed capital (₱)	0.142**	4.039
Area under MV (%)	0.004**	2.896
Irrigation	0.115	1.379
Village 1	0.383**	3.832
Village 2	0.469**	5.005
Village 3	0.626**	5.941
Village 4	0.690**	7.739
Intercept	4.087	
R^2	0.876	

[a]Dependent variable is kg of NPK nutrients. Specification is double-log.

Table 7. Input use of MVs and traditional varieties (TVs) in Rizal and Signe, Iloilo, Philippines, 1985 WS.[a]

Site and rice type	Elemental fertilizer (kg/ha)			Expenditures (₱/ha) for			Labor (d/ha)	Area (%) using				Labor productivity (kg/d)
	N	P	K	Fertilizer	Insecticide	Herbicide		Hand tractors	Direct seeding	Herbicide	Mechanical thresher	
Rizal												
MV	61	21	2	1013	208	47	59	38	89	74	100	55
TV	50	12	0.4	746	76	12	73	30	43	22	99	43
Signe												
MV	84	6	1	1051	73	14	80	0	68	24	90	30
TV	12	2	0.1	168	5	1	112	0	0	1	82	11

[a]$1 = ₱18.61.

Table 8. Cropping intensity, labor use, and productivity of MVs and TVs in Rizal and Signe, Iloilo, Philippines, 1985 WS and DS.

Site and rice type	Farms (no.)		Rice cropping index	Multiple cropping index	Yield (t/ha)			Net value added (t/ha)			Net return (t/ha)			Net return (t/ha) on rice and nonrice crop		
	WS	DS			WS	DS	Whole year	WS	DS	Whole year	WS	DS	Whole year	WS	DS	Whole year
Rizal																
MV	62	40	1.4	1.8	3.2	2.6	4.2	2.3	1.8	3.0	1.5	1.3	2.0	1.6	1.5	2.1
TV	18	–	1.0	1.5	3.2	–	3.2	2.4	–	2.4	1.7	–	1.7	1.7	–	1.7
Signe																
MV	35	22	1.4	1.9	2.4	1.9	3.1	1.6	1.2	2.0	0.5	0.5	0.7	1.1	0.8	1.1
TV	30	–	1.0	1.6	1.2		1.2	0.8	–	0.8	0.3	–	0.3	0.5	–	0.5

coefficient for the Nueva Ecija villages is due to the typhoon experienced late in the growing season.

This analysis relates production environment, technology, and productivity within a season. However, modern rice technology increases the productivity of the land per year through crop intensification. The input use, cropping intensity, and economic return for MVs and TVs were compared in Rizal and Signe, where TVs are still planted. Rizal, in particular, illustrates the impact of short-duration varieties and associated technologies, which save water by reducing turnaround time, on crop intensification in rainfed lowlands.

Table 7 reports the levels of input use and adoption of labor-saving technology of farmers using MVs and TVs in Rizal and Signe. The levels of fertilizer, insecticide, and herbicide application were higher for MVs. The difference was not as great in Rizal as in Signe, because the rainfall pattern provided more moisture in the second season and the terrain is only moderately sloping. In fact, the TV planted in Rizal was actually an improved local variety (BF3). Labor use per hectare for WS was lower for MVs than for TVs in both villages, primarily because of more direct seeding.

Table 8 shows the effects of modern rice technology through crop intensification. The rice cropping index for farmers using MVs was 1.4 compared with 1.0 for only 1 crop of rice for farms using TVs. Farms using MVs planted nonrice crops in the second season, and also as a third crop. Hence, the rate of crop intensification measured by the multiple cropping index was also higher for MVs.

When the whole year is considered, the labor use per hectare was higher on MV farms even if labor use for other crops is considered. The yield of TVs in Rizal was slightly lower than the yield of MVs, but the net value added per hectare and net return were higher because of the lower cost of inputs. However, when the possibility of having a second crop of rice is considered, the net value added and net return per hectare per year were higher for MVs than for TVs. In Signe, the advantage in yield and economic return of MVs over TVs was much greater because of the poorer growing conditions where TVs were planted. Even in WS alone, the average yield of MVs was about double that of TVs.

Cropping systems program

Analysis of the physical and biological environment

Multiple Cropping, Plant Pathology, Entomology, and Agronomy Departments

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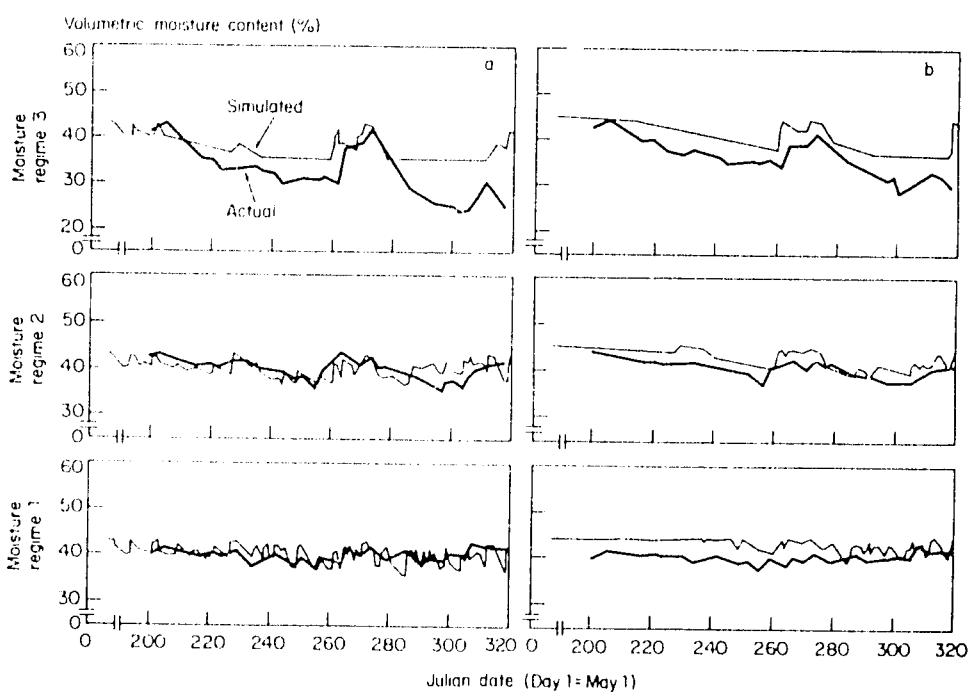
Interdisciplinary cropping systems research is currently being conducted in two Philippine rice environments. Identification of crop technologies to increase and sustain yield in upland systems on acid infertile soils is conducted in Claveria, Misamis Oriental. Development of more productive cropping patterns in partially irrigated lowland systems is conducted in Guimba, Nueva Ecija. A general description of physical and biological characteristics of these environments was given previously (Annual reports for 1984-86).

AN UPLAND EVAPOTRANSPIRATION MODEL

Multiple Cropping Department

An evapotranspiration model that provides standard indices of water availability was adapted to upland rice. The crop and soil parameters were estimated for the variety UPLRi-5 in a 1983 experiment at IRRI in which six varieties were planted on seven dates and irrigated with a line source sprinkler system. The model calculates for each day the infiltration of water into the soil. Potential crop evapotranspiration (PET) is computed from a measure of evaporative demand — a growth stage pan factor — and is adjusted for seasonal effects. A soil depth of 45 cm was the reservoir from which roots could extract water. Evapotranspiration reductions, caused by soil water limitations, were obtained by multiplying evapotranspiration by a function dependent on the water available in the root zone.

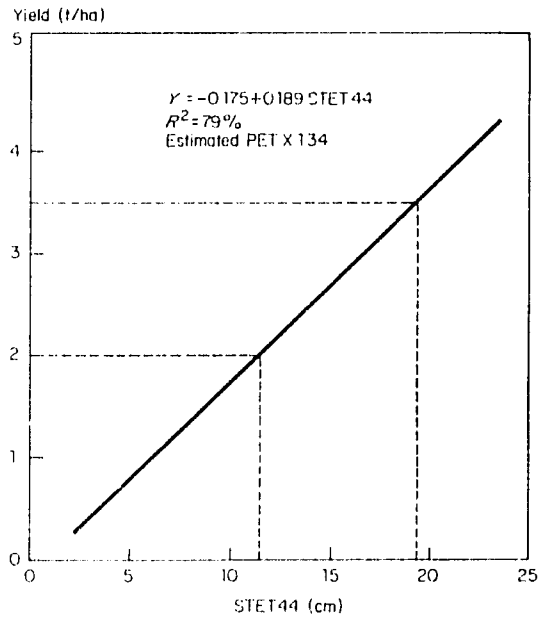
The plot of actual and simulated water content showed good agreement except for an underestimation in the driest regime (Fig. 1). This may imply that the rooting habit of UPLRi-5 when the soil is dry is different from that described in the model. It is also likely that evaporation directly from the soil surface was greater than simulated because the canopy was not well developed. When the actual grain yield was regressed on a model-derived evapotranspiration index, the summation of evapotranspiration values for the last 44 d of



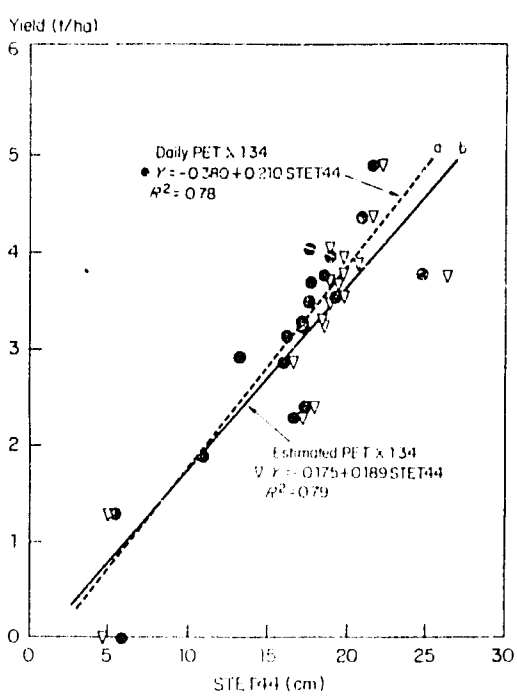
1. Comparison of simulated and actual volumetric soil water contents for layers: a) 20 cm (actual) and [(5-15) + (15-30)]/25 (model); b) [20 + 40]/2 (actual) and [(15-30) + (30-45)]/30 (model), 7th planting, line source sprinkler experiment, IRRI, 1983.

growth (STET44) best explained the actual yield variations. Comparison of 4 alternative estimates of evaporative demand used with the model showed that estimated PET × 1.34 was the best, although the results from the model using daily PET × 1.34 were not very different (Fig. 2). The factor 1.34 refers to the ratio of estimated Class A pan evaporation mean and estimated PET mean. These estimated means were the means for May to November 1979-85. Using estimated PET × 1.34 in the model, evapotranspiration levels were used to define the water adequacy for upland rice (Fig. 3). Levels of STET44 between 11.5 and 19.4 cm give moderate yields; values greater than 19.4 cm correspond to high yields.

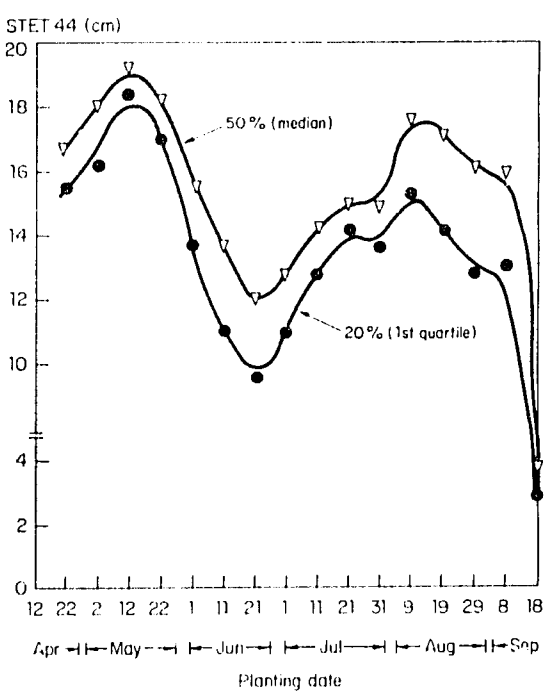
To evaluate the availability of water for different planting dates in Claveria, daily rainfall was generated for 20 wet seasons using records from Manolo Fortich, a station located 35 km south of Claveria. Figure 4 shows that upland rice plantings between 1 and 20 May are to be preferred, and



3. Quantities of STET44 required for 2.0 and 3.5 t/ha upland rice yields using regression line b in Figure 2. IRRI, 1983.



2. Regressions of upland rice grain yield on model-derived evapotranspiration (STET44), IRRI, 1983 WS. For the water-balance model, daily PET × 1.34 and estimated PET × 1.34 were the input variables for evaporative demand.



4. Median and quartile model-derived STET44 (actual ET) values for planting between 12 Apr and 18 Sep. Rainfall was generated by using simulation-model parameters estimated from long-term Manolo Fortich data.

plantings between 1 Jun and 15 Jul are to be avoided. Since Manolo Fortich receives slightly less rainfall than Claveria, the estimated values are likely to be conservative. However, the seasonality should be correct.

ASSESSMENT OF GROWTH-LIMITING NUTRIENTS IN TWO ACID UPLAND SOILS

Multiple Cropping Department

Two of IRRI's outreach sites — the cropping systems research site in Claveria (Misamis Oriental, northern Mindanao) and the upland rice screening site in Cavinti, Laguna — are located on acid upland soils. These soils (Ultisols) have good physical properties but possess certain chemical characteristics that adversely affect crop growth. The Cavinti soil has a higher cation exchange capacity (CEC) but contains appreciably lower amounts of bases than the Claveria soils (Table 1). Exchangeable Al is higher in Cavinti (6-10 meq/100 g soil) than in Claveria (< 3 meq/100 g soil), resulting in a wide difference in Al saturation of the CEC between the 2 soils.

To determine the growth-limiting factors associated with these soils, a pot experiment was conducted in the greenhouse using topsoil (0-20 cm) collected from the 2 sites — one set from Cavinti, and one each from the Claveria villages of Bangonbangon and Patrocinio. The Bangonbangon soil was dark brownish gray, with 2.5 meq exchangeable Al/100 g soil, in contrast with Patrocinio's reddish brown and 0.1 meq exchangeable Al/100 g. The Cavinti soil had 7.3 meq exchangeable Al/100 g and was yellowish brown. Ten nutrient treatments were applied (Table 2).

The number of tillers at 61 d after emergence varied across the 3 soils (Fig. 5). On the average, Bangonbangon had the most (3.0 tillers) and Cavinti the least (2.2 tillers). Withdrawing P from the complete treatment drastically affected tiller production. This was evident in the response of T1 and T7, which produced the lowest tiller counts in all three soils. The effect was more drastically observed on Cavinti than on Claveria soils (Fig. 5).

Table 1. Some chemical characteristics of Cavinti and Claveria acid upland soils (0-20 cm), Philippines.

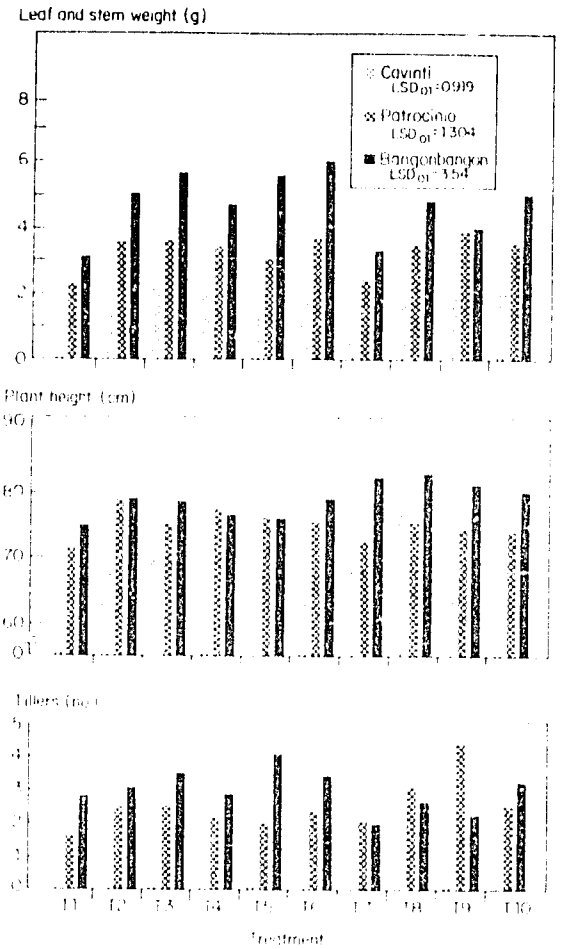
Characteristic	Cavinti, Laguna	Claveria, Misamis Oriental
pH 1:1 H_2O	4.0- 4.5	4.5- 5.4
Exchangeable bases (meq/100 g)	1 - 2	2 - 4
Cation exchange capacity (meq/100 g)[a]	19 -24	6 -12
Base saturation (%)	5 -12	20 -30
Exchangeable Al (meq/100 g)	6.8-10.7	0.5- 3.0
Al saturation (%)	25 -40	nil to 20
Available P (Bray 2) (ppm)	4 - 9	4 - 8
Exchangeable K (meq/100 g)	0.2- 0.4	0.4- 0.5
Organic C (%)	- 2	1 - 2
Total N (%)	0.2- 0.3	0.1- 0.2

[a] Ammonium acetate extraction method.

Table 2. Description of the treatments used in the pot experiment using acid upland soils from Cavinti and Claveria, Philippines, 1986.

Treatment no.	Composition[a]	Remarks
T1	Control	
T2	N + P + K + lime (0.8 LR) + Mo + B + S + Cu + Zn + Fe + Mn + Mg	Complete
T3	N + P + K + Mg + lime (0.8 LR)	Minus micronutrients
T4	N + P + K + Mg + lime (0.4 LR) + Mo + B + Zn + S + Cu	Lower lime, minus Fe, Mn
T5	N + P + K + Mg + Mo + B + Zn + S + Cu	Minus lime, Fe, Mn
T6	N + P + Mg + lime (0.8 LR) + Mo + B + Zn + S + Cu	Minus K, Fe, Mn
T7	N + K + Mg + lime (0.8 LR) + Mo + B + Zn + S + Cu	Minus P, Fe, Mn
T8	P + K + Mg + lime (0.8 LR) + Mo + B + Zn + S + Cu	Lower N, minus Fe, Mn
T9	N + P + K + lime (0.8 LR) + Mo + B + Zn + S + Cu	Minus Mg, Fe, Mn
T10	N + ½P + K + Mg + lime (0.8 LR) + Mo + B + Zn + S + Cu	Lower P, minus Fe, Mn

[a] LR = lime requirement.



5. Growth components of UPLRi-5 at 61 d after emergence for 10 nutrient treatments in 3 acid upland soils under greenhouse conditions, IRRI, 1986. For treatment definitions, see Table 2.

Reducing the lime rate by 50% (T4) or withdrawing it entirely (T5) from the complete treatment (T2) did not significantly affect the growth of UPLRi-5. Among the nutrient elements, P deprivation produced the greatest growth-limiting effect. This suggests that the enhancement of available P in these acid upland soils is a critical activity in managing them for sustained crop production.

DISEASE SURVEY

Plant Pathology Department

Surveys were continued in crop year (CY) 1986-87 to determine prevalent diseases at the Claveria site and those that could have influenced crop establishment and production. In the cowpea - maize - mungbean cropping pattern, cowpea was infected with cowpea little leaf, a virus disease producing stunting and mottled, wrinkled, or curled and undersized leaves. Ten of 11 fields in 3 villages were affected. Cowpea at the bud to flowering stages had infection as high as 40%, but younger plants had only 5% or less.

In 4 of 10 fields surveyed, cowpea was infected with *Fusarium*, and the plants were either wilting or dead. The incidence was 20% in a field in Patrocinio and less than 50% in fields in Ane-i and Hinaplanan.

In the rice - maize - mungbean cropping pattern, leaf blast (Bl) was most severe on rice in Hinaplanan, where a farmer's variety, Speaker, had 22% infection (mean diseased leaf area) in a plot with 60-15-15 NPK fertilizer, and 15% in an unfertilized plot. UPLRi-5, the recommended variety, had <5% infection in plots with fertilizer but was infected with brown spot (7%) in Hinaplanan in unfertilized fields. In Ane-i, fertilized Speaker was also infected with leaf Bl (9%). In another fertilizer trial, UPLRi-5 had severe leaf Bl in plots with the highest fertilizer rate (70-20-20 NPK + 3 t chicken manure). Leaf Bl was most severe in Hinaplanan.

Collar rot and neck Bl prevailed when the rice crop approached maturity. Collar rot incidence ranged from 2 to 34%, and neck Bl had a severity score of 0.4-8.5. Sheath rot incidence ranged from 2 to 9%, but severity was from 13 to 18%.

Few farmers' fields had maize at the mid-whorl stage during the survey, and only one had downy mildew (5% incidence).

No disease survey was conducted in the second or third crop.

POPULATION CHANGE OF ENDOMYCORRHIZAL FUNGI IN FIELDS OF RAINFED LOWLAND RICE

Plant Pathology Department

The numbers of infectious propagules of indigenous vesicular-arbuscular mycorrhizal (VAM) fungi were determined at different stages of the lowland rice - mungbean - maize cropping pattern in a rainfed field in Manaoag, Pangasinan, Philippines. The results were similar to those from irrigated ricefields in Guimba, Nueva Ecija

(Annual report for 1985). The VAM populations were high at the maturity of the upland crops in Pangasinan, as they had been in Nueva Ecija. A notable difference was that, while the endomycorrhizal population in the irrigated Guimba ricefields decreased or remained low during the rice growing season, the population in the rainfed Pangasinan field increased from 46 infective VAM propagules/100 g soil at the seedling stage to 133 at maturity. The population after fallow was much lower in Pangasinan than in Guimba, which may be explained by the presence in Guimba of weeds in which the VAM fungi survived during fallow. In Pangasinan, the farmer plowed under the soil weeds and stubble soon after harvest, destroying nearly all vegetation and thereby reducing the fungi that depend on plant roots for survival.

RICE PESTS

Entomology Department

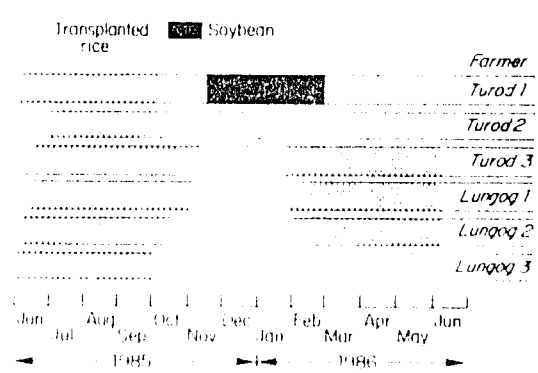
Sixty farmers were interviewed during the wet season (WS) concerning their knowledge of rice pests and control practices. Each farmer mentioned 0-7 pests; these were ranked on a scale of 0-10 (10 most important). From most to least important were rice bug (RB) (6.5), stem borer (SB) deadhearts (4.9), rats (4.5), birds (4.1), root aphids (4.0), SB whiteheads (3.9), white grub (2.5), and leaffolder (LF) (2.3). Pests causing outbreaks in the past were rats (68% of farmers responding), RB (33%), birds (20%), white grubs (13%), and root aphids (12%). When shown specimens or damaged plants, the farmers correctly identified RB (90% farmers correct), discolored grains (43%), LF (37%), SB deadheart (37%), root aphid (37%), SB whitehead (35%), and insect defoliation (30%). Least known were brown planthopper (0%), green leafhopper (0%), and soil pests (16%).

Farmers ranked resistance to pests (57%) behind high yield (72%) and eating quality (58%) as good traits when choosing rice varieties. More than half of the farmers grew more than one variety, citing characteristics of yield (38%) and taste (27%) more than risk avoidance (3%) as reasons. As a reason for changing varieties, susceptibility to pests ranked highest (38%). Less important were late maturity (27%) and low yield (22%). Kaytan ranked highest (33%) of the 43 upland rices named as resistant to pests. Mechanisms of pest resistance mentioned were hard stem (25%), antifeedant component (8%), hard seed coat (against birds) (8%), and long awns (against birds) (5%). Twenty-eight percent of the farmers believed that pest susceptibility changes with time because of repeated planting of the same variety.

Claveria farmers practiced a large number of cultural pest control methods. In an open-ended question, they were asked to describe their indigenous practices. Most frequently mentioned were magical rituals (45% of farmers elaborated 23 practices), smudging (22% burned rubber or grass to repel rice bugs), and scarecrows (8%). A number of the rituals included offering food to spirits, ceremonial killing of the pest to scare others away, or saying prayers to appease spirits or to ask help from God. When given a list of indigenous practices, farmers said they controlled pests through altering planting dates (97%), praying (97%), sanitation (95%), crop rotation (85%), tillage (85%), smudging (77%), choosing to plant at an appropriate phase of the moon (new moon worst) (72%), and planting with neighbors (mostly for bird control) (72%).

Most farmers named vertebrates as natural enemies of pests: birds (72%), cats (for rat control) (22%), chickens (20%), and snakes (for rat control) (12%). Only 8% named spiders, and none named parasites or pathogens.

Most farmers had experimented with insecticides, but none used them regularly. Seed treat-



6. Cropping patterns used by 6 farmers in Guimba, Nueva Ecija, Philippines, 1985-86. Turod = upper stratum, lungog = low-lying, water-accumulating areas.

ment rather than spraying was common. Farmers used mostly DDT (23%), kerosene (8%), or ash (5%). Eighty-five percent of the farmers acknowledged that natural enemies were poisoned by insecticides. In spite of a low rate of adoption, farmers were surprisingly well informed about safety practices when applying pesticides. The most commonly mentioned safe practices were covering the nose while spraying (75%), spraying with the wind (52%), wearing long sleeves (50%), and bathing after spraying (37%).

FARMERS' CROPPING PATTERNS AND WEED CONTROL PRACTICES

Agronomy Department

The cropping patterns used by six farmers in Guimba, Nueva Ecija, in 1985-86 are illustrated in Figure 6.

Weed growth was prolific between the beginning of the rainy season in April and the start of land preparation in June, resulting in the addition of weed seed and vegetative propagules to the soil during land preparation. Weed seeds were also disseminated through the irrigation water, with maximum inflow being observed during land preparation.

In transplanted rice (TPR), 32 weed species were recorded in 1985 WS and 22 in the 1986 dry season (DS). Factors influencing the weed communities in each field were landscape position, time spent on land preparation, amount and time of fertilizer application, water depth, rate of herbicide applied, and extent of hand weeding.

Farmers' weed control practices in TPR in DS were no weeding, application of butachlor at rates lower than recommended, and a combination of butachlor and hand weeding. By doing 2 hand weedings during the critical period of competition, rice yields could be increased by 14-75% (Table 3).

Table 3. Grain yield of transplanted rice as affected by weed control practices. Guimba, Nueva Ecija, Philippines, 1986 DS.

Landscape position and farmer	Cultivar	Weed control[a]	Grain yield (t/ha)	Yield increase (%)
Turod 3	R10	Weeded check No weeding	3.5 2.0	75
Lungog 1	IR21015	Weeded check Butachlor (0.39 kg ai/ha at 4 DT + hand weeding at 23 DT	3.1 2.3	35
Lungog 2	IR60	Weeded check Butachlor (0.25 kg ai/ha) at 3 DT	5.0 4.4	14

[a]DT = d after transplanting.

Table 4. Grain yield of soybean as affected by weed management and tillage practices in the turod 1 farmer's field. Guimba, Nueva Ecija, Philippines, 1986 DS.

Tillage	Grain yield (t/ha)		Yield increase (%) due to weeding
	Weeded check	Farmer's practice	
Low	0.94	0.45	109
High	1.12	0.80	40

In the soybean field, two levels of tillage were used: low, which consisted of one plowing and one rototilling, and high, which had an additional rototilling after weed seedling emergence. *Cynodon dactylon* predominated in the low-tillage area and *Echinochloa colona* in the high-tillage area. Three hand weedings during the critical period of competition resulted in a 40-109% yield increase over the farmer's practice of not weeding (Table 4).

Cropping systems program

Analysis of the social and economic environment

Agricultural Economics Department

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AGROECONOMIC PROFILE OF NORTHERN MINDANAO

Since 1985, IRRI and the Philippine Ministry of Agriculture and Food have been conducting cropping systems research to develop cropping patterns adapted to the upland areas of northern Mindanao. Economic research was conducted on the relationship of the ongoing research to the regional farm economy. Northern Mindanao's current agricultural production environment and its likely interaction with intensified crop production were examined, as well as current multiple crop diversification and cropping intensity.

Soils. The soils of northern Mindanao are highly variable; however, mountain soils with Entisols, Inceptisols, Ultisols, Alfisols, and Eutropepts with Dystropepts predominate. The soils are moderate to well drained and well suited to the production of maize, coconut, upland and lowland rice, and secondary upland crops.

Coconut is widely grown on Entisols in the coastal areas; maize is more frequently grown on Alfisols, Inceptisols, and Mollisols in the lowlands and uplands. Soils grown to rice are classified as Typic Pelluderts, a poorly drained, clayey Vertisol. Cassava is usually grown on soils with high base saturation (Typic Eutropepts).

Climate. The climate is characterized by Coronas' Types II and B. Type II has no dry season but has a very pronounced maximum rainfall period from November to January; Type B has no pronounced seasons and is relatively dry from November to April and wet during the rest of the year. The region has favorable rainfed lowland and dryland environments; with careful management, and as long as the onset of the rains is not late, two successive crops can easily be grown in a year on the same land.

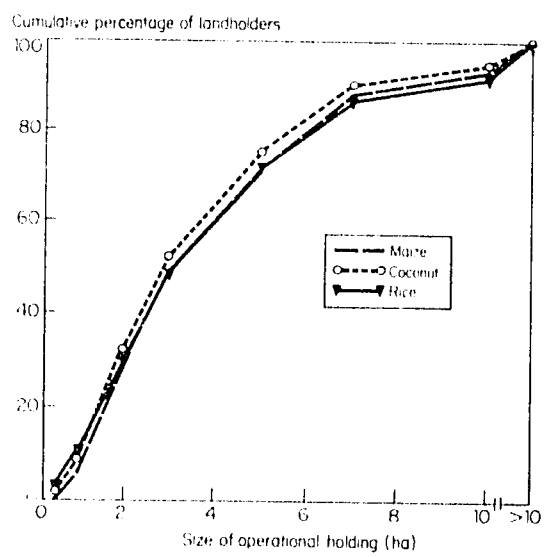
Crop occurrence in the region is closely related to climate. Coconut predominates under climate Type II, maize under Type B; upland rice is of low occurrence under Type II but prevalent under Type B. In contrast, lowland rice is grown mostly under Type II.

Land use. Maize is the most important crop in the region, accounting for 40% of the total farm area of about 966,000 ha. Maize is suited to the western provinces of Misamis Oriental, Agusan del Sur, and Bukidnon, and is planted in 40-63% of the total farm area. Coconut is concentrated in 5 coastal provinces — from 38% of the farm area in Agusan del Norte to 82% in Camiguin. Rice ranks a distant third, occupying 18%.

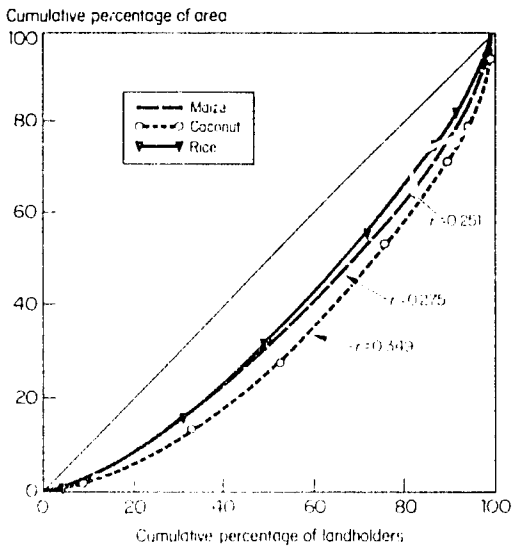
Farms and farm size. Over the period 1971-80, the region's total number of farms increased by 58% and farm area by 23%. While total farm area registered an average growth rate of over 2%, average farm size decreased from 4.3 to 3.7 ha (14%), indicating that the increase in farm population outstripped the supply of new farmland.

Farm size distribution was positively skewed, with a mode of 2.0 ha. The majority of the farms in the region were small, with 50% having cultivated areas of 3 ha or less (Fig. 1); however, they accounted for only about 30% of the total area (Fig. 2). Only 7% of the farms were larger than 10 ha, but they accounted for almost 20% of the total farm area. There appears to be a more equitable distribution of rice and maize lands than of coconut farms.

Rice farming systems. Four rice farming systems based on the degree of water control exist in the region — irrigated, rainfed lowland multiple crop, rainfed lowland single crop, and upland single crop. The majority of the rice farms were rainfed, accounting for over 60% of the total rice area. Only



1. Size distribution of operational holdings with 3 major crops in northern Mindanao, Philippines, 1980.



2. Lorenz curves indicating distribution of landholdings for 3 major crops in northern Mindanao, Philippines, 1980.

16% of the rice area was irrigated. Upland rice areas represented slightly over 20% of the total rice area.

Multiple cropping systems. Over 50% of the farms in the region practiced successive cropping, and 25% reported interplanting (Table 1). Interplanting was most common in provinces with coconut as the predominant crop and was highest in Surigao del Norte, involving 43% of the farmers. This implies that much of the interplanting was done under coconut trees. Successive planting was more common in provinces with maize or rice as the dominant crop.

Sixty-seven percent of the irrigated area was planted to a second rice crop. The multiple cropping intensity of rainfed lowland rice was 122%. Under upland conditions, land is usually left idle after a single rice crop; maize - maize is the predominant cropping pattern.

SOCIOECONOMIC PERSPECTIVE OF THE UPLAND RICE SITE IN CLAVERIA

At the Ministry of Agriculture and Food-IRRI acid upland rice on-farm research site in Claveria, in-migration has meant increasing populations and the conversion of fragile tropical forest ecosystems to agricultural use. These agroecosystems, in turn, have evolved from shifting cultivation to permanent cereal cropping of questionable sustainability.

Ethnohistory and cropping patterns. Data gathered through intensive informal interviews, supplemented with secondary material, show that Claveria's agricultural system underwent several changes. The original Higao-nons or Bukidnons practiced shifting cultivation. With migration from the Visayas beginning in the 1920s, land was divided into large holdings for cattle ranching and logging, and smallholdings for sedentary agriculture. Various commercial enterprises — e.g., abaca growing and a silkworm industry — were begun but were short-lived.

At present, most Claveria farmers manage several crops. Traditional maize (and the maize - maize pattern) is predominant. Rice is planted in limited areas and is a desired crop, but its longer cropping period (allowing only one crop a year)

Table 1. Multiple cropping by province, northern Mindanao, Philippines.[a]

Province	Interplanting		Successive planting	
	Farms (no.)	Percent of total units	Farms (no.)	Percent of total units
Agusan del Norte	4,115	15.4	11,310	42.5
Agusan del Sur	2,932	10.3	18,508	64.9
Bukidnon	13,175	18.0	51,344	70.1
Camiguin	2,025	30.7	1,837	27.8
Misamis Occidental	10,327	29.4	15,272	43.4
Misamis Oriental	17,063	33.2	24,311	47.3
Surigao del Norte	16,460	43.1	13,560	35.5
Northern Mindanao	66,097	25.4	136,142	52.4

[a]Source: 1980 *Census of agriculture*, National Census and Statistics Office.

and greater labor requirements contribute to the preference for maize. Coffee and cacao are grown in groves planted throughout the area as a source of income. Tomato production is gaining popularity because of its profitability for those with capital and for small farmers because of the benefits from P residues after fertilization with chicken manure. Cassava is important because of a strong, stable market for dried cassava chips; because it requires little labor; and because, like rice, it uses nutrient-depleted soils. Better lands are allocated to maize, poorer lands to rice or cassava.

Sustainability is a big problem. Many farmers have settled in several places in the region, migrating repeatedly in the face of declining crop yields. Now, almost all report declining maize and rice yields because of poor soils, nutrient depletion due to continuous cropping, and soil erosion.

Farmers' soil nutrient management practices. A key feature of farming systems research is a farmer focus. In practice, however, farmers' perceptions of problems and solutions are usually not as tightly woven into the research nexus as is desirable. In Claveria, farmers' soil fertility management practices and perceptions are integral components in setting research objectives and in formulating and testing potential solutions. Similarly, farmers are being involved in the evaluation of research results and in the definition of possible innovations to increase and sustain agricultural productivity. It is assumed that understanding farmers' practices will help to make development and testing of technical innovations more farmer-appropriate, in part by indicating how and in which areas different sets of farmers are "pre-adapted" to specific changes.

Farmers' practices and perceptions related to soils, land, fertilizer, weeds, fallow, weed indicator species, and soil erosion were elicited and examined. Migration and settlement, land resources and access, crops and cropping, and yield changes over time were also investigated. Data were analyzed, and implications for system sustainability and possible intensification were considered.

Farmer erosion control. The farmers described their soils as either reddish and poorer or dark and richer. The depth of the top layer of darker soil was reportedly decreasing. The farmers recognized soil erosion from rainfall runoff and soil nutrient depletion from continuous cropping as major problems in sustaining the local farming systems. They knew about the potential benefits of fallowing for nutrient regeneration but had correctly seen few such benefits. The farmers were somewhat in agreement regarding plant indicators of fertility. Slopes of 8-30% characterize most of the arable land. Farmers were keenly aware of soil erosion and discussed erosion control measures such as contour cultivation, weedy buffer strips between plots, diversion and drainage canals, banana groves in runoff channels, planting of perennials on slopes and in field drainage outlets, and low to zero tillage methods for steep plots.

However, erosion control practice lagged behind knowledge. True contour plowing was not observed, and most farmers could not fallow or plant perennials on sloping plots because of inadequate land resources. Several rice farmers were trained in contour farming, and research was begun to monitor their adoption and adaptation of the technique.

Nutrient recycling. Farmer knowledge of nutrient recycling methods such as composting, mulching, green manuring, and incorporation of crop residues was variable but increasing. A few were composting, especially rice and maize residues and animal manure. More were incorporating crop residues. Labor remained a constraint to composting and incorporation. Farmer knowledge of purchased fertilizers and lime was adequate suited to local conditions and farmer circumstances. Fertilizer and lime were not applied to traditional maize and rice, and were not applied to substantially sloping plots because of potential erosion losses. Hybrid maize was planted using lime and commercial fertilizers when a government program provided credit for input, but hybrid maize adoption was otherwise very limited, except on fields previously grown to tomatoes.

Tomato cropping was being adopted, and this may be very significant in terms of working with farmers to improve system sustainability via improved nutrient management. Tomato production for the Manila market involves a system of roads, transport, information, and capital. Outside

and local entrepreneurs finance inputs (lime, fertilizer, chicken manure) and market the crop; small farmers provide land and labor, and receive a share of the profits. Entrepreneurs and farmers were breaking even at the worst, and often did well. More importantly, however, 1) farmers were able to plant up to three maize crops (the first a hybrid) on land planted to tomato without further fertilizer; and 2) many farmers throughout the area saw financed tomato and the subsequent use of fertilizer residues as the desired method of soil rehabilitation.

Table 2. Reasons for not expanding the cowpea area, Claveria cropping systems site, Misamis Oriental, Philippines, 1986.

Reason	Farmers reporting (%)
Limited number of buyers	26
Inadequate labor	19
Limited amount of capital	19
Inadequate seed availability	10
Limited land area	10
Unstable price	7
No response	9
Total	100

MARKETING STUDIES IN CLAVERIA

Market studies initiated in Claveria concentrated initially on identifying the markets for cowpea, which is an introduced crop. Seventy-eight percent of the cowpea produced in Claveria comes from the cropping pattern fields (1,000 m^2 farmer cooperator) and the balance from farmers who planted it on their own initiative. The size of the farmer-managed plots ranged from 250 m^2 to 3.0 ha.

Seventy-five percent of the production entered the active cowpea market. Depending on the time of disposal, cowpea commanded \$0.30-\$0.59/kg (av \$0.40). Farmers who harvested and disposed of cowpea early (September) obtained higher prices.

The major outlet for cowpea was the Cagayan de Oro City market; it absorbed 70% of the total disposable cowpea beans of the farmers in the area. The Claveria market absorbed 2.2% of the production, and the balance was sold directly to consumers by the farmers themselves.

The Cagayan de Oro traders passed on the commodity mostly (80%) to consumers and the rest to market vendors or bakeshops. Cowpea was a small portion of the traders' total portfolio of commodities.

Farmers' sources of information about prices varied considerably. Thirty-nine percent obtained their price information from the merchant when selling the crop, 32% from the merchant before selling, and 10% from other farmers.

The extent of the area grown to cowpea in Claveria has been stagnant. Table 2 summarizes the reasons.

The potential constraints imposed by available labor, power, cash, credit, input and output markets, and tenure on the adoption of improved technologies were examined at the site. Labor use and power use are not constant throughout the year; however, farmers reported labor scarcity corresponding to labor peaks for tillage, weeding, and harvest. Unlike tillage and weeding labor, a sizable amount of labor for harvesting is contributed by nonfarming households, many of whom are migrant laborers. Therefore, new technologies that would abruptly increase tillage, weeding, or harvesting labor may encounter some difficulty in adoption.

Farm family income at the site was estimated at less than \$340/yr. When food expenditures are subtracted from total income, there is little cash left for investment in the production system. The limited cash outlay in the traditional maize - maize technology (\$11/ha) reflects the scarcity of capital and credit in the area. New crop technologies requiring increases in cash investment will have little chance of success without expanded credit support.

Farmers generate cash income by selling limited amounts of foodgrains — rice and maize — and cash crops, notably coffee, cassava, banana, and vegetables. Sales take place in a number of ways: 1) traders who come to the farm, 2) in the local market, and 3) in the Cagayan de Oro City market. Poor roads, limited transport, and a lack of local demand for these commodities contribute to the farmers' weak market position.

Most local lands are not accessible to small farmers; large areas are not being cultivated because of 1) large areas held by absentee owners, 2) extensive pasture lease lands, or 3) medium-sized properties managed by tenant-caretakers. The large majority of farmers — small owners, renters, and tenants — complain of declining yields, degraded soils, and insufficient land. Most say that because of insufficient land, they cannot give up land for fallowing to improve the sustainability of the local farming system. Renters and tenants say they cannot make longer-term, more permanent improvements because the land does not belong to them.

Cropping systems program

Pest control in rice-based cropping systems

Plant Pathology, Entomology, and Agronomy Departments

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DISEASES

Plant Pathology Department

Chemical control. In Guimba, Nueva Ecija, Philippines, locally available fungicides were tested for their effectiveness in controlling rice diseases in IR64 during crop year 1986-87. In the lungog landform, which comprises low-lying areas where water accumulates in wet season (WS) and remains longer in dry season (DS), stem rot prevailed. Although benomyl appeared to be effective, the grain yield was not increased (Table 1). This could be due to late infection, stem rot being confined to the leaf sheaths. In turod, the upper stratum where water does not stay for extended periods, sheath blight (ShB) was often present. Both copper oxychloride and benomyl were effective.

In Claveria, Misamis Oriental, Philippines, locally available fungicides were assessed for their effectiveness against rice diseases in UPLRi-5. Edifenphos was most effective against collar rot and neck blast in Hinaplanan (Table 2). Sheath rot and ShB were low. The control of blast disease offered by edifenphos was not reflected in yield. Grain yields were low, ranging from only 0.4 to 0.6 t/ha, perhaps because of the severe drought that affected the total crop growth.

At IRRI, the efficiency of chemical control of Cercospora leaf spot in mungbean planted before rice in relation to crop development was studied. Disease severity was significantly different between sprayed and unsprayed plants regardless of crop stand (Fig. 1). In plants with good stand, the difference in disease severity between unsprayed and sprayed plants was significant until the mature seed stage. In plants with poor stand, the infection level at the mature seed stage was similar, but sprayed plants had more leaves left attached to the plant (4.6 mean leaf count/plant) than unsprayed plants (2.2 mean count). Plants with good stand were taller, regardless of treatment (Table 3). Grain yield was higher in plants with fungicide than without fungicide in plots with good stand, but not in plots with poor stand. It is beneficial to apply fungicide against Cercospora leaf spot in mungbean grown before rice in fields where the crop is well established.

Table 2. Efficiency of fungicides available at the cropping systems site in the control of diseases of upland rice[a] UPLRi-5 in Hinaplanan village, Claveria, Misamis Oriental, Philippines, 1986.

Fungicide[b] and concentration (g ai/liter of H_2O)	Blast incidence (%)		Incidence (%) of	
	Collar rot	Neck rot	Sheath rot	Sheath blight
Copper oxychloride (1.53 g)	18.3 a	6.6 ab	7.6	0.6
Chlorothalonil (0.95 g)	29.7 bc	8.6 b	8.9	0.3
Mancozeb (1.6 g)	22.1 ab	6.0 ab	8.2	0.2
Edifenphos (0.5 ml)	12.8 a	2.5 a	8.4	0.8
Untreated	34.4 c	8.4 b	6.7	0.6

[a]As first rice crop sown on 2 Jun 1986. [b]Applied as foliar spray at 30 d after sowing and at booting to heading.

Effect of endomycorrhizal fungus on disease control. The endomycorrhizal fungus *Glomus* sp., isolated from a ricefield in Manaoag, Pangasinan, Philippines, was used to challenge the pathogen

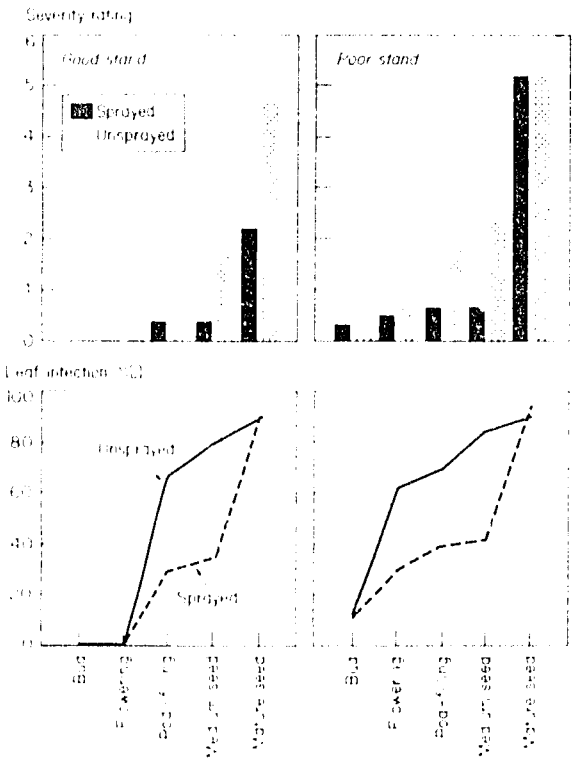
Table 1. Efficiency of fungicides available at the cropping systems site in the control of 2 diseases of first rice crop (IR64) in lungog and turod landforms.[a] Guimba, Nueva Ecija, Philippines, 1986.

Fungicide[b] and concentration (g ai/liter of H_2O)	Lungog		Turod		
	Stem rot incidence[c] (%)	Grain yield (t/ha)	Sheath blight incidence (%)		Grain yield (t/ha)
			Based on hill	Based on tiller	
Mancozeb (1.32)	46.3 bc	5.9 a	17.5 b	4.5 b	4.8 a
Benomyl (0.50)	10.9 a	6.1 a	5.5 a	0.7 a	4.8 a
Copper oxychloride (1.53)	55.9 d	5.7 a	4.3 a	0.5 a	4.4 a
Phenazin oxide (0.12)	45.5 bc	6.0 a	18.3 b	4.9 b	4.4 a
Kasugamycin (0.02)	48.5 cd	6.0 a	17.2 b	3.3 b	4.2 a
Untreated	39.2 b	5.9 a	21.6 b	4.2 b	4.5 a

[a]Data were taken at harvest. [b]Applied as foliar spray at 30 d after transplanting and at booting to heading. [c]Infection was confined to the leaf sheath, leaving the stalk unaffected.

Rhizoctonia. Infection in the leaf sheaths of maize fell from 66.6 to 33.3% in steamed soil and from 33 to 8.3% in natural field soil (Fig. 2). Disease severity was also less in infected mycorrhizal plants (Figs. 3-5).

Glomus sp. had no effect on *R. solani* infection in peanut.



1. Cercospora leaf spot infection levels on sprayed and unsprayed mungbean plants with good and poor stand, grown before rice. IRRI, 1986.

Table 3. Effect of fungicide treatment on growth of mungbean with good and poor stand, IRRI, 1986.

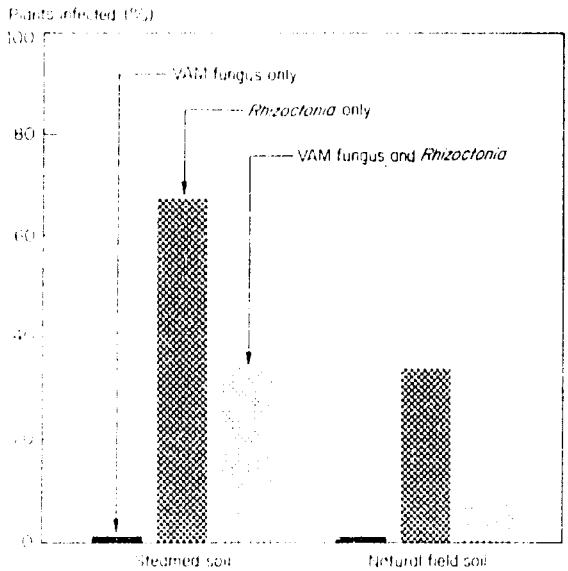
Treatment[a]	Plant height[b] (cm)	Grain yield (t/ha)
	Good stand	
Sprayed	54.1	0.97
Unsprayed	51.3	0.68
Difference		0.29**
	Poor stand[c]	
Sprayed	45.2	0.42
Unsprayed	43.7	0.43
Difference		0.01[ns]

[a]Sprayed plants received chlorothalonil at 0.95 g ai/liter H_2O at 26 d after emergence (early bud stage). [b]Taken at medium seedling stage. [c]Plants were stunted, with chlorotic and undersized leaves because of soil problems.

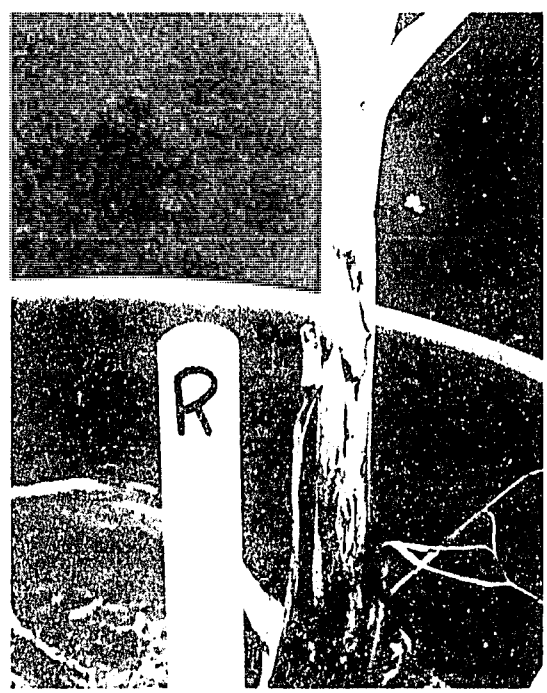
INSECTS

Entomology Department

Sprayed and unsprayed interplot effects. The configuration of yield loss plots in normally



2. Effect of vesicular-arbuscular mycorrhizal (VAM) fungus on infection by *Rhizoctonia solani* in maize at 26 d after seeding. IRRI, 1986.



3. Nonmycorrhizal maize plant with *Rhizoctonia* infection. IRRI, 1986.

4. Mycorrhizal maize plant with *Rhizoctonia* infection, IRRI, 1986. Note shorter lesion height than in nonmycorrhizal plant in Lane 3 (G = *Glomus* sp.).

rectangular farmers' fields often results in untreated plots being bordered on three sides by plots receiving frequent insecticide applications. Farmers believe the insecticide odor of the treated area repels insects from treated plots so yield loss cannot be measured. A trial tested the effect of intensively sprayed plot borders on insect and natural enemy abundance in square plots of 50, 100, 350, and 1,000 m². The plots were set up in a farmer's field in Zaragoza, Nueva Ecija, and replicated three times in a randomized complete block design. Weekly applications of 1 kg ai monocrotophos EC/ha during the vegetative and ripening phases and 1 kg ai chlorpyrifos + BMPC EC/ha during the reproductive phase were sprayed in a 10-m wide swath along plot borders. Two men held up a 1.5-m high and 8-m long fine mesh cloth barrier between the sprayed and unsprayed areas to minimize drift.

Arthropods were sampled along north-south and east-west transects perpendicular to the plot borders 7 m into the sprayed areas and through the centers of unsprayed plots to the opposite sides. Pairs of hills were sampled at intervals 0.5-2.0 m apart, depending on plot size. Whorl maggots (RWM), defoliators, and leaffolders (LF) were

5. Effect of *Glomus* sp. on *Rhizoctonia* infection in maize in pot experiment, IRRI, 1986. Left to right: soil inoculated with *Glomus* sp. and *Rhizoctonia solani* (G + R), inoculated with *Glomus* only (G), and inoculated with *Rhizoctonia* only (R).

sampled based on the percentage of damaged leaves from each pair of hills. Hoppers and predators were suctioned by D-Vac sampler from a pair of hills enclosed in a frame barrier.

The presence of an adjacent insecticide-treated strip slightly depressed RWM, defoliators, LF, and *Cyrtorhinus lividipennis* mirid predators along the immediate border of untreated plots (Table 4). Lower populations occurred within 1-3 m from the treated border (Fig. 6). The closer to the border, the greater was the effect. The affected insects probably had made trivial movements into the treated area, dying with contact. Because stem borers were too few to be efficiently sampled in the trial, no conclusions can be drawn on this important pest group.

The most revealing effect was the depression of *Cyrtorhinus* at 5 wk after transplanting and the subsequent increase in green leafhopper (GLH) a week later (Table 4). *Cyrtorhinus* is a key predator of GLH. The effects of plot size on defoliators and *Microvelia douglasi atrolineata*, a veliid hopper predator, showed no trend and were significant only on one sampling date, not for the overall average.

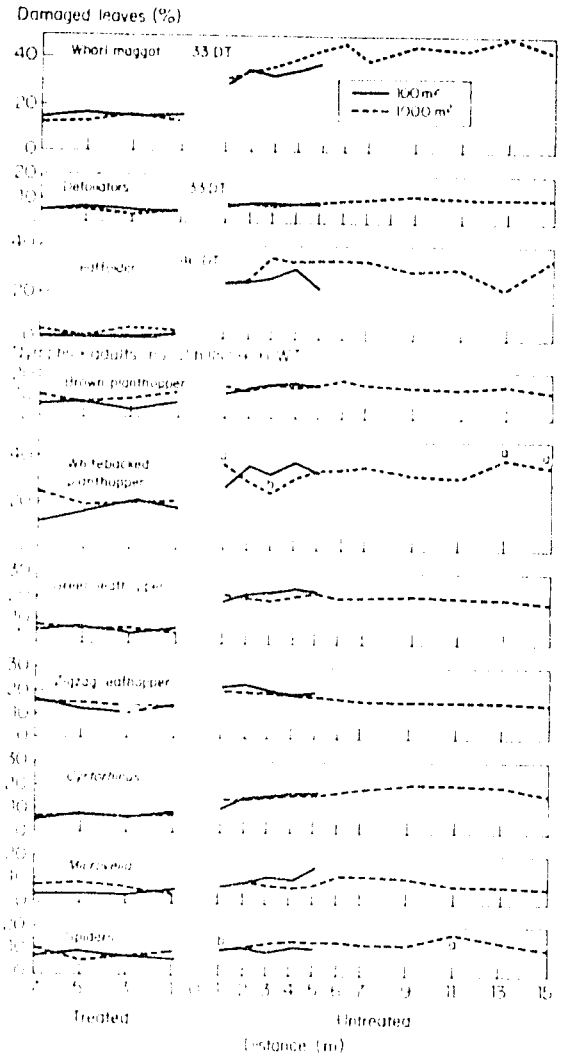
We conclude that the effects of insecticide on an untreated plot act only within 3 m of a sprayed border, and plot size of 100 m^2 or larger will not cause interplot interference, provided no drift occurs.

Insecticide seed treatment. Seed and seedling insect pests attack upland rice, maize, and cowpea in Claveria. Ants prefer maize to rice or cowpea. Seedling maggot *Atherigona oryzae* attacks both upland rice and maize and is more damaging on maize, which cannot compensate by tillering. Cowpea is damaged in the first 2 wk after emergence by beanfly *Ophiomyia phaseoli* and

Table 4. Arthropod abundance averaged from samples taken along perpendicular transects in untreated plots from insecticide-sprayed borders of 4 plot sizes with irrigated transplanted rice.[a] Zaragoza, Nueva Ecija, Philippines, 1983 DS.

Arthropod	Sampling time (WT)[b]	Arthropods (no.) 50 m^2[c]	100 m^2[d]	350 m^2[e]	1000 m^2[f]	F-test Plot size	Distance from border
Whorl maggot (% damaged leaves)	2, 4[h]	31.4 a	29.9 a	33.0 a	30.8 a	ns	**
Defoliators[g] (% damaged leaves)	2	17.9 ab	16.6 ab	21.8 a	15.4 b	*	**
	4	7.7 a	8.7 a	9.0 a	8.3 a	ns	**
Leaffolder (% damaged leaves)	6	2.2 a	2.8 a	2.5 a	3.4 a	ns	*
Brown planthopper (no./2 hills)	4, 5, 6[h]	12.3 a	14.3 a	13.1 a	14.2 a	ns	ns
Whitebacked planthopper (no./2 hills)	4, 5, 6[h]	29.3 a	33.2 a	26.2 a	31.9 a	ns	ns
Green leafhopper (no./2 hills)	6	28.7 a	23.0 ab	20.9 ab	19.9 b	**	ns
	4, 5, 6[h]	25.1 a	22.0 a	18.8 a	20.3 a	ns	ns
Zigzag leafhopper (no./2 hills)	4, 5, 6[h]	22.0 a	20.8 a	17.5 a	17.7 a	ns	ns
Cyrtorhinus (no./2 hills)	5	13.7 b	24.2 ab	29.2 a	27.7 a	**	ns
	4, 5, 6[h]	12.4 a	14.8 a	18.6 a	17.4 a	ns	*
Microvelia (no./2 hills)	5	11.0 b	11.9 ab	22.2 a	8.5 b	*	ns
	4, 5, 6[h]	11.6 a	11.0 a	15.6 a	9.1 a	ns	ns
Spiders (no./2 hills)	4, 5, 6[h]	11.5 a	11.8 a	12.8 a	13.3 a	ns	ns

[a]Av of 3 replications. In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. [b]WT weeks after transplanting. [c]A pair of hills sampled 1, 1.5, 2, 2.5, and 3 m from edge to center along N, S, E, W ordinates. [d]A pair of hills sampled 1, 2, 3, 4, and 5 m from edge to center along N, S, E, W ordinates. [e]A pair of hills sampled 1, 2, 3, 4, 5, 7, and 9 m from edge to center along N, S, E, W ordinates. [f]A pair of hills sampled 1, 2, 3, 4, 5, 6, 7, 9, 11, 13, and 15 m from edge to center along N, S, E, W ordinates. [g]*Rivula atimeta*, *Naranga aenescens*, and *Nymphula depunctalis*. [h]Averaged for inclusive sampling dates.



6. Abundance of rice insect pests and their natural enemies along a perpendicular transect from the border between insecticide-treated and untreated 100-m² and 1,000-m² plots, Zaragoza, Nueva Ecija, Philippines, 1983 DS. Mean of N, S, E, W transects. DT = days after transplanting, WT = weeks after transplanting.

thrips *Thrips palmi*. Controlling these pests by foliar sprays not only is laborious, demanding of scarce water, and expensive, but works poorly in rainy environments typical of Claveria.

Insecticide seed treatment would eliminate most of the cited problems. Carbosulfan STD (seed treatment dust) formulation, applied to upland rice and maize in farmers' fields in 1985, resulted in the death of a number of chickens. Chickens roam free and dig up seed before emergence, often following seed furrows and causing loss of stand. The red-purple dye of carbosulfan is no deterrent to the chickens.

In preliminary trials, chickens avoided seed treated with powdered lime. A replicated experiment on three farms compared several seed coating methods with cassava flour and lime — two inexpensive, locally available materials. No insecticide was used in the experiments. A paste made from cassava flour (10 g) added to 90 ml of hot water served as a seed coating material either alone or with powdered lime dust or dry cassava flour. Coated seeds of rice, maize, and cowpea were mixed with uncoated seeds and spread on four fertilizer sacks, randomly placed, per farm. Chickens were allowed to roam in the experimental area for 3 d. All the uncoated maize and rice seeds were consumed, but only 18% of the cowpea seed. Chickens preferred cowpea seeds coated with cassava paste and pecked up 36% of them from the fields. Seeds coated with wet cassava paste, then dry cassava flour, were least preferred by chickens, which left 33% of rice and 46% of maize seeds. The highly exposed seeds in this trial allowed for greater seed loss than would occur if the seed were sown in soil. Cases of dead chickens were few in the 1986 trials where carbosulfan-treated seeds were coated. Coating treated seeds with cassava flour or lime powder is also safer for farmers who sow seed by hand.

A DS seed treatment trial showed excellent control of seedling maggot on upland rice and beanfly on cowpea (Table 5). Increased plant stand in rice came from seedling maggot control. The seedling maggot population was not high enough to measure directly on maize, but seed treatment plus coating increased maize and cowpea plant growth more than seed treatment alone. The coating had no measurable benefit on the smaller-seeded and more densely sown rice. Seed treatment did not control thrips on cowpea.

Phytotoxicity to cowpea and maize was noted in carbosulfan treatments with cassava paste coating. The seeds were treated ahead of time and stored in sealed plastic bags for several days. We stored cassava paste-coated upland rice, maize, and cowpea seed for 42 d in sealed plastic bags and did not observe phytotoxicity. It is best to treat the seed on the day of planting, but if seed will be treated and stored, it should be allowed to air-dry in the

Table 5. Effectiveness of carbosulfan seed treatment and seed coating on seedling insect pests of UPLRi-5 rice, IPB Var. 1 maize, and IT82D-889 cowpea.[a] Claveria, Misamis Oriental, Philippines, Nov-Dec 1985 DS.

Treatment[b]	Upland rice			Maize	Cowpea		
	Plant stand (no./2-m row) at 24 DE	Seedling maggot[c] larvae + pupae (no./20 plants) at 24 DE	Foliage dry weight (g/2-m row) at 28 DE	Foliage dry weight (g/2-m row) at 28 DE	Beanfly[d] larvae + pupae (no./16 plants) at 10 DE	Thrips[e] (no./16 leaf buds) at 10 DE	Foliage dry weight (g/16 plants) at 28 DE
Coating + insecticide[f]	114 a	1 a	14.8 a	9.7 a	0 a	2.5 a	23.5 a
Insecticide[g] only	118 a	1 a	14.8 a	7.2 ab	0 a	4.2 a	19.4 ab
No coating or insecticide	81 b	8 b	7.9 b	5.4 b	35 b	1.2 a	17.2 b

[a] Av of 4 replications. DE = days after emergence. [b] Carbosulfan (Marshal 25STD) at 0.2 kg ai for cowpea and maize, and 0.3 kg ai/ha for rice. [c] *Atherigona oryzae*. [d] *Ophiomyia phaseoli*. [e] *Thrips palmi*. [f] Cassava flour paste, insecticide + lime powder, then lime powder as a final coating. [g] Insecticide slurry

shade before storing in paper bags. Plastic bags should not be used for storage, as they do not allow air to pass.

Yield losses from insects on grain legumes. Yield loss trials were conducted in farmers' fields at six sites in the Philippines from 1976 to 1986. Complete protection plots received three monocrotophos sprays during the preflowering stage and three deltamethrin sprays during postflowering. Total loss was measured as the yield difference between the complete protection and untreated plots. Plots were 50-100 m^2, and a plastic barrier was held between plots during spraying to prevent drift. Yield loss could be partitioned between preflowering and postflowering, as the third and fourth treatments selectively omitted sprays from each stage while protecting the other.

The lowest yield loss of 22% (0.22 t/ha) occurred in mungbean before rice in Solana, Cagayan, Philippines, where protected fields averaged 1.07 t/ha and untreated fields 0.85 t/ha in 1981-82 (Table 6). About 77% of the yield loss was attributed to bean podborer *Maruca testulalis*. The relatively low preflowering yield loss was caused by low numbers of beanfly *O. phaseoli*, thrips *T. palmi*, and flea beetle *Medythia suturalis*.

Mungbean planted after rice in 3 provinces was under severe attack by the same pest complex, averaging a 65% (0.83 t/ha) yield loss, 64% of which was due to podborers. Yield losses in the preflowering and postflowering growth stages were remarkably similar among the three provinces. Yields in the protected fields were high at 1.27 t/ha. Yield loss was higher in late monsoon because of the interaction of drought stress and insect damage. Mungbean planted after rice becomes stunted from preflowering insect attack, and the root system cannot keep pace with the declining residual moisture. Often the crop grows entirely without rainfall. Rainfall is frequent with early monsoon mungbean, and the decreased solar radiation from monsoon clouds results in lower yields than after the rainy season.

Insect losses in cowpea were similar to those in mungbean. Cowpea grown in the early monsoon in dryland soils in Misamis Oriental suffered less yield loss (43%, 0.61 t/ha) than cowpea in Iloilo (78%, 0.47 t/ha) after wetland rice under drought stress.

Table 6. Yield losses from insect pests on mungbean and cowpea in the Philippines, 1976-86.

Province	Year	Fields (no.)		Yield (t/ha)		Yield loss			
				Protected	Untreated	Total		Relative	
						t/ha	%	Preflowering (%)	Postflowering (%)
				Mungbean, early monsoon					
Cagayan	1981	5		1.22	1.08	0.14	11	0	100
	1982	4		0.91	0.61	0.30	33	45	55
			$\bar{X}$ =	1.07	0.85	0.22	22	23	77
				Mungbean, late monsoon					
South Cotabato	1985	5		1.38	0.52	0.86	62	27	73
	1986	4		1.31	0.20	1.11	85	43	57
			$\bar{X}$ =	1.35	0.36	0.99	74	35	65
Nueva Ecija	1984	5		1.36	0.57	0.79	58	56	44
	1986	5		1.11	0.67	0.44	40	17	83
			$\bar{X}$ =	1.24	0.62	0.62	49	37	63
Pangasinan	1976	6		0.69	0.19	0.50	72	23	77
	1977	7		1.37	0.08	1.29	94	17	83
	1978	4		1.41	0.32	1.09	77	62	38
	1979	4		1.22	0.48	0.74	61	41	59
	1980	4		1.25	0.43	0.82	66	31	69
	1982	6		1.31	0.51	0.80	61	43	57
			$\bar{X}$ =	1.21	0.34	0.87	72	36	64
Late monsoon average			$\bar{X}$ =	1.27	0.44	0.83	65	36	64
				Cowpea, early monsoon					
Misamis Oriental	1985	5		1.63	0.98	0.65	40	43	57
	1986	5		1.21	0.64	0.57	47	46	54
			$\bar{X}$ =	1.42	0.81	0.61	43	44	56
				Cowpea, late monsoon					
Iloilo	1978	4		0.42	0.07	0.35	83	2	98
	1979	4		0.80	0.22	0.58	73	14	86
			$\bar{X}$ =	0.61	0.15	0.47	78	8	92

Yield loss trials underscore the need for greater insect protection on late season mungbean and cowpea throughout the Philippines. Early monsoon grain legumes also suffer high yield losses from insects and can benefit from protection.

WEEDS

Agronomy Department

Land preparation. *Transplanted rice.* Land preparation techniques were tested in an attempt to control *Paspalum distichum*, a perennial grass that continues to be a major problem in lowland rice in Guimba. In one trial where tillage in all treatments consisted of one plowing plus two harrowings, *P. distichum* was significantly reduced in the unweeded plots when a hand tractor was used for harrowing compared to when a water buffalo was used (27.2 g/m^2 vs 84.4 g/m^2). Yields in the unweeded plots were the same (2.0 t/ha), regardless of the method of harrowing, because of an increase in other weed species, particularly *Scirpus supinus* and *Monocharia vaginalis*. Hand weeding and a combination of butachlor plus hand weeding resulted in a significant yield increase in all treatments.

In another trial, the number of harrowings or the time between harrowings had no effect on *P. distichum*. Either all of the harrowing operations were done with a water buffalo or one of the harrowings was done with a hand tractor. It

appears that at least two harrowings with a hand tractor are needed to reduce *P. distichum* growth.

Upland crops. In trials conducted in Claveria, we studied the effect of number of plowings and harrowings at 15- to 20-d intervals during DS on weed growth and yield of rice, maize, and cowpea. In rice and maize, weed weight was reduced and less time was spent on weeding as the number of plowings and harrowings increased. In cowpea the reverse was observed. In maize, *Rottboellia cochinchinensis* was observed only at the lowest tillage level, but in cowpea both *Borreria laevis* and *R. cochinchinensis* increased as the number of harrowings increased. In cowpea, *Cyperus compressus* was greatly reduced as the number of plowings and harrowings increased.

Despite the fact that the land preparation treatments affected weed growth, yields in the unweeded plots in all crops were not significantly different. In the plots that were weeded twice, land preparation treatment had no effect on the yields of rice and cowpea. In contrast, maize yields increased in the hand-weeded plots as the tillage level increased: the plot that was plowed and harrowed 4 times yielded 2.6 t/ha; that which was plowed and harrowed twice yielded 1.4 t/ha.

Comparison of weed control practices in upland crops. *Maize.* In one maize trial where the dominant weeds were *R. cochinchinensis*, *Digitaria setigera*, and *D. longiflora*, all weed control practices except two significantly reduced weed weight compared with the untreated check (Table 7). The highest yields were obtained with hand weeding, a combination of interrow cultivation and hoe weeding, and combinations of different interrow cultivation techniques plus hand weeding. The highest net return and marginal benefit-cost ratio (MBCR) were obtained with interrow cultivation plus hoe weeding (Table 7).

In another trial, the farmer's practice of interrow cultivation at 28 and 40 d after emergence (DE) was no better than the unweeded plot in terms of weed control and grain yield (Table 8). The highest net return and MBCR were again obtained with interrow cultivation plus hand weeding.

Cowpea. In the cowpea experiment, where the dominant weed was *D. setigera*, hoe weeding plus hand weeding at 14 and 28 DE resulted in good weed control, the highest yield, the highest MBCR (Table 9), and an acceptable marginal rate of return (Fig. 7).

Crop rotation. An experiment begun at IRRI in 1985 determined the effect of weed control practices on weed growth and crop yield in a FPR - FPR - mungbean cropping pattern. The weeding treatments and the crop grown determined the dominant weed species. Adequate weed control in rice using hand weeding or combinations of butachlor or rotary weeding plus hand weeding prevented the dominance of any weed species. In the other treatments, except when butachlor was applied, *Echinochloa glabrescens* and *M. vaginalis* dominated. Butachlor application resulted in the predominance of *P. distichum*. *E. colona* was the dominant weed in mungbean.

Weeding treatments in the first crop had no residual effect on weed growth in the second crop. In the third crop (mungbean), weed growth in the unweeded plots did not vary, regardless of the weeding treatments in the first two crops. Hand weeding in mungbean resulted in weed reduction, but in most cases did not result in increased yields because of lack of water.

In the fourth crop (FPR), butachlor performed poorly compared with the other weed control treatments, particularly when the second and third crops were not weeded. Differences in weed growth among treatments were generally reflected in the yield. Hand weeding (3.2 t/ha) and combinations of hand weeding plus butachlor (3.1 t/ha) or rotary weeding (2.9 t/ha) resulted in higher yields than butachlor alone (1.7 t/ha) or no weeding (0.3 t/ha).

Control of weed species. *Scirpus maritimus.* In DS cropping pattern trials, the yield of rotary weeded plots in a continuous FPR pattern was significantly higher than that of bentazon-treated and untreated plots (Table 10). Bentazon-treated plots, however, had higher yields than the untreated check, which gave no yield because of high *S. maritimus* population.

When maize was intercropped with soybean, the highest yields were obtained with hand weeding. Herbicide-treated and untreated plots had low yields because of uncontrolled broadleaf and grassy weeds. Where maize was planted alone, hand-weeded plots gave the highest yields. Because of the buildup of broadleaf weeds, the untreated check gave a low yield.

Table 7. Weed weight, grain yield, and cost and return analysis of weed control practices in IPB Var. 1 maize, Ane-i, Claveria, Misamis Oriental, Philippines, 1986 WS.[a]

Weed control practice[b]	Dry weed weight (g/m^2) at 45 DE	Grain yield (t/ha)	Cost (₱/ha)			Return (₱/ha)		Rate of return (₱/₱)[d]		MBCR[e]
			Man	Man-animal	Total	Gross	Net[c]	Man	Man-animal	
IRC + hoe weeding (CP)	19.5 abc	4.7 a	192	150	342	9091	8749	47	59	6.1
HW	9.2 a	4.7 a	402	–	402	9036	8634	22	–	5.1
Lithao + HW & IRC + HW (DMP)	11.0 abc	4.7 a	306	113	419	8993	8574	29	77	4.7
Lithao + hoe weeding & IRC + hoe weeding (CP)	19.9 abc	4.6 a	209	113	322	8920	8598	42	77	6.0
IRC + HW (CP)	13.0 abc	4.5 a	280	150	430	8552	8122	30	55	3.6
IRC + hoe weeding (DMP)	24.7 bcd	4.3 ab	188	150	338	8335	7997	44	54	3.9
Lithao + hoe weeding & IRC + hoe weeding (DMP)	29.2 cd	4.3 ab	184	113	297	8308	8011	45	72	4.4
Lithao + HW & IRC + HW (CP)	14.4 abc	4.3 ab	340	113	453	8273	7820	24	70	2.8
IRC + HW (DMP)	30.1 bcd	4.1 ab	190	150	340	7939	7599	41	52	2.8
IRC (DMP)	99.1 ef	4.1 ab	–	150	150	7843	7693	–	52	5.6
Lithao + IRC (CP)	92.9 efg	4.1 ab	–	113	113	7776	7663	–	69	5.8
IRC (CP)	56.1 de	3.6 ab	–	150	150	7004	6854	–	47	–
Lithao + IRC (DMP)	148.0 fg	3.2 b	–	113	113	6232	6119	–	55	–
No weeding	170.8 g	3.2 b	–	–	–	6228	6228	–	–	–

[a]US$1 = ₱20.00. [b]All weeding practices were applied at 14 and 28 d after emergence. IRC = interrow cultivation, CP = conventional plow, HW = hand weeding, DMP = double moldboard plow. [c]Net return = gross return – total variable cost. [d]Rate of return: man = gross return (₱) – man-animal (₱) ÷ man (₱); man-animal = gross return (₱) – man (₱) ÷ man-animal (₱).

[e]Marginal benefit-cost ratio (MBCR) = $\frac{\text{gross return of treatment} - \text{gross return of farmer's weed control practice}}{\text{total variable cost of treatment}}$

Table 8. Weed weight, grain yield, and cost and return analysis of pendimethalin application combined with other weed control methods in DMR-2 maize. Patrocinio, Claveria, Misamis Oriental, Philippines, 1986 WS.[a]

Weed control practice[b]	Dry weed weight (g/m²) at 45 DE	Grain yield (t/ha)	Cost (₱/ha)			Return (₱/ha)		Rate of return[d] (₱/₱)		MBCR[e]
			Labor and power	Material	Total	Gross	Net[c]	Labor and power	Material	
Pendimethalin (1.0) & IRC (DMP) + hoe weeding, PE & 28 DE	8.1 abc	2.5 a	131	342	473	5302	4829	38	15	3.7
IRC (CP) + HW, 14 & 28 DE	5.5 ab	2.5 ab	299	–	299	5252	4953	18	–	5.6
Pendimethalin (1.0) & hoe weeding, PE & 28 DE	5.6 ab	2.2 abc	158	342	500	4647	4147	27	13	2.2
Pendimethalin + atrazine (1.0 + 2.0), PE	16.4 cde	2.1 abc	23	587	610	4420	3810	167	7	1.4
Pendimethalin (1.0) & IRC (CP) + HW, PE & 28 DE	14.7 bcd	2.1 abc	158	342	500	4414	3914	26	12	1.7
Pendimethalin (1.0) & IRC (DMP) + HW, PE & 28 DE	6.2 ab	2.0 abc	131	342	473	4232	3759	30	12	1.4
Pendimethalin (1.0) & IRC (CP), PE & 28 DE	17.5 de	1.9 abc	90	342	432	3894	3462	39	11	0.8
HW, 14 & 28 DE	4.8 ab	1.8 bcd	331	–	331	3713	3382	11	–	0.5
Pendimethalin (1.0) & HW, PE & 28 DE	3.4 a	1.7 cd	220	342	562	3630	3068	15	10	0.1
Pendimethalin (1.0), PE	20.9 de	1.7 cd	23	342	365	3609	3244	142	10	0.1
Pendimethalin (1.0) & IRC (CP) + hoe weeding, PE & 28 DE	7.7 abc	1.7 cd	143	342	485	3565	3080	23	10	0
IRC (CP), 28 & 40 DE	28.8 ef	1.7 cd	134	–	134	3563	3429	27	–	–
Pendimethalin (1.0) & IRC (DMP) PE & 28 DE	17.7 de	1.7 cd	90	342	432	3476	3044	35	10	–
No weeding	51.6 f	1.1 d	–	–	–	2263	2263	–	–	–

[a]US$1 = ₱20.00. [b]PE = preemergence. [c]Net return = gross return – total variable cost. [d]Rate of return: man = gross return (₱) – man-animal (₱) ÷ man (₱); man-animal = gross return (₱) – man (₱) ÷ man-animal.

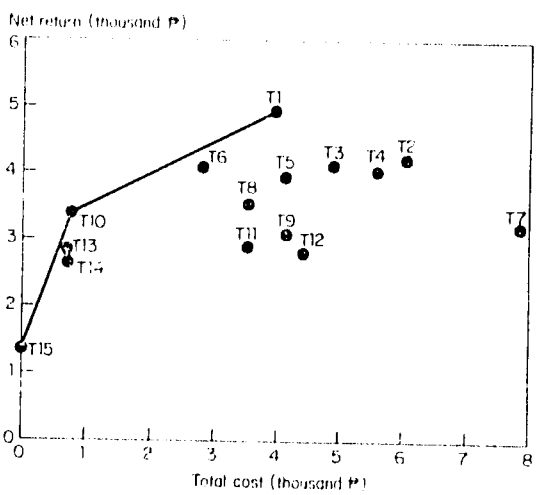
[e]Marginal benefit-cost ratio (MBCR) = $\frac{\text{gross return of treatment} - \text{gross return of farmer's weed control practice}}{\text{total variable cost of treatment}}$

Table 9. Weed weight, grain yield, and cost and return analysis of weed control practices in IT82D-889 cowpea. Ane-i, Claveria, Misamis Oriental, Philippines, 1986 WS.[a]

Weed control practice[b]	Dry weed weight (g/m²) at 45 DE	Grain yield (kg/ha)	Cost (₱/ha)			Return (₱/ha)		Rate of return[d] (₱/₱)		MBCR[e]
			Man	Man-animal	Total	Gross	Net[c]	Man	Man-animal	
T1. Hoe weeding + HW	16 ab	954 a	391	–	391	5342	4951	13.7	–	5.3
T2. HW	17 ab	870 ab	602	–	602	4872	4270	8.1	–	2.6
T3. IRC + HW (CP)	36 ab	833 ab	414	75	489	4665	4176	11.1	56.7	2.8
T4. Lithao + HW & HW	8 ab	819 ab	518	38	556	4586	4030	8.8	107.1	2.3
T5. IRC + HW (MP)	20 ab	782 ab	337	75	412	4379	3967	12.8	53.9	2.7
T6. Hoe weeding	17 ab	776 ab	282	–	282	4346	4064	15.0	–	3.8
T7. Lithao + HW + hoe weeding	17 ab	725 ab	746	38	784	4060	3276	5.4	87.0	1.0
T8. Cult-a-eze (furrower) + HW	10 ab	692 ab	352	–	352	3875	3523	11.0	–	1.7
T9. Lithao & HW	4 a	628 abc	376	38	414	3517	3103	9.3	83.0	0.6
T10. IRC (CP)	46 ab	620 abc	–	75	75	3472	3397	–	46.3	2.5
T11. HW, 30 DE	12 ab	587 abc	359	–	359	3287	2928	9.2	–	–
T12. Lithao + HW & hoe weeding + HW	16 ab	583 abc	402	38	440	3265	2825	8.0	75.3	–
T13. Cult-a-eze (furrower)	140 c	529 bc	67	–	67	2962	2895	44.2	–	–
T14. IRC (MP)	111 bc	495 bc	–	75	75	2772	2697	–	37.0	–
T15. No weeding	181 c	238 c	–	–	–	1338	1338	–	–	–

[a]US$1 = ₱20.00. [b]MP = mini plow. All weed control practices were applied at 14 and 28 d after emergence (DE), except 1 HW at 30 DE. [c]Net return = gross return – total variable cost. [d]Rate of return: man = gross return (₱) – man-animal (₱) ÷ man (₱); man-animal = gross return (₱) – man (₱) ÷ man-animal (₱).

[e]Marginal benefit-cost ratio (MBCR) = $\frac{\text{gross return of treatment} - \text{gross return of farmer's weed control practice}}{\text{total variable cost of treatment}}$



7. Net benefit curve of various weed control practices in cowpea, Ane-i, Misamis Oriental, Philippines, 1986 WS. See Table 9 for key to treatments.

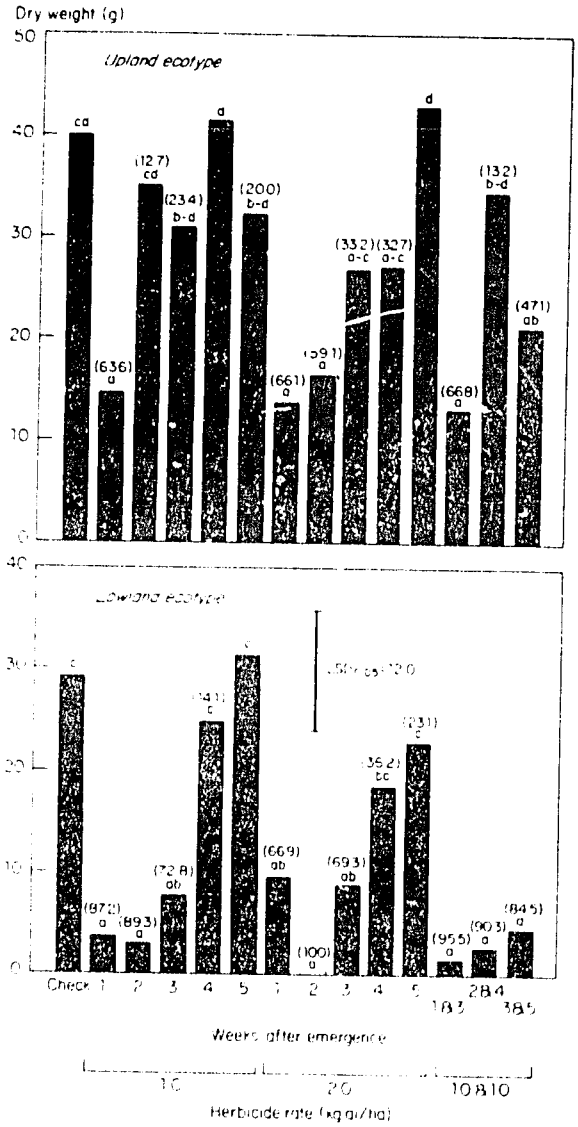
In continuous TPR during WS, rotary weeded and herbicide-treated plots had similar yields, which were higher than that of the untreated check (Table 11).

In the upland crop - TPR pattern, yield differences were similar to those in continuous TPR. Yields of the untreated plots were low because of the annual sedge *Fimbristylis miliacea*.

In dry seeded, rainfed bunded rice following maize, yields were higher with hand weeding alone. The butachlor and untreated plots gave low yields because of *Macroptilium lathyroides* and *Ipomoea triloba*. *Cyperus rotundus* was absent in the herbicide-treated and untreated check plots.

Cyperus rotundus. The effect of bentazon applied at different rates and different times on two ecotypes of *C. rotundus* was studied in a greenhouse trial. Total dry weight was reduced when the herbicide was applied during the first 3 wk of growth. Differences were observed between the ecotypes.

When 1.0 kg ai bentazon/ha was used, the total dry weight of the upland ecotype was significantly reduced only when the herbicide was applied at 1 wk after planting (Fig. 8). When 2.0 kg ai/ha was applied, growth reduction was observed if the herbicide was applied up to 4 wk after planting.



8. Total dry weight and percentage reduction (numbers in parentheses) in 2 ecotypes of *Cyperus rotundus* as affected by different rates of bentazon applied at different times. The vertical line indicates comparison between ecotypes at each treatment level.

Under wetland conditions, preemergence applications of butachlor and thiobencarb, and postemergence application of propanil, effectively controlled *I. rugosum* (Table 13). No plants emerged when preemergence herbicides were applied, and all the plants that had emerged were killed by propanil. In contrast to dry seeded conditions, flooding a few days after application increased the effect of the preemergence treatments and prevented the germination of any ungerminated seeds in the propanil treatment. Butachlor failed to reduce shoot dry weight when it was applied at the one- or two-leaf stages, whereas thiobencarb significantly reduced shoot dry weight when it was applied at the two-leaf stage. All the plants that survived the butachlor and thiobencarb treatments were stunted.

Table 12. Effect of herbicide treatment on shoot dry weight and height of *Ischaemum rugosum* at 15 d after seeding under simulated dry seeded conditions. IRRI, 1986.

Herbicide treatment	Time of application	Shoot dry weight (mg/plant)	Plant height (mm)
Butachlor	Preemergence	0.6 b	5 ab
	1-leaf stage	2.9 d	22 c
	2-leaf stage	5.0 f	48 d
Thiobencarb	Preemergence	1.2 c	7 ab
	1-leaf stage	3.3 de	24 c
	2-leaf stage	4.3 ef	46 d
Pendimethalin	Preemergence	0.4 a	3 a
	1-leaf stage	3.0 d	22 c
	2-leaf stage	5.6 b	44 d
Propanil	2-leaf stage	1.4 c	43 d
	3-leaf stage	0.5 ab	18 bc
Untreated	–	21.6 g	247 e

Table 13. Effect of herbicide treatment on shoot dry weight and height of *Ischaemum rugosum* at 15 d after seeding under simulated wetland conditions. IRRI, 1986.

Herbicide treatment	Time of application	Shoot dry weight (mg/plant)	Plant height (mm)
Butachlor	Preemergence	0 a	–
	1-leaf stage	120 c	42 a
	2-leaf stage	120 c	54 b
Thiobencarb	Preemergence	0 a	–
	1-leaf stage	113 bc	44 a
	2-leaf stage	67 b	52 b
Propanil	2-leaf stage	0 a	–
	3-leaf stage	0 a	–
Untreated	–	125 c	156 c

Cropping systems program

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PARTIALLY IRRIGATED ENVIRONMENT

Multiple Cropping Department

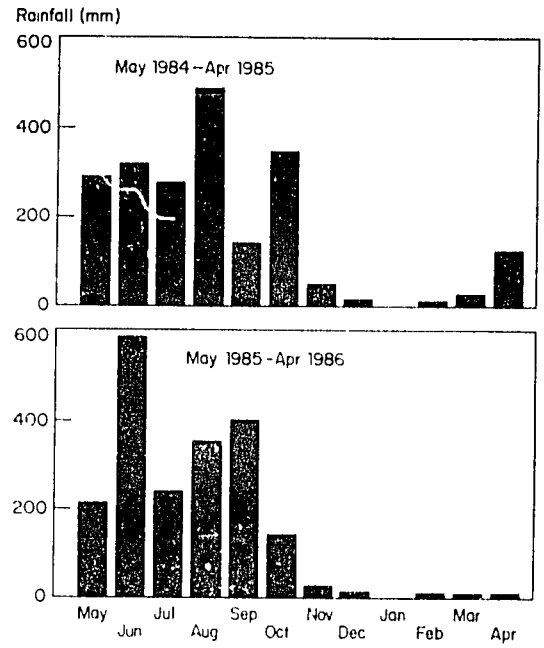
An on-farm research project was implemented in 1984 in a tubewell pump service area in Gaimba, Nueva Ecija, Philippines, to test procedures for irrigating rice and upland crops grown in rotation. The project aims to develop cropping patterns that farmers can manage with their own resources for producing higher returns to land, to cash inputs, and to labor than present patterns. In the process, we are trying to determine what irrigation management strategies can be used to distribute limited and costly water efficiently throughout most of the service area. IRRI, the Ministry of Agriculture and Food, and the National Irrigation Administration are collaborating, and details of the site and research plans have been reported (Annual reports for 1984 and 1985). With minor modifications, the methods used in cropping systems (CS) research in on-farm lowland rainfed environments are being used in this partially irrigated environment.

Soils at the research site are deep and uniform, ranging from silty clays to loams, and are therefore suitable for upland crop cultivation during the dry season (DS).

Twenty-four farmer-cooperators tested cropping patterns in approximately 1,000-m^2 fields in the service area. Twelve fields are located on lungog and 12 on turod land. (Lungog land is lower-lying than turod land and therefore easier to irrigate for rice but harder to drain for upland crops in DS.) Rice - rice - upland crop patterns are being tested for farmer acceptability on lungog lands and rice - upland crop - upland crop patterns on turod lands.

The crop year (CY) at the research site is conveniently divided into three seasons: wet season (June to October), the transition period (November to January), and late DS (February to May). The divisions are arbitrary, but these seasons are sufficiently different to affect crop performance. A major and important difference with respect to field operations and crop adaptation occurs during the transition season. Monthly rainfall during CY 1985-86 is shown in Figure 1.

Transition season rice on lungog. Because transition rice in lungog is fraught with constraints, rice establishment in test fields during CY 1985-86 was suspended, and research was started to determine yield limitations imposed by solar radiation, temperature, and strong winds, which usually occur during December until early February. Low solar radiation from booting to maturity constrains yields; low temperatures hamper panicle exsertion and promote sterility; and strong, dry winds place crops under high transpiration demands.



1. Monthly rainfall, May 1984-Apr 1986, Nueva Ecija, Philippines.

Planting date. An experiment in lungog studied 6 transplanting dates at 3-wk intervals from 30 Oct 1985 to 12 Feb 1986 to determine the effects of early transition planting on the yield and yield components of rice and to relate them with solar radiation, temperature, and wind conditions. Early planting (30 Oct) significantly obtained the lowest yield, and 22 Jan planting the highest (Table 1). Panicle exsertion was hampered in early planting dates (30 Oct to 11 Dec), with a mean of 74% compared with a mean of 97% in the late planting dates. The decrease in yield in the latest planting date (12 Feb) was due more to a water stress effect than to any of the climatic factors. During this period the pump discharge decreased from 112 to 56 liters/s.

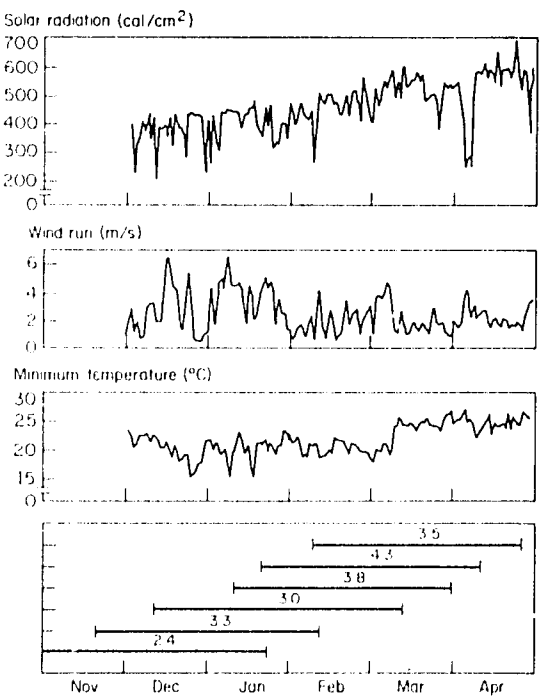
Table 1. Yield and yield components of IR58 as affected by transplanting date. Guimba, Nueva Ecija, Philippines, crop year (CY) 1985-86.

Transplanting date	Yield (t/ha)	Plant height (cm)	Total dry matter yield (t/ha)	Productive tillers (no./hill)	Panicle exsertion (%)
30 Oct 1985	2.4 e	52.8 c	3.4 d	16 c	73 c
20 Nov	3.3 cd	51.3 c	5.7 b	17 c	73 c
11 Dec	3.0 d	55.2 bc	4.6 c	22 ab	75 c
1 Jan 1986	3.8 b	55.0 bc	6.0 a	24 a	91 b
22 Jan	4.3 a	64.0 a	5.5 b	20 b	99 ab
12 Feb	3.5 bc	59.3 b	5.6 b	22 ab	100 a
Difference between treatment means	**	**	**	*	**
CV (%)	6.0	3.6	11.4	7.9	3.3

The growth durations of IR58 at different planting dates were plotted against daily minimum temperature, wind run, and solar radiation (Fig. 2). Minimum temperatures were relatively lower during December to early March, dipping to a low of 16-18 °C continuously for 3-8 d during several periods in December and January. These periods coincided with the heading stages of early plantings, resulting in poor panicle exsertion. Wind velocity was also stronger and solar radiation relatively lower in December to late January, which contributed to lower total dry matter and grain yield of early transplantings.

Variety trials for cold tolerance. Twenty-two rice cultivars from the International Rice Testing Program and three varieties currently planted at the research site were planted at two planting dates (14 Nov and 10 Dec 1985) in a cold tolerance trial. The yields and some agronomic characteristics are summarized in Table 2. All entries planted in December performed better than those in November. IR2061-522-6-9, IR8866-30-3-1-4-2, IR9202-5-2-2-2, IR29725-109-1-2-1, IR31851-63-1-2-3-2, IR64, and IR25572-87-3-3 performed better than the other entries and were recommended for further testing.

Wind barrier experiment. Wind barriers, 4 m long and 2 m high and made of plastic sheets, were placed perpendicular to the wind direction in each of 9 plots (8 × 8 m) to ascertain the effects of wind on the yield and agronomic characteristics of IR58. The field layout of one plot is shown in Figure 3. The yields and some agronomic characteristics are summarized in Table 3. Near the wind barrier, yield from crop cuts slightly increased, panicle exsertion was generally better, and plants were taller.



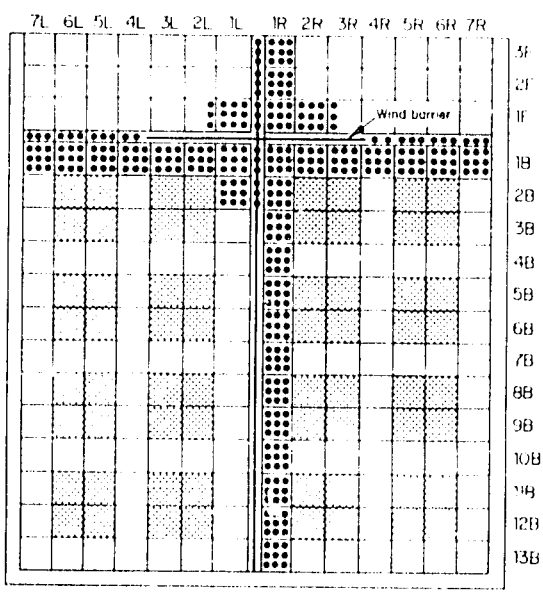
2. Field durations (transplanting to harvest) of IR58 plotted against temperature, wind velocity, and solar radiation. Numbers on bottom graph are yields in t/ha. Guimba Diversified Cropping Systems Project, Philippines, CY 1985-86.

Transition season maize in turod. The mean yield of maize in 1984 was only 2.6 t/ha. The major constraint was crop establishment. In many fields, large clods that formed during primary tillage were

Table 2. Yield and yield components for 2 plantings[a] of rices tested for temperature response. Guimba, Nueva Ecija, Philippines, CY 1984-85.

	Variety or line	Yield (t/ha)		Plant height (cm)		Tillers (no.)		Panicle exsertion (%)		TDMY[b] (g/10 hills)	
		1	2	1	2	1	2	1	2	1	2
V1	IR2061-522-6-9	2.1	3.9	76.1	79.3	11	23	98	97	200	266
V2	IR5716-18-1	1.6	4.1	60.1	67.1	14	21	81	94	204	280
V3	IR8866-30-3-1-4-2	2.3	4.0	62.7	66.2	16	22	81	97	170	228
V4	IR9202-5-2-2-2	2.1	3.4	73.8	74.6	15	22	90	92	220	295
V5	IR9202-33-4-2-1	1.9	2.8	84.7	99.6	11	19	100	98	182	300
V6	IR9758-K2	0.7	2.6	48.5	62.4	13	24	76	98	157	204
V7	IR13155-60-3-1-2-1	1.2	1.6	75.0	88.0	16	18	94	98	218	208
V8	IR13155-60-3-1-3	1.1	1.4	70.0	86.0	12	19	98	96	117	274
V9	IR15579-135-3	1.0	3.6	80.2	90.4	14	18	98	94	184	272
V10	RPKn-2	1.0	1.9	79.0	91.4	8	19	98	94	186	272
V11	IR60	1.6	4.7	50.1	61.4	20	22	70	89	129	170
V12	IR25588-7-3-1	2.6	3.7	58.1	64.1	13	21	74	99	160	240
V13	IR29692-94-2-1-3	1.6	3.6	57.7	63.7	18	19	76	95	173	221
V14	IR29725-109-1-2-1	2.1	3.6	58.2	63.6	16	29	84	97	130	251
V15	IR31802-48-2-2-2	1.9	4.2	58.8	64.2	15	25	79	97	152	262
V16	IR31851-63-1-2-3-2	2.0	3.2	54.4	57.7	20	23	91	98	132	205
V17	IR31868-64-2-3-3-3	1.6	3.8	53.4	60.8	17	19	96	98	248	212
V18	IR32307-107-3-2-2	1.6	3.4	49.9	62.1	22	29	88	89	144	218
V19	IR32429-47-3-2-2	1.8	3.7	50.1	59.4	17	24	91	94	157	200
V20	IR32429-122-3-1-2	1.7	3.7	55.4	64.8	19	26	92	95	126	258
V21	IR56	1.5	2.7	57.6	61.4	18	22	82	92	186	217
V22	IR58	1.9	4.3	50.4	57.8	22	17	72	87	106	157
V23	IR64	2.3	3.8	67.5	61.4	17	26	90	96	184	225
V24	IR25572-87-3-3	2.1	4.5	53.2	61.4	17	19	93	72	199	192
V25	MRC9552-756	1.5	3.2	53.2	63.6	14	21	78	86	153	246
	Av	1.7	3.4	61.5	69.3	16	22	87	94	173	235

[a]First transplanting = 14 Nov 1985, second transplanting = 10 Dec 1985. [b]Minus grains.



3. Field layout of plot in the wind barrier experiment showing the location of crop cuts for yield determination (cross hatching). Guimba Diversified Cropping Systems Project, Philippines, CY 1985-86. L = left, R = right, F = front, B = back, ● = hill.

not significantly reduced in size by secondary tillage with local implements. Consequently, soil-seed contact was poor, and emergence was low. Other constraints were drought, especially in fields far from the pump, and waterlogging in fields close to ditches or adjacent to flooded ricefields. In 1985, fields were allowed to dry sufficiently, then were flush-irrigated before they were prepared, resulting in relatively good soil tilth. Consequently, crop emergence improved, and the mean shelled maize yield was 3.4 t/ha — about 2 t/ha higher than in 1984.

Because hybrid maize seeds are not readily available in local markets and, if available, are expensive, farmers prefer an open-pollinated variety (OPV). A study was conducted to compare the performance of a hybrid and an OPV under various rates and times of N application. The N source was urea, an NH_4^+-N form. To compare NH_4^+-N and NO_3^--N forms of fertilizer, 2 treatments were added using NO_3^- fertilizer at 40 and

Table 3. Yield and agronomic characteristics of IR58 as affected by distance from a 4-m wind barrier. Guimba, Nueva Ecija, Philippines, CY 1984-85.

Crop cut no.	Yield (t/ha)	Grain:straw	Total tillers (no.)	Plant height (cm)	1000-grain weight (g)	Panicle exsertion (%)
			60 cm from wind barrier			
1	2.9	0.8	30	49.2	21.1	70
2	3.2	0.8	21	50.9	21.6	82
3	3.0	0.9	30	52.7	21.1	80
4	2.9	0.7	28	51.7	21.3	70
			2.4 m from wind barrier			
1	2.8	0.7	30	49.1	20.6	73
2	2.8	0.8	32	49.5	21.3	74
3	2.7	0.7	27	49.0	20.7	76
4	2.9	0.7	32	50.0	21.0	71
			4.2 m from wind barrier			
1	2.8	0.8	27	49.6	21.2	73
2	2.8	0.8	29	48.5	21.2	76
3	2.9	0.8	25	48.9	20.9	78
4	2.7	0.7	26	50.2	21.4	76
			6 m from wind barrier			
1	2.9	0.8	20	51.0	21.4	73
2	2.7	0.8	29	49.7	21.3	84
3	2.8	0.7	32	44.7	20.9	74
4	2.9	0.8	25	51.3	21.0	76

80 kg N/ha. Results showed no significant difference between NH_4^+ -N and NO_3^- -N fertilizer and among times of fertilizer application, meaning that farmers can delay fertilization until hilling up to assure that the crop is not damaged by floods, pests, or other hazards. OPV (Institute of Plant Breeding variety) gave a significantly higher yield than hybrid corn (SMC 305), especially under low N rates.

Late dry season crops. Because test fields in lungog were surrounded by flooded ricefields until May 1986 and were too wet for mungbean, no upland crop was established on that landform.

In turod, mungbean performed well. The mean yield obtained in CY 1985-86 was 1.1 t/ha, higher by 0.2 t/ha than in CY 1984-85. Mungbean is of interest to farmers in the project area as a late DS crop in turod because it yields well, is relatively easy to establish, does not require fertilizer, competes well with weeds, requires only 70 d, has a good price in the local market, and is not excessively demanding on labor.

1986 wet season. Grain yields from cropping pattern fields averaged 5.0 t/ha, 1.0 t/ha higher than in 1984 and 0.5 t/ha higher than in 1985 for the same season. In 1986, more favorable weather conditions prevailed, and populations of stem borer and other insect pests were lower than in the previous years. Moreover, the planting of tungro-resistant varieties such as IR64 eliminated this problem.

Technical feasibility. The designed alternative cropping pattern in turod — rice - maize - mungbean (R - M - MB) — is a pattern with agro-economical potential. However, labor, power, marketing, and irrigation were seen as potential constraints to its adoption on a substantial part of the turod. Household labor generally was not sufficient to meet labor requirements during peak periods of land preparation, seeding or transplanting, and harvesting, when the whole turod area was planted to R - M - MB.

The local Land Bank of the Philippines office at Guimba offered to extend credit loans to farmers at the research site who would adopt the R - M - MB pattern starting CY 1986-87. Negotiations between LBP and officers of the farmer's irrigators association are in progress.

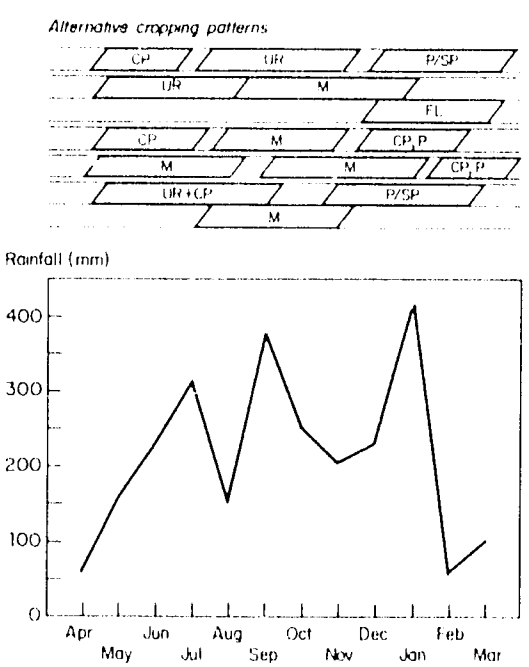
In lungog, unless problems during the transition period (October-December) involving climatic factors are solved, yields of the second rice crop in the R - R - MB pattern will always be low. The

establishment of the second rice crop of farmers' traditional patterns should be discouraged because during this period (February to April) pump discharge is at its lowest level of 56 liters/s and cannot sustain the normal transpiration requirements of rice. One possibility is to plant an upland crop in January.

UPLAND RICE ENVIRONMENT WITH ACID SOILS

Multiple Cropping and Agricultural Economics Departments

Agronomic performance. Five alternative cropping pattern groups were evaluated during CY 1985-86 in Claveria, Misamis Oriental, Philippines. Each pattern was designed to include at least one legume crop in addition to the major cereals rice and maize. The patterns and corresponding monthly rainfall distribution are given in Figure 4. The mean yield data for upland rice (UR), maize (M), cowpea (CP), peanut (P), and sweet potato (SP) are summarized in Table 4. In the cropping patterns in which CP (IT82D-889) was the first



4. Designed cropping patterns and monthly rainfall distribution, Claveria cropping systems site, Misamis Oriental, Philippines, 1985-86. CP = cowpea, UR = upland rice, P = peanut, SP = sweet potato, M = maize, FL = fallow.

Table 4. Yields of implemented experimental and farmers' cropping patterns. Claveria, Misamis Oriental, Philippines, CY 1985-86.

Cropping patterns[a]	Observations (no.)	Yield[b] (t/ha)		
		Crop 1	Crop 2	Crop 3
M - M[c]	20	1.5	1.1	–
M - M - CP	4	3.4	3.3	0.5 (2)
M - M - FA	4	3.3	3.3	–
CP - UR - CP	4	0.9	2.7	0.2 (2)
CP - UR - FA	3	1.5	1.0	–
CP - M - CP	7	0.9	3.4 (1)	0.2
UR - M	6	3.7	1.4	–
UR - CP	2	4.2	0.7	–
UR - FA	3	4.5	–	–
UR + CP/M - SP	2	3.4+0.3	1.3	11.9
UR + CP/M - P	1	4.2+0.5	0.5	1.7
UR + CP/M - CP	2	2.6+0.6	0	0.7

[a]M = maize, CP = cowpea, FA = fallow, UR = upland rice, P = peanut, SP = sweet potato. [b]Numbers in parentheses indicate failures. [c]Farmers' traditional cropping pattern.

crop, mean yields were 0.9-1.5 t/ha. Using rice variety UPLRi-5, yields increased from 1.5 t/ha to 4.0 t/ha (167% increase) during the first crop. The mean yield of M using IPB Var. 1 was 3.3 t/ha, or 1.2 t/ha higher than the baseline data of 2.1 t/ha (57% increase). In the UR + CP intercrop, the yields of both crops were lower than their monoculture yields. However, the overall benefit was still in favor of the intercrop (land equivalent ratio = 1.25).

For the second crop, the yield of maize in the CP - M - CP pattern averaged 3.4 t/ha and was slightly higher than in M - M - CP. Maize yield in CP - M - CP was much higher than in UR + CP/M - SP, UR + CP/M - P, and UR + CP/M - CP. Only 6 of 11 three-crop patterns were successfully executed; the third crops were CP, P, and SP. The rainy season length was inadequate for a third crop in situations where planting of the first and second crops was delayed. The yields of CP as a third crop were generally low (10-70% of first crop yields). P and SP yields were high.

Assessing economic viability of cropping patterns. Enterprise budgeting, using current prices of inputs and outputs, was applied to evaluate the profitability of the experimental patterns (Table 5). All the implemented test patterns yielded higher returns above variable cost (RAVC) and similar or higher returns to labor and power than the tradi-

Table 5. Costs and returns[a] of various cropping patterns on experimental (E) and farmers' (F) plots. Claveria cropping systems site, Misamis Oriental, Philippines, 1985-86.

Cropping pattern[b]	Sites (no.)	Yield[c] (t/ha)			Cost ($/ha)			Gross return ($/ha)	Return above variable costs ($/ha)[d]	Rates of return ($/$)		MBCR to replace M - M (F)[g]
		1	2	3	Labor and power	Materials	Total variable cost			Labor and power[e]	Materials[f]	
CP - UR - CP (E)	4	0.94	2.70	0.17 (2)	170	184	354	704	350	3.1	2.9	1.8
CP - UR - FA (E)	3	1.45	1.02	–	197	174	371	659	288	2.5	2.6	1.5
UR - M (E)	6	3.69	1.35	–	103	125	228	587	359	4.5	3.9	2.8
UR - FA (E)	3	4.54	–	–	101	113	214	552	338	4.4	3.9	2.8
UR - CP (E)	2	4.15	0.65	–	184	179	363	699	336	2.8	2.9	1.7
CP - M - CP (E)	7	0.90	3.41	0.24	131	136	267	788	521	5.0	4.8	3.4
M - M - CP (E)	4	3.37	3.26	0.51 (2)	126	152	278	867	589	5.7	4.9	3.7
M - M - FA (E)	4	3.30	3.29	–	119	174	293	754	461	4.9	3.6	2.7
UR + CP/M/SP (E)	2	3.38 + 0.34	1.31	11.92	124	136	260	1106	846	7.8	7.2	5.7
UR + CP/M/P (E)	1	4.18 + 0.48	0.46	1.65	82	150	232	1692	1460	18.8	10.8	12.2
UR + CP/M/CP (E)	2	2.60 + 0.60	0	0.74	115	115	230	781	551	5.8	5.8	4.4
M - M (F)[h]	5	3.00	1.50	–	118	105	223	488	265	3.2	3.5	2.0
M - M (F)[i]	20	1.50	1.10	–	104	11	115	272	157	2.5	15.1	–

[a]$1 = ₱20.50. [b]CP I182D-889, UR UPLRi-5, M IPB Var 1. [c]Numbers in parentheses indicate number of trials that failed. [d]Gross return – total variable cost. [e]Gross return – material cost/labor and power cost. [f]Gross return – labor and power cost/material cost.

[g]Marginal benefit-cost ratio = $\frac{\text{gross return of potential pattern} - \text{gross return of prevalent pattern}}{\text{total variable cost of potential pattern} - \text{total variable cost of potential pattern}}$

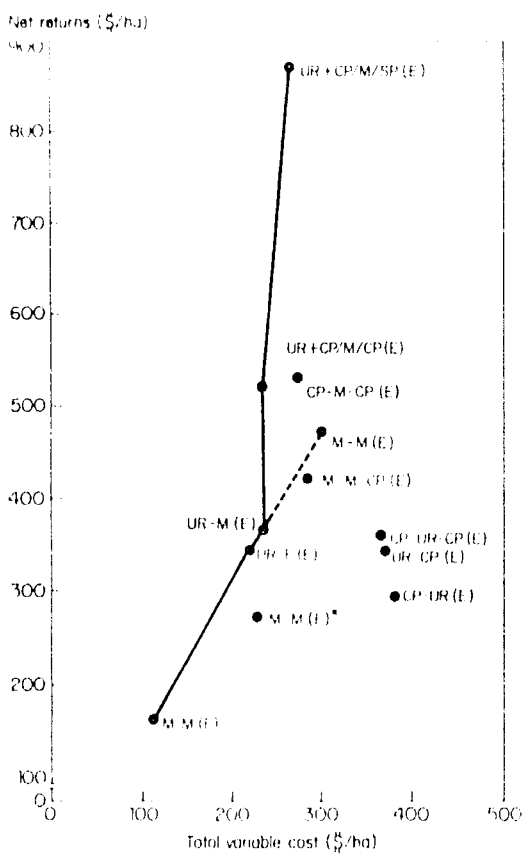
[h]Based on improved (hybrid) variety. [i]Based on farmers' variety.

tional M - M pattern. However, because the test patterns involved increased cash expenditures on material inputs such as fertilizers and insecticides, the rates of return to material costs were lower for the test patterns. Four patterns — UR - fallow (FA), UR - M, UR + CP M CP, and UR + CP M SP — dominated the test patterns. The UR + CP M P pattern was excluded from this consideration because it was tested in only one farmer's field.

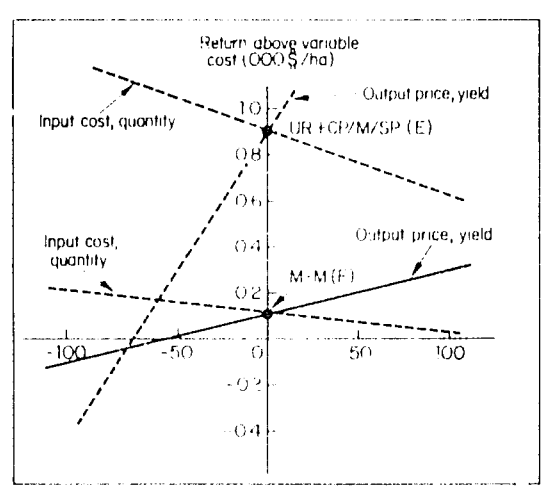
The improved UR - M technology increased production by 104% and net gain by $202/ha (129%). The UR + CP M SP pattern generated the highest net gain of $846/ha, yielding a marginal benefit-cost ratio (MBCR) of 5.7, i.e., for each $1.00 increase in variable costs above the farmer's pattern, an increase of $5.70 was returned.

Sensitivity analysis. The traditional M - M technology used a white (local) variety, and predominantly labor and power production factors (90% of total investment). The UR - M pattern increased total investments from $115 to $228/ha (98%). Similarly, the most profitable pattern (UR + CP M SP) increased total investments by 126%. The net benefit is shown in Figure 5. 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. Figure 6 compares the farmers' prevalent M - M pattern with the UR + CP M SP pattern. The improved pattern required larger percentages of change in costs, yields, or prices than the farmers' pattern to reduce RAVC to zero. UR + CP M SP required an increase in variable cost of 325%, or a decrease in yield or price of 76% to reduce RAVC to zero. In contrast, the farmers' M - M pattern required a 137% increase in variable cost or a decrease in yield of 58% to do so.

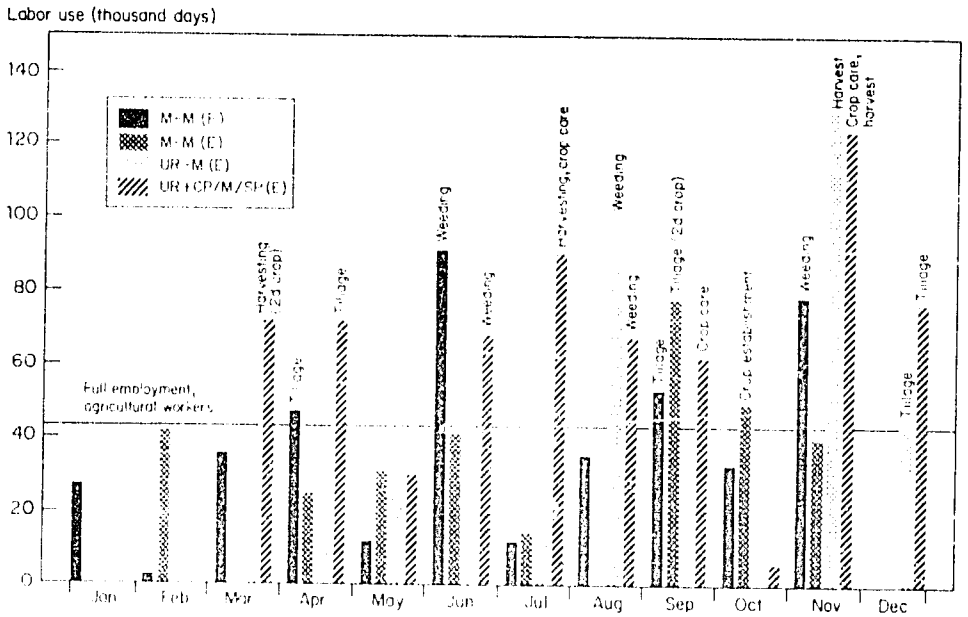
Technical feasibility. The improved cropping patterns changed labor use at the site as shown in Figure 7. It would be impossible for all farmers to adopt any one of the cropping patterns, since the total labor requirements substantially exceed the existing labor supply. Under the traditional M - M pattern, farmers have reported labor scarcity during tillage. Total labor use with the UR - M pattern was 7% lower than with the traditional pattern; however, labor for harvesting and threshing the first UR crop increased by 89%, from 14 to



5. Net benefit curve of farmers' (F) and experimental (E) cropping pattern technologies under upland conditions, Claveria, Misamis Oriental, Philippines, 1985-86. The asterisk (*) indicates hybrid maize.



6. Sensitivity analysis of experimental cropping pattern UR + CP M SP (E) and farmer's dominant pattern M - M (F). Claveria, Misamis Oriental, Philippines, 1985-86.



7. Monthly labor use at Claveria cropping systems site if all farmers adopted the cropping pattern. Misamis Oriental, Philippines, 1985-86.

27 d/ha, which could cause a labor bottleneck in November. Although UR + CP/M SP increased labor use by only 23%, it could cause a labor scarcity during most parts of the year. Given the labor scarcity at the site, it is doubtful that this cropping pattern would be adopted extensively in the area.

Fertilizer and liming trials on mungbean. Mungbean (MB) is a food legume that generally has low and unstable yields on the acid upland soils of the research site. A series of experiments started in 1985 determined the factors that limit the growth, nodulation, and grain yield of MB. One experiment in CY 1986 investigated the crop's fertilizer requirement in this acid upland environment. Mean MB yields as affected by fertilizer treatment at four locations are shown in Table 6. Yields across fields varied markedly. Fields 1 and 4 were considered low fertility fields because the yields from the unfertilized plot were low and the responses to fertilizer treatments were high; fields 2 and 3 were considered high fertility fields because the yields of the unfertilized plots were relatively higher and the responses to fertilizer treatments were marginal.

The effect of liming was significant only at two locations on the plateau. The other fields were on the lower parts of the foothills and the plain. At all locations, responses to fertilizer treatments were highly significant. Responses to N, P, or K alone were not significant except in field 3 (data not given). The difference between inorganic fertilizer and chicken manure was significant in three of four

Table 6. Grain yield of mungbean CES 1D-21 in 4 fields as affected by N, P, K, and chicken manure.[a] Claveria, Misamis Oriental, Philippines, 1985 WS.

Treatment[b]	Grain yield (t/ha)			
	Field 1	Field 2	Field 3	Field 4
Control	0.18	0.61	0.51	0.16
13 P + 25 K	0.22	0.57	0.57	0.28
20 N + 13 P	0.29	0.68	0.70	0.32
20 N + 13 P + 25 K	0.23	0.63	0.71	0.31
20 N + 26 P	0.38	0.62	0.65	0.34
20 N + 26 P + 25 K	0.34	0.57	0.84	0.38
40 N + 26 P	0.38	0.61	0.61	0.39
40 N + 26 N + 25 K	0.42	0.69	0.73	0.41
2.5 t chicken manure/ha	0.77	0.61	1.03	0.67
5.0 t chicken manure/ha	1.00	0.65	0.89	0.67
LSD (.05)	0.11	0.10	0.11	0.08
CV (a) (%)	64	61	55	41
CV (b) (%)	39	22	22	30

[a]Mean across 2 lime rates and 4 replications. [b]In kg/ha except for chicken manure.

Table 7. Partial budget for 10 fertilizer treatments on mungbean in low fertility stratum. Claveria, Misamis Oriental, Philippines, 1985 WS.

Treatment	Mean yield (kg/ha)		Net yield (kg/ha)		Gross benefit ($/ha)		Total variable cost ($/ha)		Net benefit ($/ha)	
	Without lime	With lime	Without lime	With lime	Without lime	With lime	Without lime	With lime	Without lime	With lime
Control	110	228	91	190	64	133	0	39	64	94
NPK (kg/ha)										
0-30-30	170	326	142	271	99	190	31	70	68	120
20-30-0	220	383	184	319	130	223	33	72	96	151
20-30 30	270	337	164	280	115	197	43	82	72	114
20-60-0	260	465	216	387	152	167	54	91	98	131
20-60-30	285	443	237	369	116	258	63	102	103	156
40-60-0	300	475	249	395	175	277	65	104	110	173
40-60-30	292	451	242	376	171	263	75	114	96	146
Manure (t/ha)										
2.5	670	775	557	645	391	452	137	175	254	276
5.0	750	923	628	769	440	539	272	311	169	296

Table 8. Partial budget for 10 fertilizer treatments on mungbean in high fertility stratum. Claveria, Misamis Oriental, Philippines, 1985 WS.

Treatment	Mean yield (kg/ha)		Net yield (kg/ha)		Gross benefit ($/ha)		Total variable cost ($/ha)		Net benefit ($/ha)	
	Without lime	With lime	Without lime	With lime	Without lime	With lime	Without lime	With lime	Without lime	With lime
Control	540	588	450	489	312	343	0	39	312	304
NPK (kg/ha)										
0-30-30	547	597	456	497	319	348	31	70	288	278
20-30-0	678	703	565	585	396	410	33	72	363	338
20-30-30	619	723	516	603	361	422	43	82	318	317
20-60-0	574	693	478	577	335	404	54	91	281	313
20-60-30	679	737	565	614	396	430	63	102	333	328
40-60-0	546	677	418	564	318	395	65	104	253	291
40-60-30	695	707	571	589	420	412	75	114	345	298
Manure (t/ha)										
2.5	832	810	704	675	486	472	137	175	349	297
5.0	774	765	635	637	452	446	272	311	180	136

fields. The difference between 2.5 and 5.0 t/ha of chicken manure was significant only in 2 fields.

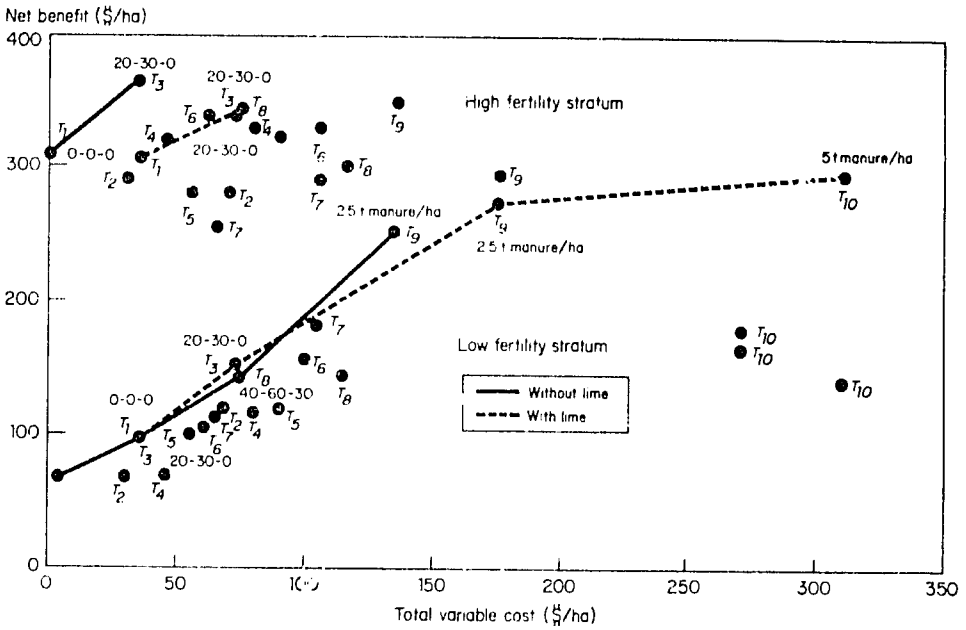
The last two columns in Tables 7 and 8 were used to construct the net benefit curve in Figure 8. The economically dominant treatments were joined by a line and were used in computing the MBCR shown in Table 9. All of the fertilizer increments have a MBCR exceeding the value of 1.0. In the high fertility stratum, the application of lime does not significantly affect the economic benefits.

The analyses indicate that, on fields with favorable native soil fertility, MB production may be quite profitable without nutrients or lime, but yields are modest — about 0.5-0.6 t/ha. Nutrient or lime inputs increase net costs but do not

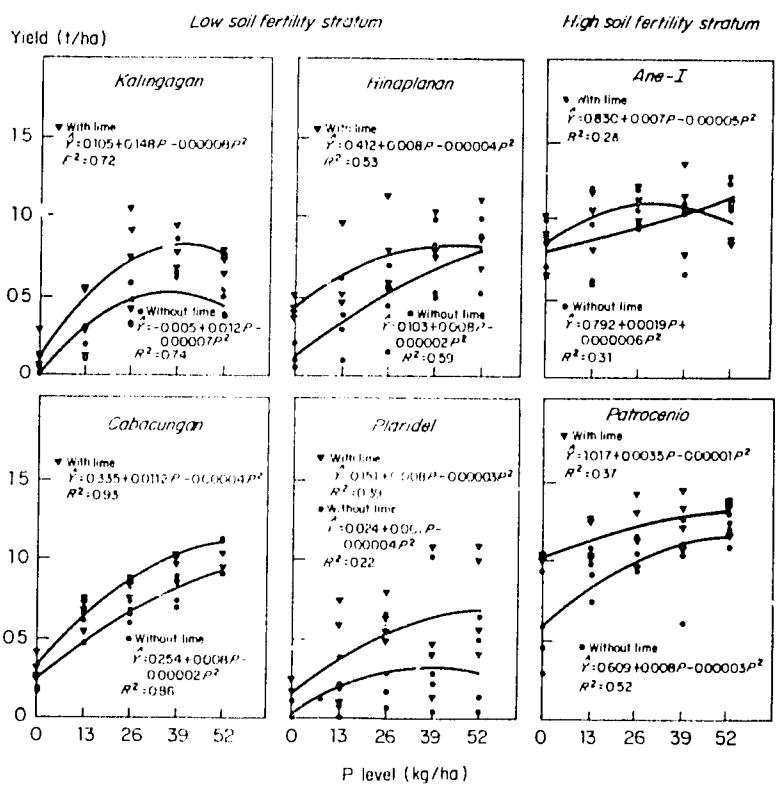
Table 9. MBCR for fertilizer treatments on mungbean. Claveria, Misamis Oriental, Philippines, 1985 WS.

Fertilizer increment[a]	Marginal cost ($/ha)	Marginal benefit ($/ha)	MBCR
Low fertility, no lime			
Control to 20-30-0	33	66	2.0
20-30-0 to 40-60-0	32	45	1.4
40-60-0 to 2.5 t manure/ha	72	216	3.0
Low fertility, with lime			
Control to 20-30-0	33	90	2.7
20-30-0 to 2.5 t manure/ha	103	229	2.2
High fertility, no lime			
Control to 20-30-0	33	84	2.5
High fertility, with lime			
Control to 20-30-0	33	67	2.0

[a]Three figures joined by hyphens indicate NPK in kg/ha.



8. Net benefit curve for 10 fertilizer treatments on mungbean at 2 fertility strata in acid upland soil of Claveria, Misamis Oriental, Philippines, 1986 WS.



9. Grain yield response of mungbean CES 1D-21 to P and lime in 6 soils. Claveria, Misamis Oriental, Philippines, 1986 WS.

significantly improve net benefits. In fields of lower native fertility and low yields (0.1 to 0.2 t/ha), MB production is economically unattractive. The addition of lime and high rates of P may double or triple grain yields from this low base level and increase net returns to MB production to a level on par with local M production. However, this gain in net benefits is achieved only by increasing cost of materials to a level about 5-6 times greater than the cost of materials presently invested in M production. This suggests that field selection is a dominant factor in determining successful MB production in this environment.

In 1986, the effects of P and lime on MB were examined more closely at six locations. Base yields varied greatly among sites as in the previous year, ranging from 0.03 to 0.80 t/ha in the control treatment. The effects of fertilizer and lime treatments on MB yield were significant at all locations. The effect of P was strongly linear. Except for the field in Ane-i, lime affected grain yield significantly. The interaction between P and lime was not significant in any field. Figure 9 illustrates the grain yield responses of MB in six fields. The effect of lime and P explained only 31% of variation in Ane-i, indicating that in this field there were other factors affecting yield.

Cropping systems program

Selecting and testing varieties for rice-based cropping systems

Rice Farming Systems Program

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VARIETAL TESTING

Although IRRI has no mandate to develop varieties of upland crops for rice farming systems, we are collaborating with national institutions and international centers to identify such varieties. The most important upland crops grown with rice are mungbean, soybean, cowpea, peanut, sorghum, maize, sweet potato, and chickpea. Three national research institutions have research programs to develop legume varieties for rice farming: the Philippine Institute of Plant Breeding (IPB), Thai Field Crops Research Institute (FCRI), and Indonesian Central Research Institute for Food Crops (CRIFC). The project with IPB covers screening of lines, hybridization, and selection of mungbean, soybean, and peanut. We collaborate with the International Institute of Tropical Agriculture (IITA) on evaluating cowpea and soybean cultivars for rice farming systems. We are also collaborating with the International Crops Research Institute for the Semi-Arid Tropics on screening varieties of sorghum, chickpea, and pigeonpea for rice farming. The Rice Farming Systems Program evaluates these crops.

The most promising varieties identified by the projects, FCRI, and CRIFC are given to IRRI for seed increase. They are then distributed to national programs involved in collaborative research on varietal testing of upland crops before and after rice through the Asian Rice Farming Systems Network (ARFSN).

Mungbean. Mungbean varietal improvement was done by the IPB project in Los Baños. The plantings before and after rice resulted in the selection of 99 lines for evaluation in the preliminary yield trial for crop year 1986-87.

Preliminary yield trials with 81 entries were conducted before and after rice in Los Baños and Pangasinan. The 20 promising lines were then placed in an advanced yield trial. Five entries — IPB M79 22-108, IPB M80 10-3, VC2778 A, IPB M79-25-123, and VC2719 A — were selected for inclusion in ARFSN varietal testing after rice; they yielded more than 3 t/ha in Pangasinan. Check variety Pag-asa 3 yielded 1.1 t/ha. Another five entries — IPB M80-8-19, IPB M79-12-179, IPB M80-21-36, IPB M80-31-36, and IPB M80-36-33 — were selected for inclusion in ARFSN varietal testing before rice; their mean yield (based on 2 locations) ranged from 1.2 t to 1.7 t/ha.

Soybean. At IRRI, we screened 240 lines for their adaptability, disease reaction, maturity, and yield performance. Of these, 42 lines were advanced for yield tests. Among the early-maturing cultivars, AGS 148, EGSY-73, and UPL SY-2 gave the highest yields of 1.9, 1.8, and 1.8 t/ha, respectively. Among the medium-maturing cultivars, Improved Pelican, IPB SY 138-28, IPB 152-2, TGx 888-48C, and TGx 562-4D were found to be promising, with seed yields of 2.0-2.4 t/ha. Among the late-maturing cultivars, Jupiter R, TGx 711-01D, GC 60068-9, TGx 713-09D, and TGx 239-250 gave the highest yields of 2.3, 2.2, 2.1, and 2.1 t/ha, respectively. These cultivars matured within 98 d after planting.

In another study, 36 genotypes with different maturity durations were evaluated and compared for resistance to water stress imposed during the reproductive phase using a line source sprinkler irrigation system. The reproductive period was synchronized by adjusting the planting dates. Medium-duration cultivars had higher yield and water stress tolerance than short-duration ones. Long-duration ones did not show any yield advantage. GC 60115-8 and TGx 239-17E were most suitable for rainfed and drought-prone areas, while 7207-1 and Manchuria were best suited to irrigated conditions.

The IITA-IRRI Grain Legume Project transmitted six lines to IPB during the year for its germplasm collection.

Preliminary yield trials with 81 entries were conducted before and after rice. Based on the yield data and other agronomic characteristics, 20 lines were selected for the general yield trial before rice in the 1986-87 cropping pattern year, and 20 lines for the general yield trial after rice. There were 21 entries in the general yield trial before and after rice in 1985-86. Five entries — B 3039, NO. 29, IPB SY 153-17, B 3037, and IPB SY 154-21 — were selected for inclusion in ARFSN varietal testing after rice; they yielded 0.7-1.2 t/ha. The check variety UPL SY-2 yielded 0.5 t/ha.

Peanut. The IPB project grew 426 lines in the observational nursery during the dry season (DS)

and 2,215 lines in the wet season (WS). Several lines were selected for inclusion in a replicated observational nursery. The preliminary yield trial with 64 entries and the general yield trial grown in Los Baños and at Pangasinan State University were affected by drought, and no selections were made.

We evaluated 42 varieties from IPB, ICRISAT, and Taiwan, China, under zero tillage after rice and under upland conditions with high tillage. In the lowland trials, UPL PN-4, EG PN-11, and EG PN-18 were the highest yielders of shelled bean and fresh fodder among lines from IPB. They gave yields of 1.8, 1.7, and 1.6 t/ha of shelled beans and 10.9, 10.8, and 10.8 t/ha of fresh fodder, respectively. These varieties mature in 105 d. Among the ICRISAT entries, UPL PN-4 (local check), ICGS(E)-26, ICGS(E)-46, and ICGS(E)-114 were the highest shelled bean yielders, the first with 1.0 t/ha and the rest with 0.9 t/ha. ICGS(E)-114 gave the highest fodder yield (6.8 t/ha), followed by UPL PN-4 (6.2 t/ha). These lines mature in 95 d. Among the Taiwan entries, UPL PN-4 was also the top yielder of shelled beans (1.4 t/ha); NS 8304 and NS 82100 ranked next, yielding 1.1 t/ha each. NS 6340 gave the highest fodder yield (9.4 t/ha), followed by Acc 12 with 8.9 t/ha. These varieties mature in an average of 105 d.

In the upland trials, UPL PN-4 was also the top yielder (1.4 t/ha) of shelled bean among the lines from IPB. UPL PN-2 and IPB PN 30-29 ranked next, yielding 1.3 and 1.2 t/ha, respectively. The highest fodder yield was obtained from IPB PN 30-29 and IPB PN 48-75, with 4.9 t/ha each. UPL PN-4 yielded 4.0 t/ha of fresh fodder. Among ICRISAT lines, ICGS(E)-26 gave the highest grain yield (1.2 t/ha). Other high-yielding entries were ICGS(E)-32, ICGS(E)-46, and ICGS(E)-4 (4.2 t/ha). Among the Taiwan lines, NS 8264 and UPL PN-4 (Acc 12) were the top bean yielders, with 1.4 and 1.3 t/ha, respectively. NS 82100 and UPL PN-4 gave the highest fodder yield (9.5 t/ha each).

Cowpea. Two hundred sixty advanced breeding lines were evaluated for their adaptability, disease reaction, and yield performance. Of these, 30 promising entries were advanced to general yield trials. Among the grain types, the most promising lines were TVx 2907-02D, EG 03, and Vita 4. The highest yielding vegetable lines were Farve 13, BS3 (6-14R × AS), and EG BS-2. Ten dual-purpose (seed and fodder) cowpea lines were also evaluated after lowland rice. The most promising were TVx 3410-02J, TVx 3381-02F, and TVx 1948-012F. They produced 8-10 t fodder/ha in addition to seed.

Four international trials received from IITA were planted under upland conditions. The trials consisted of early and medium maturity, bruchid-resistant vegetable cowpea varieties. The promising lines among the early maturers were IT82D-812, IT82D-789, IT83S-850, and IT83S-844. Among the medium-maturing cultivars, IT82D-709, IT82D-952, IT82D-699, and IT83S-860 performed well and produced seed yields of over 0.8 t/ha.

The top 45 lines selected from 350 lines screened for acidic soil tolerance in 1985 were further evaluated in a preliminary yield trial in June 1986. The most promising white-seeded cultivars were IT82D-871 and 83F-795-2; IT83S-85 and IT81D-1206-179 were the best red-seeded varieties.

Thirty new early-maturing lines of cowpea from IITA were evaluated before lowland rice. The highest yielding lines were IT83S-883, IT82D-789, IT83S-495-2, and IT83S-374-1. All four maintained a determinate growth habit.

Sorghum. In international adaptation trials, 25 sorghum varieties and 25 hybrids from ICRISAT were tested under upland conditions at IRRI during DS. Eight yielded more than 5 t/ha. ICSV-112 and ICSV-194 were the top grain yielders, with 5.8 and 5.7 t/ha, respectively. The highest fodder yield was obtained from ICSV-137 (22.8 t/ha) and ICSV-138 (21.9 t/ha). Days to heading ranged from 49 in ICSV-161 to 64 in ICSV-138.

Among the hybrids, the top grain yielders were ICSH-162 and ICSH-159, with 7.6 and 7.3 t/ha, respectively. ICSH-106 and ICSH-168 gave the highest fodder yield of 21 t/ha. The hybrids matured earlier (46-60 d) than the other entries. In both tests, the check variety UPL SG-5 was among the lowest yielders of grain and fodder.

Six cultivars (P611, P782, and P822 with compact head types; P6129, Cosor 5, and Pioneer 8258 with intermediate head types) were compared for performance under irrigated conditions. P6129

and P611 produced the highest grain yields of 6.1 and 5.7 t/ha, and were significantly superior to the other cultivars.

Pigeonpea. The 10 most promising pigeonpea varieties from the 1985 screening were evaluated under zero tillage after lowland rice in DS. Grain yield was 1.6-2.5 t/ha, with QPL 72 and ICPL 87 the top yielders. The highest fodder yield was obtained from TCF 6-1-1, with 6.4 t/ha. Other high fodder-producing varieties were ICPL-6 and QPL 72, with 6.3 t/ha each. These varieties mature in 98 d.

Sweet potato. Eleven varieties of sweet potato from IPB and the Visayas State College of Agriculture (VISCA) were evaluated under both lowland and upland conditions at IRRI. The lowland trial was with zero tillage and the upland trial with high tillage. In the lowland trial, V2-1 from VISCA and Ci 693-9 gave the highest marketable tuber yields, 12.1 and 9.1 t/ha, respectively. Fresh fodder yield was highest, however, in Kinabakab (7.5 t/ha), followed by G 113-2b with 7.1 t/ha. In the upland trial, the highest marketable tuber yield was obtained from G67-1a (11.8 t/ha), followed by G 113-2b (8.4 t/ha) and G 145r-4 (8.1 t/ha). G 113-2b also gave the highest fodder yield (9.7 t/ha); G 145r-4 and Kinabakab ranked 2d, with 9.1 t/ha.

CHEMICAL ANALYSIS OF FODDER FROM UPLAND CROPS

Crop residues after grain harvest are good sources of feed, especially during DS, when feed is very limited. In the varietal testing of some upland crops, we also recorded the fodder yield after grain harvest and the percentages of crude protein and crude fiber in the fodder with the assistance of the Institute of Animal Science of the University of the Philippines at Los Baños. Samples were taken from 1986 WS.

In mungbean, crude protein and crude fiber percentages significantly differed among varieties. Crude protein content was highest in IPB M79-13-29 (9.31%) followed by that in IPB M79-9-82 and VC 2768 (7.34% each). Crude fiber was lowest in IPB M79-9-82 (36.24%) and IPB M79-13-29 (39.67%). IPB M79-9-82 gave the highest grain yield (1.3 t/ha) among the varieties tested.

In peanut, the highest crude protein content was obtained from Hong Mei Chao (7.48%) from China, followed by UPL PN-4 from IPB (7.12%). Crude fiber was lowest in IPB PN-48-90 and UPL PN-4 (29.5% each). IPB PN-48-90 had a crude protein content of 6.51%.

In field maize, significant differences were also obtained in the crude protein and crude fiber contents of the stover. Ranjuna, a variety from Indonesia, gave the highest crude protein content (7.40%), followed by Suwan 2 from Thailand (7.24%). The percentages of crude fiber ranged from 26 to 29%. IPB Var 2 and Early DMR Comp. 2 gave the lowest values.

Cropping systems program

Agronomic management in rice-based cropping systems

Multiple Cropping Department and Rice Farming Systems Program

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RESPONSE OF RICE AND HYBRID MAIZE TO GREEN MANURING, NITROGEN RATE, AND METHOD OF NITROGEN APPLICATION

Multiple Cropping Department

A field trial at IRRI examined rice grain and N yield responses, using *Crotalaria juncea* as green manure for maize and *Sesbania rostrata* for rice in a green manure - maize - green manure - irrigated rice cropping pattern. The soil had pH 6.1, CEC 328 meq/100 g soil, 95 meq exchangeable K/100 g soil, and the following for each kilogram of soil: 12 g organic C, 1.3 g total N, 17 mg available P, 515 g silt, and 382 g clay.

N rates of 29, 57, 85, and 116 kg/ha were applied in single and split N applications to maize and rice in plots with or without green manure. In maize, the single application was a sidedressing of all N fertilizer at 25 d after emergence (DE); the split application was 1/2 at planting and half at 25 DE. In rice, the single application was a topdressing of all N at panicle initiation (PI); the split application was 1/2 at transplanting and half at PI. Treatment combinations were analyzed in a randomized complete block design (RCBD) replicated four times.

Maize grain and N yields are shown in Table 1. A single N application increased grain yield by 1.05 t/ha over a split application, regardless of green manure treatment. The average N accumulation for *Crotalaria* was 53 kg/ha, which produced a yield increase of 1.4 t/ha over plots without green manure. Green manure treatment alone increased grain yield significantly over fallow plots by 2.8 t/ha. Green manure treatments, N rates, and methods of N application were all important factors in increasing maize yield and, in most cases, N uptake. These are independent main effects in increasing yield, as indicated by insignificant interaction terms except in green manure × N application methods for N uptake.

Rice yield response differed from that of maize (Table 2). Split N application increased yield significantly by 0.6 t/ha over single application regardless of green manuring treatment, while green manure alone increased grain significantly by 1.6 t/ha over fallow treatment. Grain yield tended to stabilize at about 4.0 t/ha on green manured plots with supplemental N, suggesting that the 112.8 kg N/ha contributed by the *Sesbania* green manure to the wet season (WS) rice crop is sufficient, especially when solar radiation is low.

Regression analyses were used to examine the pattern and extent of N efficiency, N utilization, and N recovery for maize (Fig. 1) and rice (Fig. 2). The yield response to N applied on maize was linear over the range of N applied, regardless of application method and the presence or absence of green manure. The N efficiency rate of a single N application, regardless of green manure treatment, was 41.5 kg grain/kg N applied, while that of split N was 29.4. This is associated with N recovery values of 90.9% for a single application of N, and

Table 1. Maize grain yield and N uptake as influenced by *Crotalaria juncea* green manuring rates and methods of N application. IRRI, 1984 DS.

Treatment	Grain yield (t/ha)					N uptake (kg/ha)				
	Without green manure		With green manure		Mean	Without green manure		With green manure		Mean
	Single	Split	Single	Split		Single	Split	Single	Split	
Green manure alone[a] (control)		4.2					101.1			
N rate (kg/ha)										
0 (control)		1.4					54.7			
29	3.0	2.9	5.4	3.9	3.8	78.4	95.6	12.4	104.6	100.7
57	4.8	2.9	6.5	5.3	4.9	125.3	97.6	157.4	134.6	128.9
85	5.7	4.0	6.6	6.4	5.7	141.5	129.8	156.7	141.6	142.4
116	7.3	5.4	7.6	7.4	6.9	183.2	145.6	207.0	150.7	172.6
Mean	5.2	3.8	6.5	5.8	5.3	132.1	117.2	162.3	132.9	136.2

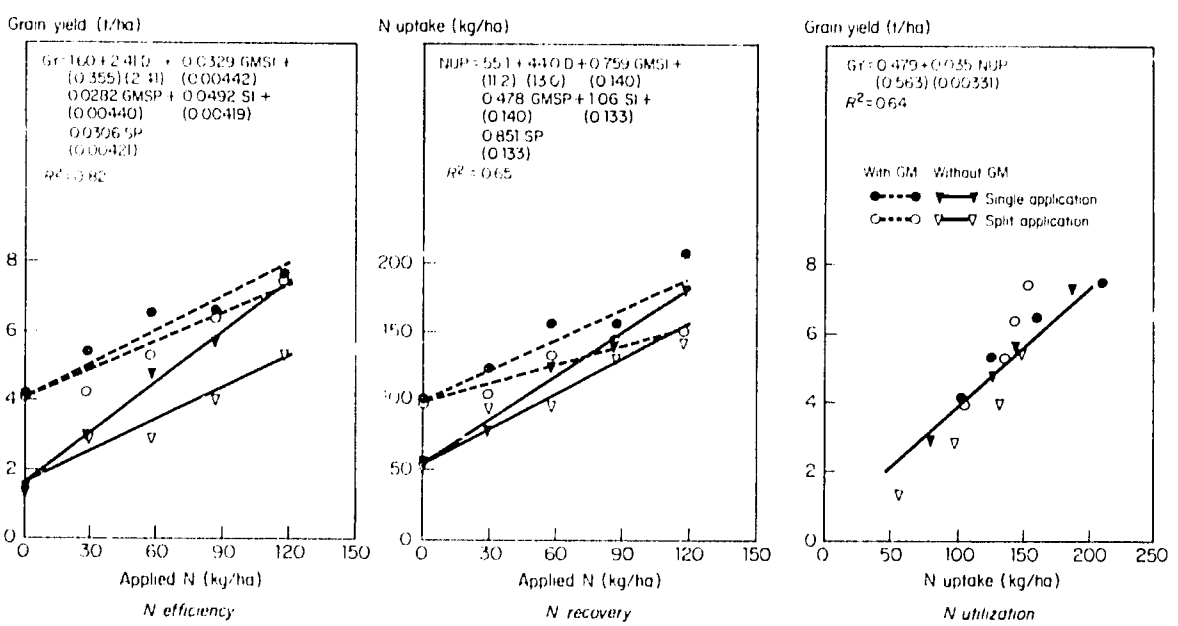
[a]53 kg/ha.

66.5% for split application. Despite differences in N efficiency and N recovery, the N utilization pattern was similar regardless of N source and method of N supplementation.

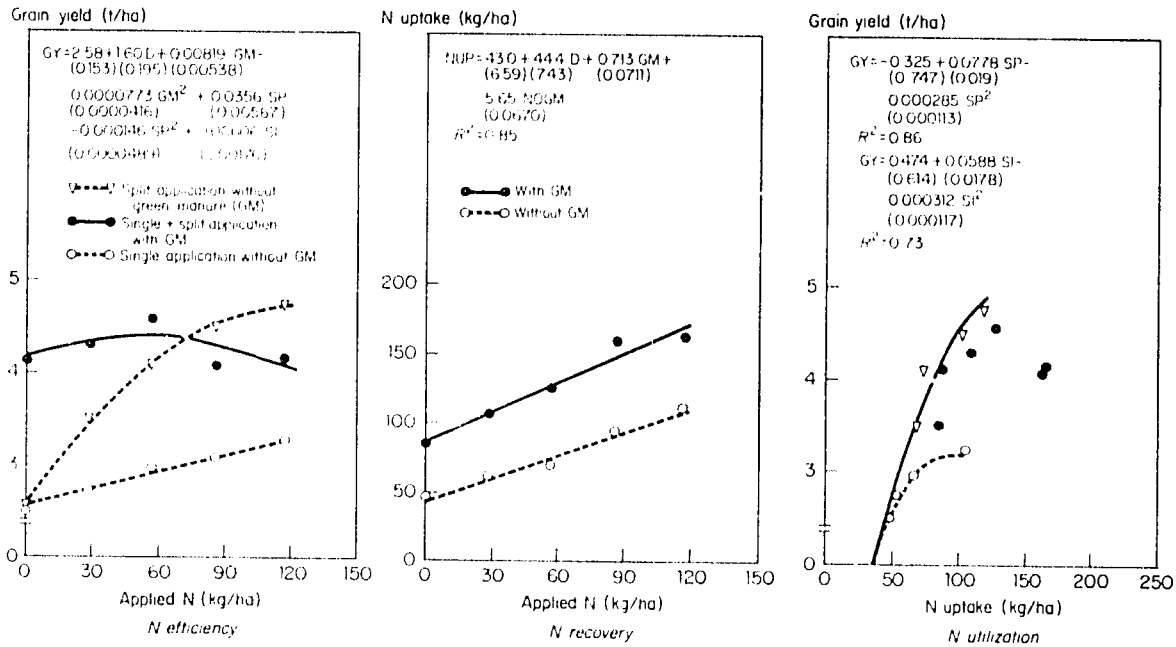
The N efficiency of green manured plots of rice with N supplementation tended to level off at about 4 t/ha regardless of N application method (Fig. 2). Without green manure, the yield response to applied N was linear for a single application, but the grain:N rate was very low at 6:1. N recovery was similar with respect to N application methods, but green manured plots had a higher N recovery (71.3%) than those without green manure (56.5%). The soil supplied 43 kg N/ha. N utilization showed that a single dose was inferior to split application. These responses suggest that proper methods of N supplementation and N rates are important considerations in exploiting the potential of green manuring technology in a green manure - maize - green manure - rice cropping sequence.

Table 2. Rice grain yield and N uptake as influenced by *Sesbania rostrata* green manuring rates and methods of N application, IRRI, 1985 WS.

Treatment	Grain yield (t/ha)					N uptake (kg/ha)				
	Without green manure		With green manure		Mean	Without green manure		With green manure		Mean
	Single	Split	Single	Split		Single	Split	Single	Split	
Green manure alone[a] (control)		4.1					84.8			
N rate (kg/ha)										
0 (control)		2.5					46.7			
29	2.8	3.5	4.1	4.6	3.8	52.8	67.5	108.6	104.8	83.4
57	3.0	4.1	4.7	4.6	4.1	66.0	71.2	134.8	116.2	97.1
85	3.1	4.5	4.3	3.9	4.0	89.1	99.7	157.3	163.3	127.4
116	3.3	4.8	4.1	4.2	4.1	104.0	116.1	140.8	186.2	136.8
Mean	3.1	4.2	4.3	4.3	4.0	78.0	88.6	135.4	142.6	111.2



1. Efficiency, utilization, and recovery of N in maize, with and without crotalaria green manure, IRRI, 1986 WS.



2. Efficiency, utilization, and recovery of N in rice, with and without sesbania green manure. IRRI, 1986 DS.

EFFECTS OF GREEN MANURING AND INORGANIC FERTILIZATION ON TRANSPLANTED RICE AT DIFFERENT PLANT SPACINGS

Multiple Cropping Department

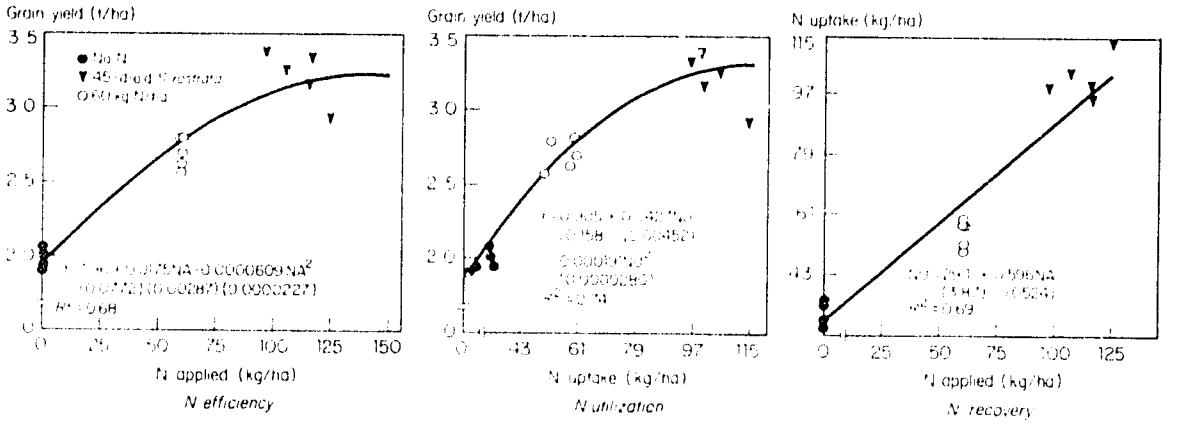
A field trial examined the effect of *Sesbania rostrata* or *aculeata* green manure and inorganic N fertilizer on transplanted rice at various planting dates. N sources were $(NH_4)_2SO_4$, organic N from 45-d-old sesbania, and N from the soil or fallow plots. Inorganic N was split-applied with half at transplanting and half at PI. Following incorporation of the green manure and fertilizer N, rice was transplanted at spacings of 10 × 10 cm, 12.5 × 12.5 cm, 15 × 15 cm, 20 × 20 cm, and 25 × 25 cm. Treatment combinations were laid out in a 3 × 5 RCBD with 4 replications.

Total dry matter yield (TDMY) was significantly affected by both N rate and source and plant spacing (Table 3). It increased significantly with higher N level, but decreased markedly with wider plant spacing. The effect of plant spacing, however, was not reflected in the grain yield and N uptake, which were primarily affected by N source and rate. Fertilizer N and green manure N increased the

Table 3. Grain, total dry matter (TDMY), and N yields of transplanted rice as influenced by green manuring, N fertilization,[a] and plant spacing. IRRI, 1985 WS.

Plant spacing (cm)	Grain yield (t/ha)				TDMY (t/ha)				N uptake (kg/ha)			
	No N	60 kg N/ha	111 kg N/ha	Mean	No N	60 kg N/ha	111 kg N/ha	Mean	No N	60 kg N/ha	111 kg N/ha	Mean
10 × 10	2.0	2.6	3.3	2.6	6.2	8.0	12.8	9.0	33	58	96	62
12.5 × 12.5	1.9	2.8	3.4	2.7	5.1	7.5	11.3	8.0	29	52	99	60
15 × 15	1.9	2.8	2.9	2.5	5.7	7.6	12.0	8.4	35	59	114	69
20 × 20	1.9	2.7	3.2	2.6	4.9	6.8	10.9	7.5	27	60	100	62
25 × 25	2.1	2.6	3.3	2.7	5.4	5.7	9.7	6.9	33	50	105	63
Mean	2.0	2.7	3.2	2.6	5.5	7.1	11.3	8.0	31	56	103	63

[a]60 kg N/ha from $(NH_4)_2SO_4$, 111 kg N/ha from 45-d-old *Sesbania rostrata* green manure.



3. Efficiency, utilization, and recovery of N from inorganic and green manure source, IRRI, 1986 WS.

yield substantially by 0.7 t/ha and 1.2 t/ha, respectively, over fallow plot yield, with a corresponding N uptake of 44.6 and 69.9% with respect to the control.

Since grain yield and N uptake were not significantly affected by plant spacing as indicated by the classification model, only N rate and source were regressed with grain yield and N uptake to examine physiological efficiency and apparent recovery of applied N (Fig. 3). Grain yield was regressed with N uptake to determine the N utilization response pattern. N efficiency and utilization responses showed similar patterns. The grain yield increment diminished as N applied and N uptake increased. N accumulation from green manure ranged from 74 to 150 kg N/ha (av 111 kg N/ha). Given this range, the maximum yield of 3.2 t/ha and N applied as 144 kg/ha were estimated as the optimum point intercept for the N efficiency response curve. The optimum grain yield was computed at 3.3 t/ha at 112 kg N uptake/ha. The apparent N recovery, however, showed a linear grain yield response over the N range tested, suggesting that recovered N was not effectively utilized, as indicated by quadratic N efficiency and utilization responses. Apparent recovery was 59.6% with 29 kg N/ha supplied by the soil.

These observations suggest that closer spacing, which needs more seedlings, and transplanting labor can be dispensed with in favor of wider plant spacing. Also, N accumulation from 45-d-old sesbania was more than sufficient to obtain optimum yields, substantiating earlier findings.

ESTABLISHMENT OF COWPEA AFTER RICE USING SEEDERS UNDER DIFFERENT TILLAGE METHODS, PLANTING TIMES, AND SEEDING DEPTHS

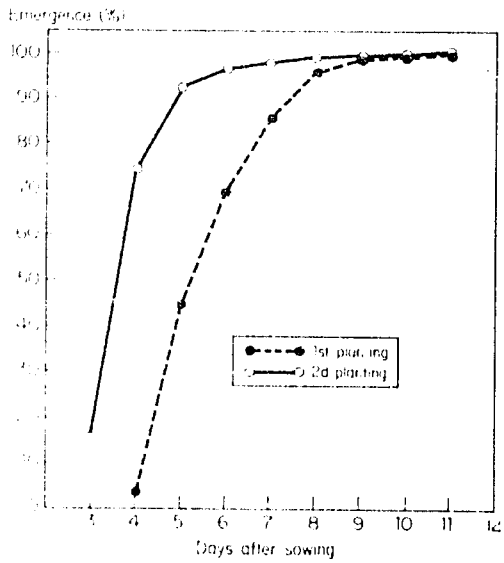
Multiple Cropping Department

A field experiment determined the effect of no tillage and strip tillage, planting time, and seeding depth on the plant establishment and yield of cowpea variety IT82-889. A strip-plot design was used with tillage and planting time as main plots and seeding depth as subplots with four replications. Tillage treatments were 1) no tillage, 2) strip tillage 10 cm deep × 10 cm wide with a rototiller, and 3) strip tillage 5 cm deep × 10 cm wide with a rototiller. Half of each plot was sown at 2.5 cm depth and half at 5.0 cm by the inverted-T seeder.

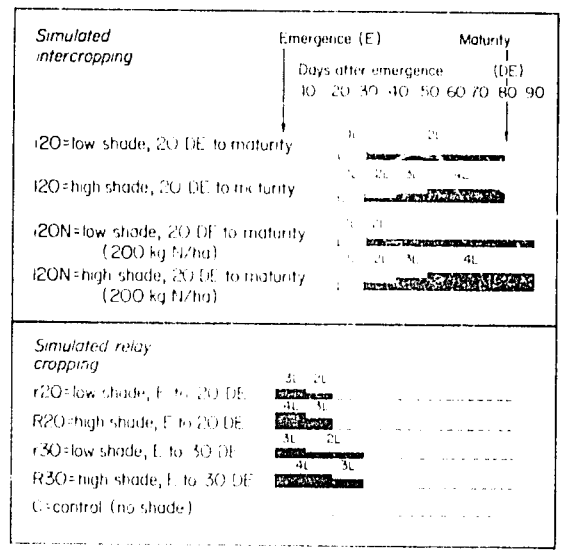
Plant establishment was significantly affected only by planting time. Planting on 3 Feb 1986 produced more plants and more rapid seedling emergence than did the first planting (Table 4,

Table 4. Effect of planting time and depth on the yield and stand of cowpea, IRRI, 1986.

Treatment	Yield (kg/ha)	Stand (plants/m²)
First planting (23 Jan)		
Shallow (2.5 cm)	630	22.2
Deep (5.0 cm)	711	24.2
Mean	671	23.2
Second planting (3 Feb)		
Shallow (2.5 cm)	660	26.2
Deep (5.0 cm)	761	28.8
Mean	711	27.5



4. Percentage of emerged plants each day after sowing. IRRI, 1986



5. Intercropping and relay cropping were simulated by covering soybean with 1-4 layers (1L, 2L, 3L, 4L) of net. IRRI, 1986 DS.

Fig. 4) probably because of favorable weather conditions during early emergence in the second planting.

Tillage did not affect yields, or yield components. Yields were significantly higher in deep planting than in shallow planting, but did not differ between planting times.

SIMULATED INTERCROPPING AND RELAY CROPPING OF SOYBEAN

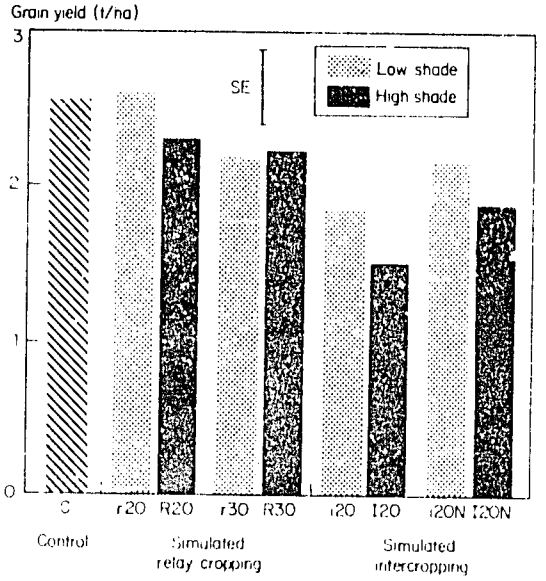
Multiple Cropping Department

A 1985 experiment studied the influence of time and duration of shading on soybean (Annual report for 1985). From February to May 1986, a similarly managed experiment was conducted, but with modified treatments in a RCBD with four replications. Shading was imposed by 1-4 layers of fish net stretched 1 m above a plot to simulate either canopy development by a dominating intercrop or gradually decreasing shading by a dominating but senescing first crop of relay soybean. Four intercropping shade scenarios were simulated in which shading began at 20 DE. Comparisons were made among low (i) and high (I) shade intensities and low and high N fertilizer rates (15 and 200 kg/ha). The high N rate was to test if it could compensate for shading. Four relay cropping scenarios were also tested at two durations (20 and 30 d) of low (r) and high (R) shade intensity. An unshaded treatment served as the control (C) (Fig. 5).

Inoculated seeds of UPL SY-2 soybean were seeded in 40-cm rows at 250,000 plants/ha in well-prepared soil after incorporating 15 kg N/ha (as prilled urea) in all treatments. In the 2 high-N treatments, 90 and 95 kg N/ha as urea supergranules were band-applied between rows at 5 and 31 DE, respectively. Weeds and insects were adequately controlled. Overhead irrigation was done weekly.

Mean maximum and minimum temperatures were 31 and 23 °C. Total rainfall plus irrigation water applied was 303 mm, and mean daily solar radiation was 18.3 MJ/m^2.

Simulated intercropping reduced grain yield more than simulated relay cropping (Fig. 6). High shade intensity also reduced grain yields more in simulated intercropping. The application of high N fertilizer only partially compensated for the shade-induced yield reduction. Within the simulated relay cropping treatments, neither the additional 10-d shade nor the high shade intensity significantly decreased yield, suggesting that soybean may be relay cropped into a dominating canopy with only a slight yield depression due to shading, provided



6. Effect of intensity of simulated relay cropping and intercropping on soybean grain yield, IRRI, 1986 DS. See Figure 5 for key to symbols.

that the period of overlap is completed before flowering starts.

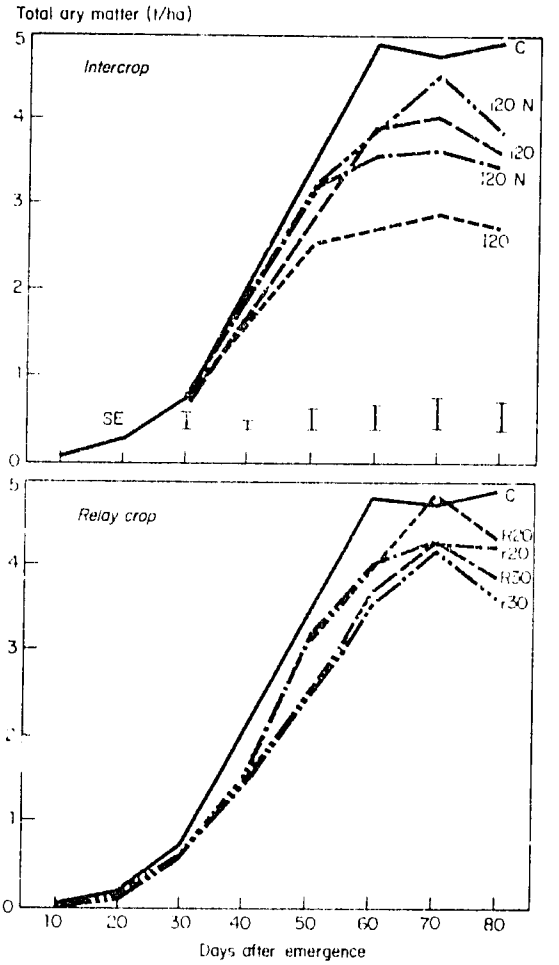
Shading did not strongly influence soybean phenology up to the beginning seed stage, which occurred at 38 DE. Simulated intercropping delayed maturity by an average of 4 d under low shade and 9 d under high shade. High N delayed maturity by 5 d.

Regardless of shading treatment, TDMYs were similar during the early growth stages, but by 40 DE the effects of simulated relay treatments were apparent, as were the effects of high N in the simulated intercropping treatments (Fig. 7).

Early shading suppressed leaf area growth. High N fertilizer increased leaf area index (LAI) at 40 DE (Table 5). By 60 DE, the LAI of all treatments was comparable to that of the control, except R30, where high shading was imposed from emergence to 30 DE.

Between 35 and 55 DE, shade reduced the net assimilation rate (NAR) regardless of other factors (Table 5). In simulated relay cropping, the 10-d longer shade duration reduced NAR significantly.

The number of pods per plant was reduced by simulated intercropping but not by simulated relay cropping (Fig. 8).



7. Total dry matter yields of soybean subjected to simulated intercropping and relay cropping. IRRI, 1986 DS.

Total N uptake was reduced by simulated intercropping, but the addition of high N fertilizer enhanced N uptake (Fig. 9). In the relay cropping treatments, N uptake was reduced in R20, r30, and R30.

INTERCROPPING UPLAND RICE AND MUNGBEAN

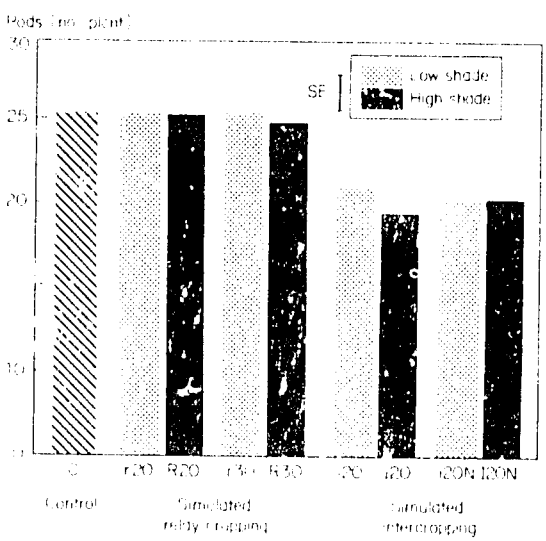
Multiple Cropping Department

The productivity of upland rice in most parts of Asia is limited by intermittent drought and low inherent soil fertility. Since upland rice is generally grown by subsistence farmers, inorganic fertilizers are seldom applied. The inadequate leaf area cover during WS leads to soil erosion and consequently

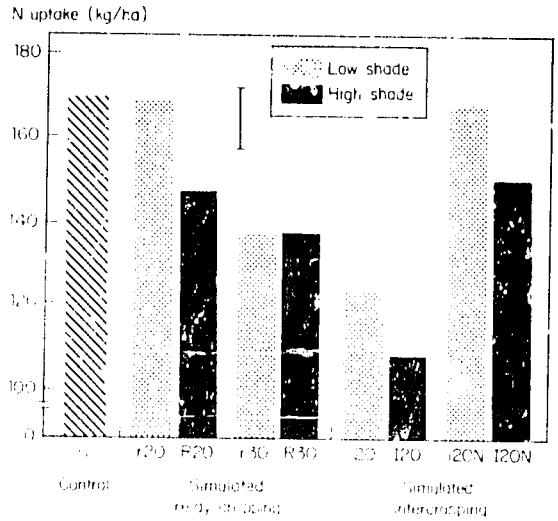
Table 5. Leaf area index (LAI) at 40 and 60 DE and net assimilation rate (NAR) at 35, 45, and 55 DE as affected by simulated intercropping and relay cropping. IRRI, 1986 DS.

Treatment[a]	LAI		NAR (g/m^2 per d)		
	40 DE	60 DE	35 DE	45 DE	55 DE
Simulated intercropping					
i20	2.9	3.2	4.3	3.1	4.0
I20	2.9	2.9	3.2	3.3	0.6
i20N	3.5	3.2	3.9	2.9	1.9
I20N	3.8	3.3	4.2	2.6	1.3
Simulated relay cropping					
r20	2.4	2.7	4.5	4.8	4.6
R20	2.3	2.9	4.3	6.5	3.1
r30	2.5	2.8	4.0	6.0	3.2
R30	2.4	2.3	4.1	4.7	4.0
Unshaded control	3.1	3.6	5.0	4.3	4.6
SE	0.3	0.2	0.5	0.6	1.0

[a]For explanation, see Figure 5.



8. Number of pods per plant in soybean subjected to simulated relay cropping and simulated intercropping. IRRI, 1986 DS.



9. N uptake of soybean subjected to simulated intercropping and relay cropping. IRRI, 1986 DS.

to reduced soil fertility. As a result, farmers face considerable risk of total or partial crop failure.

In 1984, IRRI initiated research on intercropping grain legumes with upland rice as a strategy to improve N availability to rice, increase ecological sustainability of the production system, and improve the food and nutritional security of subsistence upland rice farmers. In previous years we tested the sensitivity of intercropping to management variables such as crop proportion and varieties. In 1986, we conducted three WS experiments on the IRRI upland farm to further improve the management of intercrops. The soils of the experimental site were silty clay and at the time of sowing had the following mean chemical properties: pH 6.0, 1.54% organic C, 0.118% total N, 41 ppm available P, 1.07 meq exchangeable K/100 g, and CEC 28.0 meq/100 g. An irrigated sorghum crop was grown for 45 d before sowing to remove much of the labile N from the soils. In all experiments, rice alone (UPLRi-7, 115-120 d duration) was drilled in 20-cm rows using 100 kg seeds/ha. Mungbean alone (EG MG 174-3, 60-65 d duration) was overseeded in 40-cm rows and after germination thinned to 12-15 plants/m. In intercrop treatments sown in 20-cm rows, 2 rice rows alternated with 1 row of mungbean. Rice was sown using 100 kg seeds/ha; mungbean was overseeded and after germination was thinned to 15-18 plants/m.

The experiments, conducted in RCBD with four replications, were uniformly irrigated at sowing time to ensure germination. The subsequent rainfall was sufficient to maintain stress-free conditions. No inorganic fertilizer was applied. Pests and diseases were adequately controlled.

Resource use and plant interactions. Intercropping legumes increases the grain and N yields of rice, perhaps because of N released by decaying

roots and nodules, root exudates, and abscised leaves of the legume, or because of greater soil volume exploration by rice roots. In this experiment, these relationships were studied by selectively removing different interactions so as to assess the magnitude of belowground and aboveground plant interactions between rice and mungbean.

The experiment consisted of two monocrops each of mungbean and rice and five intercrops (Table 6). Belowground contact between intercropped rice and mungbean roots was eliminated by hammering galvanized iron sheets to 50 cm depth into the strip-tilled soil, between the rows of the 2 crops (T1). A control for T1 in which the soil was strip-tilled but no sheets were placed was included (T2). The effect of abscised leaves of mungbean on intercropped rice was quantified by removing all abscised leaves from the plots every second day starting at 30 d after sowing (DAS) (T3). To determine if intercropped rice received any advantage from the increased soil volume available to each plant after mungbean harvest, every third row of rice in a rice monoculture was harvested at the time of mungbean harvest in intercrops (T4).

Since mungbean matures much earlier than rice, there is a possibility of early-stage rice being shaded by mungbean. This possibility was eliminated by restricting mungbean foliage to 10 cm on either side of the row by a nylon net (T5). Mungbean alone treated as in T5 served as a control to study the possible effect of the nylon net (T6). An undisturbed intercrop (T7), rice monoculture (T8), and mungbean monoculture (T9) were included as general controls.

The grain yields of both rice and mungbean were reduced relative to their respective monocultures when they were intercropped (Table 6), but only by 20% in rice and 12% in mungbean. Rice N yields were the same in rice monoculture and the intercrop. Shading by mungbean did not affect rice grain yield in the intercrop. Elimination of the interactions between the roots of the two crops resulted in decreased grain yield and N uptake of rice, but had no significant effect on mungbean yield. In T4, in proportion to area, rice grain yield was 14% more than the control, indicating that intercropped rice benefited from the increased volume of soil available per plant despite the slightly decreased N uptake. Removal of abscised leaves in T3 did not affect the grain yield of either crop. Removal of every third row of rice (T4) did not decrease grain yield proportionately.

Table 6. Effect of belowground and aboveground plant interactions on grain yield of intercropped rice and mungbean, and N uptake of rice, IRRI, 1986 WS.

	Treatment	Grain yield (t/ha)		Rice N uptake (kg/ha)
		Rice	Mungbean	
T1	Intercrop with no belowground interaction	1.0	0.8	24.9
T2	Intercrop, control for T1	1.3	0.7	33.1
T3	Intercrop with abscised leaves of mungbean removed	1.3	0.7	27.7
T4	Rice, every 3d row harvested	1.3	–	28.6
T5	Intercrop, shading eliminated	1.4	0.7	30.6
T6	Mungbean, control for T5	–	0.9	–
T7	Intercrop, control	1.4	0.8	33.4
T8	Rice	1.8	–	35.4
T9	Mungbean	–	0.8	–
	SE	0.1	0.1	3.2

These results suggest that intercropped rice benefits from the increased soil volume per plant after mungbean harvest. Mungbean growth and yield are not greatly affected by intercropped rice.

Effect of delayed sowing of rice. To see if rice grain yield can be maintained at the level of rice monoculture with delayed sowing of intercropped rice, an experiment was conducted at 2 fertility levels: 1) no N added, and 2) fresh green manure (10 t 45-d-old *Sesbania rostrata* ha, equivalent to 45 kg N/ha) incorporated into the plot 1 wk before sowing. Treatments were rice monoculture, mungbean monoculture, and three intercrops. In intercrop 1, rice was sown simultaneously with mungbean, but in intercrop 2 and intercrop 3, rice was sown 15 and 30 d after mungbean sowing.

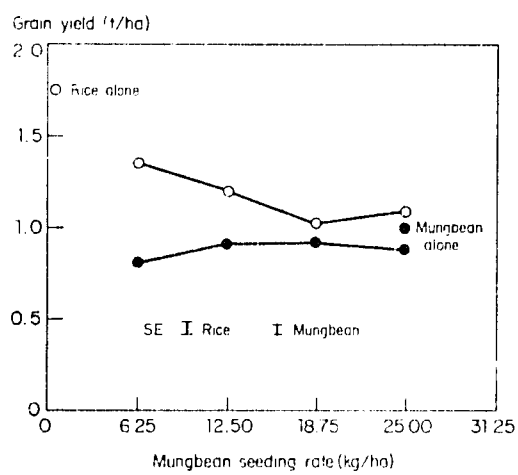
The grain yield of intercropped rice was lower than the yield of rice monoculture in high fertility soils (Table 7), but at low soil fertility there was no significant reduction. Intercropped mungbean

Table 7. Effect of delayed sowing of rice in rice + mungbean intercrop on grain yield. IRRI, 1986 WS.

Treatment	Grain yield (t/ha)	
	Rice	Mungbean
No N added		
Rice alone	1.8	–
Mungbean alone	–	1.0
Intercrop 1	1.6	0.7
Intercrop 2	1.4	0.8
Intercrop 3	1.2	0.8
Green manure added (45 kg N/ha)		
Rice alone	2.6	–
Mungbean alone	–	0.9
Intercrop 1	1.9	0.7
Intercrop 2	1.5	0.8
Intercrop 3	1.6	0.8
SE	0.2	0.1

grain yield was reduced regardless of soil fertility. Delay in rice sowing slightly increased mungbean yield, but the difference was statistically nonsignificant. Rice grain yield was less in intercrop 2 and intercrop 3 than in intercrop 1, possibly because of reduced solar radiation between PI and ripening of rice in the intercrops.

Response of intercrop to plant populations of component crops. We varied the populations of rice and mungbean by varying their seeding rates: 100 and 75 kg/ha for rice and 25, 18.75, 12.50, and 6.25 kg/ha for mungbean. Rice monoculture



10. Effect of mungbean seeding rate on yields of intercropped rice and mungbean, IRRI, 1986 WS. Grain yields of rice alone and mungbean alone are shown for comparison.

(100 kg/ha) and mungbean monoculture (25 kg/ha) were included.

Rice seeding rate had no significant effect on the grain yield of either crop. Mungbean in this experiment became tall and very leafy; therefore, as its seeding rate increased, rice grain yield decreased (Fig. 10). Mungbean yield increased slightly when the seeding rate increased from 6.25 to 12.5 kg/ha; further increase had no effect. The highest rice and mungbean yields were obtained in the intercrop with 12.5 kg of mungbean seeds/ha. In all intercrop treatments, however, grain yields of both rice and mungbean were lower than those of their respective monocultures.

RICE + MUNGBEAN VS RICE + MAIZE

Multiple Cropping Department

To test if a rice + mungbean intercrop is more productive than rice + maize, an experiment involving rice (UPLRi-5) and its intercrops with mungbean (EG MG 174-3) and maize (IPB Var. 1) was sown at zero and moderate (60 kg/ha) N levels. Table 8 shows the crop combinations and fertilizer N applied in various treatments. The experiment consisted of eight treatments laid out in RCBD with four replications.

All sowings were done in 20-cm rows in a well-prepared field. In rice + mungbean, three rice rows alternated with one row of mungbean; in rice + maize, six rice rows alternated with a maize row. Rice was drilled using 100 kg seeds/ha. Mungbean and maize were overseeded and after 3 wk thinned to 15 and 4 plants/m, respectively. Fertilizer was applied basally in mungbean, in 2 equal splits (planting and tasseling) in maize, and in 3 splits (planting, 30 DE, and PI) in rice. Crops were adequately protected from diseases and insects. Water was applied with a sprinkler irrigation system to break drought spells.

The grain yield of rice monoculture as well as intercropped rice increased significantly with N application (Table 8). Rice intercropped with mungbean yielded significantly more than rice monoculture at 0 N. In all other treatments, the yield of intercropped rice was similar to that of rice monoculture. However, the mean rice yield in rice + mungbean (1.6 t/ha) was significantly higher than that in rice + maize (1.5 t/ha). N fertilization

Table 8. Grain yields of rice alone and intercropped with mungbean or maize, IRRI, 1986 WS.

Crop combination	Applied N (kg/ha)		Grain yield (t/ha)		
	Rice	Maize or mungbean	Rice	Mungbean	Maize[a]
Rice alone	0	–	0.9	–	–
Rice alone	60	–	2.0	–	–
Rice + mungbean	0	0	1.3	0.4	–
Rice + mungbean	40	20	1.8	0.3	–
Rice + mungbean	60	0	2.0	0.3	–
Rice + maize	0	0	1.1	–	0.1
Rice + maize	40	20	1.7	–	0.2
Rice + maize	60	0	1.8	–	0.2
SE			0.1	0.04	0.1

[a] Affected by typhoon during reproductive phase.

had no significant effect on grain yields of intercropped mungbean and intercropped maize. Mean mungbean and maize grain yields were 0.3 and 0.1 t/ha.

EFFECT OF SPATIAL ARRANGEMENT AND THINNING DATE OF MAIZE ON YIELD OF INTERCROPPED PEANUT

Rice Farming Systems Program

A field trial of maize and peanut grown in monoculture and in association was conducted at IRRI during the 1985-86 dry season (DS). A yellow maize hybrid (Pioneer 3274) and a 105-d peanut variety (IPB PN-2-25) were used. Monoculture maize was planted at 75 cm between rows and 25 cm between hills with 1 plant/hill for a plant population of 53,333 plants/ha. As an intercrop, maize was planted at row spacings of 75 cm, 100 cm, and 150 cm, with 25 cm between hills and 3 plants/hill. To maintain a uniform plant population of 53,333 plants/ha in each plot, the excess plants were thinned 25 and 50 d after planting (DAP). Peanut was planted at 30 cm between rows and 20 cm between hills in both monoculture and intercrop.

Shelled bean and fodder yields were significantly reduced when peanut was grown in association with maize, the greatest reduction (75%) being with intercropped maize spaced at 75 cm between rows and thinned 50 DAP. Yield components such as number of pods per plant were also significantly reduced with closer row spacing and late maize thinning. The weight of 100 seeds, however, did not vary significantly from the monoculture. The intercropped peanut plants had sparser leaf density and taller canopy profile than the monoculture.

Planting peanut in association with maize using the cropping system described here did not have an appreciable effect on maize grain production, but the benefit of the system was the highly significant increase in total fodder dry matter production by as much as 56% over the monoculture level (Table 9). The highest fodder yield — obtained at 75-cm row spacing of the maize intercrop, thinned 50 DAP — could be attributed to the more and larger plants harvested on this date.

The land equivalent ratio (LER) for grain yield was highest at 150-cm row spacing between maize intercrop, thinned 25 DAP: a 49% advantage over monocropping. On the other hand, the LER for TDMY was highest (1.81) with maize at a row spacing of 75 cm, thinned 50 DAP — which more than compensated for the small loss (4%) in grain yield of the maize intercrop in this arrangement. These data, however, suggest that for both grain and fodder production, farmers will benefit more from the maize + peanut association if maize is spaced at 100 cm between rows and thinned 50 DAP, as shown by the 30% advantage in grain yield and 67% in total fodder production over the monoculture.

WHEAT MANAGEMENT IN TROPICAL ENVIRONMENTS

Multiple Cropping Department

Seeding rates and row widths. Rice - wheat rotation is common above 20° N, and there is

Table 9. Yield and land equivalent ratio (LER) at different row spacings with varying thinning dates of maize in the maize + peanut intercropping experiment.[a] IRRI, 1985-86 DS.

Treatment	Yield (t/ha)							LER	
	Grain		Fodder dry matter						
	Peanut	Maize	Peanut	Maize				Grain	Total fodder
				25 DAP	50 DAP	Full maturity	Total		
Peanut monoculture	0.96 a	–	3.84 a						
Maize monoculture		3.21 a			–	4.86 a	4.86 b	–	–
Intercrop									
75 cm, 25 DAP	0.29 b	2.83 a	1.09 b	0.52 a	–	4.66 a	5.18 b	1.18	1.34
75 cm, 50 DAP	0.21 b	2.39 a	0.95 b	–	3.11 a	4.46 a	7.57 a	0.96	1.81
100 cm, 25 DAP	0.38 b	3.08 a	1.14 b	0.47 a	–	4.25 a	4.72 b	1.36	1.26
100 cm, 50 DAP	0.35 b	2.99 a	1.09 b	–	2.59 a	4.16 a	6.75 a	1.30	1.67
150 cm, 25 DAP	0.50 b	3.11 a	1.22 b	0.44 a	–	4.12 a	4.56 b	1.49	1.26
150 cm, 50 DAP	0.44 b	2.85 a	1.35 b	–	1.53 b	3.63 a	5.16 b	1.35	1.41

[a]DAP = days after planting.

growing interest in extending this rotation to areas nearer the equator in Southeast Asia, where the entire demand for wheat is met by importation. To increase self-reliance, the governments of most Southeast Asian countries as well as international agencies have initiated varietal improvement programs to develop wheat varieties adapted to regional environments. Some adapted varieties were released recently.

To determine the feasibility of cultivating wheat in the postrice season and to identify optimal cultural practices, IRRI's Multiple Cropping Department has conducted studies since 1981 in Los Baños (14°10' N) and Cagayan Province (17°46' N), Philippines. During 1986, we continued our efforts to study the sensitivity of postrice wheat to management variables.

It has been observed that, relative to wheat crops in temperate and subtropical regions, the number of wheat spikes m^2 in tropical regions was low. An experiment was conducted to determine if the number of spikes could be increased by increasing seeding rate or reducing row spacing or both. The experiment sown in Los Baños on 18 Dec 1985 studied the effect of seeding rate (100 kg and 170 kg ha) and row spacing (10, 15, 20, and 25 cm) on grain yield of wheat C213-15, a recently developed line of the Institute of Plant Breeding, University of the Philippines at Los Baños. The field was fertilized at sowing time with 100-50-50 kg NPK ha. The crop was irrigated and kept free from pests and diseases.

Regardless of seeding rate, the number of shoots increased as row spacing decreased (Table 10).

Table 10. Effect of row spacing and seeding rate on wheat. IRRI, 1986 DS.

Treatment	Grain yield (t/ha)	Dry matter (t/ha)	Maximum no. of shoots/m^2	Spikes (no./m^2)	1000-grain weight (g)	Grains (no./m^2)	Grains (no./spike)
Row spacing (cm)							
10	2.79	8.05	795	417	37.2	7495	18.1
15	2.80	8.39	758	395	38.5	7685	18.9
20	2.67	8.12	674	362	38.1	7018	19.7
25	2.63	7.65	654	363	38.0	6910	19.5
Seeding rate (kg/ha)							
100	2.77	8.24	701	338	39.6	7091	20.8
170	2.67	7.86	739	427	36.3	7463	17.4

However, increased tillering was accompanied by greater shoot mortality, as indicated by spikes/m² at maturity. Nevertheless, spikes/m² increased as row spacing decreased, and there were more spikes when the seeding rate was higher.

The advantage that narrow row spacing had in number of spikes/m² was offset by a decline in 1,000-grain weight. Similarly, the increased number of spikes/m² at the higher seeding rate was offset by a decrease in the number of grains/spike as well as 1,000-grain weight. Consequently, grain yield did not differ significantly among the treatments.

This experiment indicates that increasing plant density above that which can be obtained from 100 kg seed/ha sown on 20-25 cm row spacings will not increase grain yield by compensating for the low number of spikes/m² commonly observed in lower latitudes of the tropics. Whether this will be true in environments warmer than those in this study needs to be determined.

Effects of defoliation, shading, and spikelet removal. High humidity and temperature are favorable for the growth of leaf spot caused by *Helminthosporium* sp., which reduces the effective leaf area of wheat and is believed to be a major constraint in realizing grain yield potential in the humid tropics. An experiment in Los Baños studied the effect of reduced leaf area on grain yield of UPLW-3 wheat. An additional objective was to study the sensitivity of wheat to change in the source-sink proportion. The experiment, consisting of 10 treatments, was sown on 28 Dec 1985.

The seeds were sown in 15-cm rows at 150 kg/ha in a well-tilled, silty clay field. Fertilizer at the rate of 100-50-50 kg NPK/ha was given as a single basal dose. The crop was irrigated, and pests and diseases were adequately controlled. At anthesis (45 DAS), LAI was 2.87 and dry matter was 302 g/m².

The clipping treatments were applied at anthesis to seven central rows in each plot. Sink size was reduced while maintaining the same source size by selectively cutting off 2, 4, 6, and 8 apical spikelets in a spike (11 spikelets in the control) with scissors. Source size was reduced by clipping the lamina of leaves. Radiation was reduced by stretching layers of nylon net over the crop canopy.

Dry matter at maturity in all treatments was comparable to that of the control except that it was reduced when all leaves were clipped (Table 11); this suggests that clipping of a few leaves increased assimilation by the remaining leaves, spikes, and leaf sheaths.

Grain weight increased relative to the control when two spikelets were clipped, indicating source limitation (Table 11). Removal of more spikelets while maintaining the same level of source availability did not further increase the weight of the remaining grains. This suggests a limited potential grain weight of the variety or a direct sink limitation in grain growth because of accumulation of inhibitors such as abscisic acid under high temperature. Grain weight was severely reduced when all leaves were removed and the crop was shaded. There was a small decrease in grain weight when all leaves except the flag leaf were clipped. Clipping the flag leaf alone did not significantly reduce grain weight.

Grain number was reduced when more than two spikelets were clipped. Reduction in leaf area or shading did not affect grain setting.

As a result of these effects in grain number and

Table 11. Effects of spikelet removal, defoliation, and shading on yield and yield components of wheat, IRRI, 1986 DS.

	Treatment	Grain yield (g/m²)	Dry matter (g/m²)	1000-grain weight (g)	Grains (no./m²)
T1	Control	239 a	594 a	31.4 b	7618 a
T2	2 spikelets per spike clipped	237 ab	586 a	34.5 a	6875 ab
T3	4 spikelets per spike clipped	209 bcd	562 a	34.7 a	6037 bc
T4	6 spikelets per spike clipped	184 de	583 a	33.9 a	5431 c
T5	8 spikelets per spike clipped	115 f	521 a	34.3 a	3366 d
T6	All leaves except flag leaf clipped	207 cd	514 a	29.0 bc	7153 ab
T7	Only flag leaf clipped	220 abc	572 a	29.6 bc	7464 a
T8	All leaves clipped	170 e	428 b	26.3 d	6472 abc
T9	Radiation reduced by 50%	202 cd	562 a	27.6 cd	7358 a
T10	Radiation reduced by 75%	138 f	507 ab	19.9 e	6992 ab

1,000-grain weight, grain yield was reduced when more than 4 spikelets were clipped (Table 11). Grain yield was not significantly affected as long as even one leaf was allowed to remain on the shoot. When the flag leaf was clipped, the other leaves were able to support grain growth. Only when all leaves were clipped was grain yield reduced by 29%.

We conclude that 1) the grain yield of tropical wheat is largely sink limited, 2) diseases such as *Helminthosporium* leaf spot should not be a major constraint in cultivating wheat in the lower latitudes of the tropics as long as the sink size of the varieties remains the same, and 3) shading wheat, as in intercropping, will not cause significant yield reduction as long as the shading is less than 50%.

Intercropping wheat and maize. An exploratory experiment in Los Baños in 1986 DS evaluated the feasibility of intercropping wheat with a traditional and adapted crop such as maize. Because wheat maturity is short, growth is relatively poor, and yields are low in the lower latitudes, intercropping it with relatively longer maturing maize may increase the efficiency of space and radiation. Six of the eight treatments in the experiment were intercropped combinations of wheat and maize (Table 12). Wheat was sown on 19 Dec 1985 in rows 15 cm apart at a seed rate of 170 kg/ha. Maize was planted at 2 densities (30,000 and 50,000 plants per hectare [PPH]) at these spacings: 120, 150, and 180 cm, established by planting every 8th, 10th, and 12th row, respectively. A maize monoculture (60,000 PPH at 60 cm row spacing) and a wheat monoculture were included. The field was fertilized at sowing time with 100-50-50 kg NPK/ha, and the crop was irrigated. Foot rot damage in wheat could not be fully controlled. Weeds were removed periodically by hand.

The grain yields of both wheat and maize were reduced in the intercrops relative to the monocrops (Table 12). The reduction was more in maize than in wheat. The maize population had no effect on maize grain yield, but wheat grain yield was high when the maize population was low. Maize row spacing affected maize grain yield but not wheat yield. Maize yield was higher with closer row spacings. The total productivity of the land (expressed as LER) was high when the maize population was low. The interaction between population and row spacing was nonsignificant. A part of the reduction in wheat grain yield was due to periodic removal of plants infected with foot rot. Also, there was partial lodging in intercropped wheat.

Table 12. Grain yields and LER for wheat + maize intercrop. IRRI, 1986 DS.

Treatment	Grain yield (t/ha)		LER		
	Wheat	Maize	Wheat	Maize	Total
Wheat + maize intercrop					
50,000 maize PPH					
120 cm	1.12	2.23	0.53	0.62	1.15
150 cm	1.11	1.81	0.52	0.49	1.02
180 cm	1.27	1.38	0.60	0.37	0.97
30,000 maize PPH					
120 cm	1.44	1.84	0.68	0.50	1.18
150 cm	1.42	1.84	0.57	0.49	1.16
180 cm	1.31	1.38	0.62	0.36	0.98
Monoculture					
Maize	–	3.88	0	1.0	1.0
Wheat	2.31	–	1.0	0	1.0

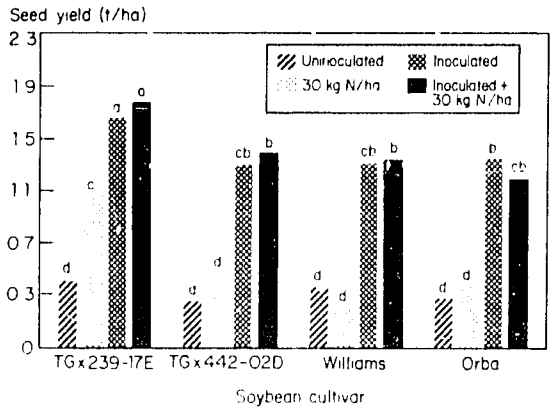
This experiment suggested that it is possible to obtain high yields of wheat as well as of the traditional low-latitude crop maize by intercropping these species, but further study is needed.

RESPONSE TO INOCULATION AND NITROGEN FERTILIZATION OF SOYBEAN AFTER LOWLAND RICE UNDER UNTILLED RAINFED CONDITIONS

Rice Farming Systems Program

A study in 1986 DS in a farmer's field in Santa Rosa, Laguna, evaluated the yield, nodulation, and agronomic responses of soybean cultivars to inoculation and N fertilization when grown after lowland rice under zero tillage and rainfed conditions. This was the first time soybean had been grown in this field. The soil was clayey alluvium deposited on gravelly volcanic sediments at 64 cm deep. The upper profile (0-13 cm) contained about 58% clay and 37% silt, and had pH 6.9, 2.2% OC, and CEC 44 meq/100 g soil. The study followed the split-plot design with four replications, with inoculation and fertilization treatments as the main plots and cultivars as subplots.

Inoculation alone and in combination with 30 kg N/ha increased yield by 76% over the control. No



11. Effect of cultivar, inoculation, and N fertilization on seed yield of soybean after lowland rice under rainfed and untilled conditions. Santa Rosa, Laguna, Philippines, 1986 DS.

significant difference in yield was obtained between inoculation alone and in combination with 30 kg N/ha in any cultivar, but these 2 treatments varied significantly from the 30 kg N/ha alone and the control (unfertilized and uninoculated) plots. Regardless of treatment, TGx 239-17E with a yield of 1.2 t/ha outyielded TGx 442-02D, Williams, and Orba. The highest yield (1.8 t/ha) was obtained from TGx 239-17E with inoculation and 30 kg N/ha (Fig. 11).

EFFECT OF MULCHING AND PHOSPHORUS APPLICATION ON YIELD OF SOYBEAN AFTER LOWLAND RICE

Rice Farming Systems Program

An experiment in a split-plot design with four replications evaluated the effect of mulching and P application on the yield of soybean after lowland rice under zero tillage conditions. Mulching treatments were the main plots and P levels the subplots. Seeds were inoculated.

Mulch at 5 t/ha significantly increased soybean yield by 29% over the unmulched plots (Table 13). Mean seed yield was higher at 18 kg P/ha than at 9 kg P/ha or in unfertilized plots.

RESPONSE OF COWPEA TO WATER STRESS

Rice Farming Systems Program

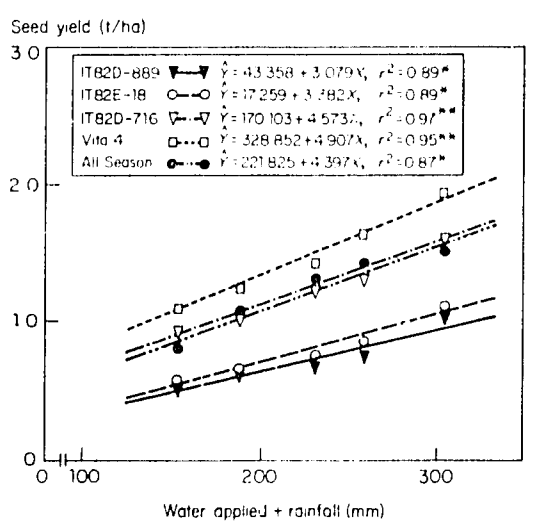
Cowpea grown on residual soil moisture after rice faces water stress during the entire growing season,

Table 13. Effect of mulching and phosphorus level on seed yield of Improved Pelican soybean after rainfed lowland rice. IRRI, 1986.

P rate (kg/ha)	Yield (t/ha)
Without mulch	
0	1.1 de
9	1.0 e
18	1.3 cd
With mulch	
0	1.6 ab
9	1.5 bc
18	1.7 a

particularly during the reproductive growth phase. Five cowpea cultivars differing in maturity were evaluated at IRRI for water stress tolerance during the reproductive phase. The crop was irrigated uniformly until 30 DAS, and a line source sprinkler system was installed at flowering (40 DAS). Irrigation applied at 7-d intervals replenished about 60% of pan evaporation. Soil moisture extraction in the dry regimes was monitored by a neutron moisture meter.

Water stress reduced seed yield in all genotypes, but the reduction was greater in early and determinate types than in medium maturity and indeterminate types (Fig. 12). Among the five cultivars, Vita 4 was the most drought tolerant,



12. Relationship between seed yield and water applied plus rainfall for 5 cowpea cultivars. IRRI, 1986 DS.

whereas IT82E-18 was the most drought susceptible, followed by IT82D-889. Vita 4 also had highest response to water application, followed by IT82D-716.

The water extraction patterns of the five cowpea cultivars in the dry regime are presented in Figure 13. Vita 4 and IT82D-716 extracted more water from the deeper soil profile than early maturing IT82D-889.

PERFORMANCE OF TEPARY BEAN AFTER LOWLAND RICE

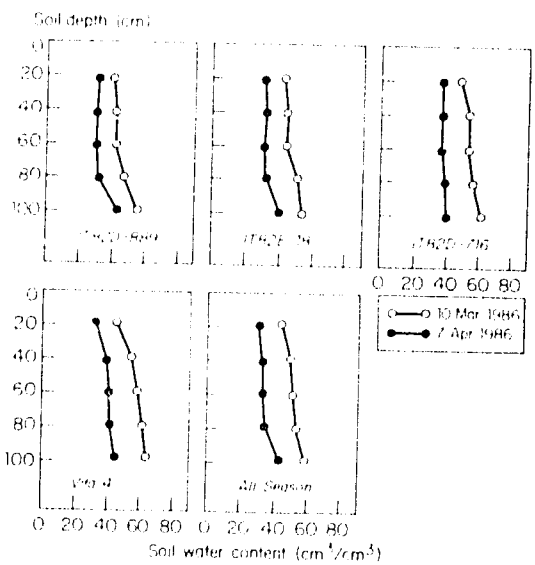
Multiple Cropping Department

Tepary bean *Phaseolus acutifolius* is a potential crop after lowland rice. A field experiment evaluated the response of tepary bean (CIAT40069) to fungicide and inoculation. Seed treatment with fungicides reduced seedling mortality, but the effects did not last long and resulted in considerable reduction in plant stand. There was a linear relationship between seed yield and plant stand at harvest (Fig. 14). The highest yield of 2.35 t/ha was obtained with 0.39 million plants/ha.

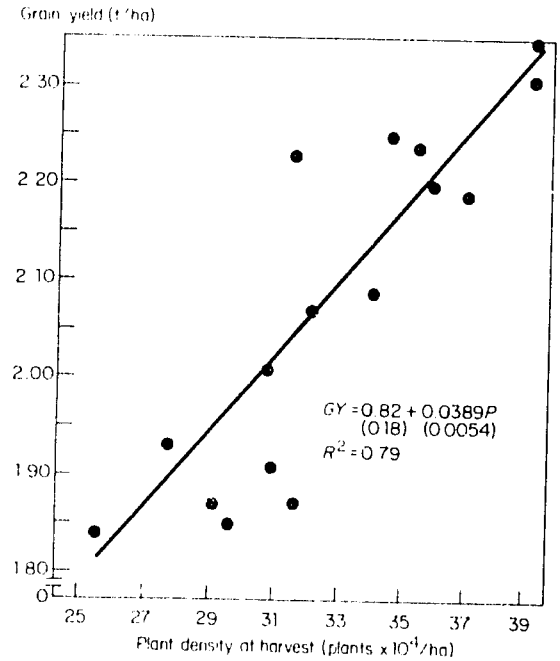
MUNGBEAN SENSITIVITY TO WATER TABLE LEVEL AND DURATION

Multiple Cropping Department

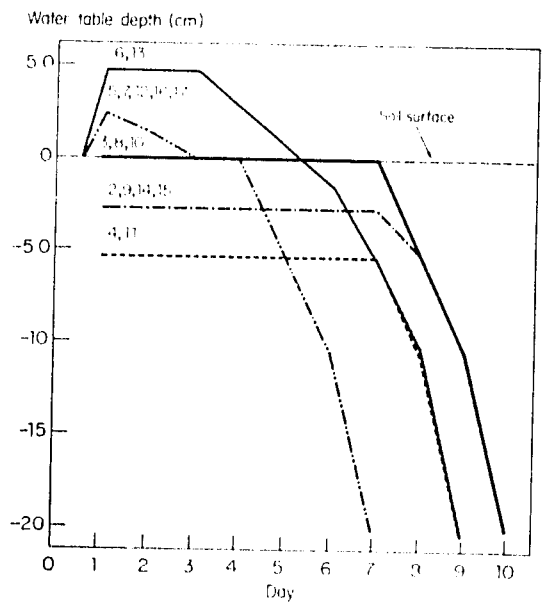
Production of mungbean before rice is constrained by waterlogging during early WS. To help develop surface drainage techniques to protect mungbean from waterlogging damage in bunded ricelands with poor surface and internal drainage, a pot experiment was conducted. Five combinations of



13. Soil moisture extraction pattern of 5 cowpea cultivars in the dry regime at 2 planting dates. IRRI, 1986 DS.



14. Tepary bean grain yield as a function of plant density at harvest. IRRI, 1986.



15. Water table treatments applied to mungbean, Solana, Cagayan, Philippines, 1986 DS and WS. Numbers refer to application of the treatment at different growth stages. Refer to Figure 16 for interpretation of the growth stages.

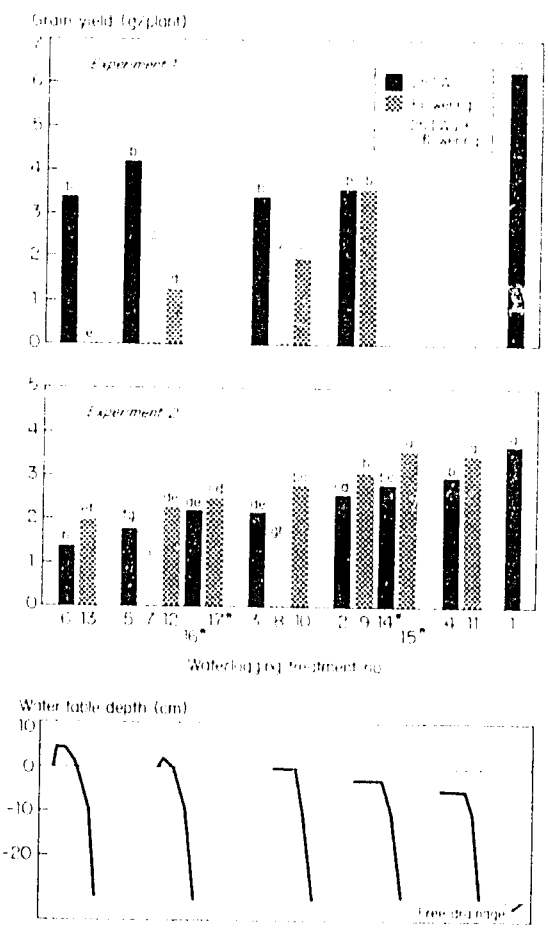
water table treatments were applied at the vegetative phase (25 DAS) or during flowering, or in both periods (Fig. 15). The most severe treatment had standing water of 5.0 cm above the ground surface for 3 d followed by slow recession.

In the first experiment conducted in 1986 DS, mungbean cultivar CES-1D21 was seeded at a depth of 2.5 cm in a clay soil (Aeric Tropaquept, 54% clay) in 35-cm-deep pots. Yields were reduced by at least 33% in all waterlogging treatments (Fig. 16). Plants were most sensitive at flowering. Yield reduction was 42% with a −2.5 cm water table, and 100% (no grain production) with −5 cm water depth. Yields were less sensitive to waterlogging during the vegetative phase.

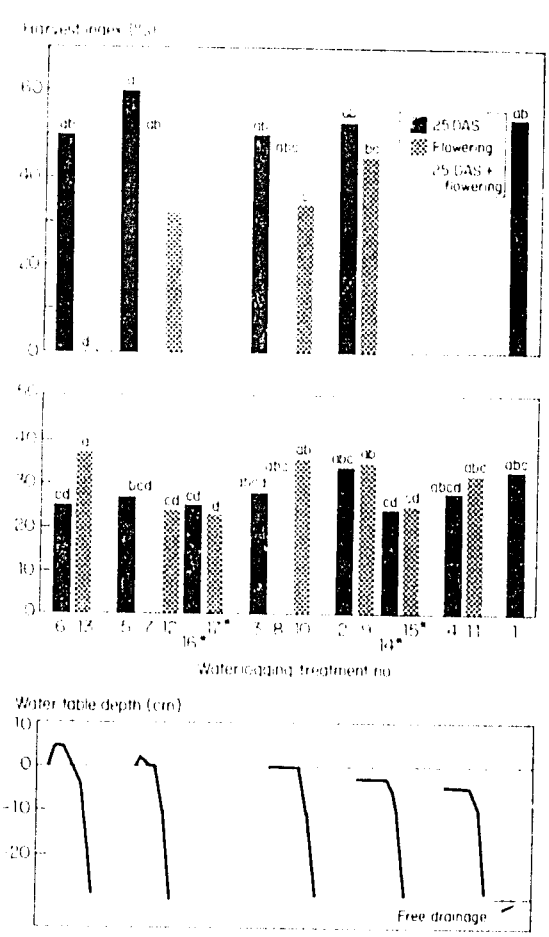
In the second experiment, the flowering stage response to waterlogging was less sensitive than in the first (Fig. 16), apparently because treatment was later in the flowering period. The difference in response compared with the first experiment indicates that, as flowering progresses, waterlogging sensitivity is reduced.

In the second experiment, plants growing from broadcast seeds were compared with those from conventional seeding at 2.5 cm and were found to be less sensitive to waterlogging (Fig. 16). This indicates that the location of the crown of the plant in relation to the water table is important in determining response to waterlogging.

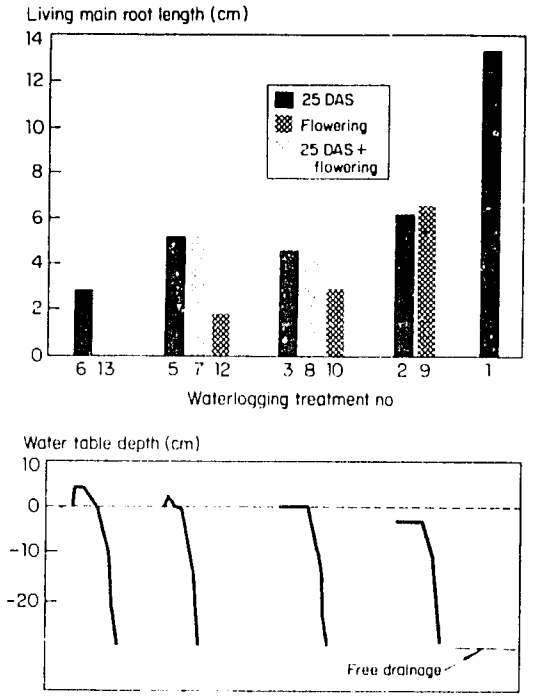
Harvest indices (Fig. 17) of the plants stressed by waterlogging were not reduced as much as grain yield. The length of the main root remaining alive after the treatment was severely reduced in all waterlogging treatments (Fig. 18).



16. Effect of waterlogging treatment and seeding method on grain yield of mungbean, Solana, Cagayan, Philippines, 1986. Asterisks denote treatments in which seeds were placed on soil surface.



17. Effect of waterlogging treatment and seeding method on harvest index of mungbean, Solana, Cagayan, Philippines, 1986. Asterisks denote treatments in which seeds were placed on soil surface.



18. Effect of waterlogging treatment on length of living main root of mungbean, experiment 1, Solana, Cagayan, Philippines, 1986.

The results indicate that major yield reduction can be prevented only by ensuring that the base of the mungbean plant is at least 2.5 cm above the water table during waterlogging in a clay soil.

Machinery development and testing

Agricultural Engineering Department

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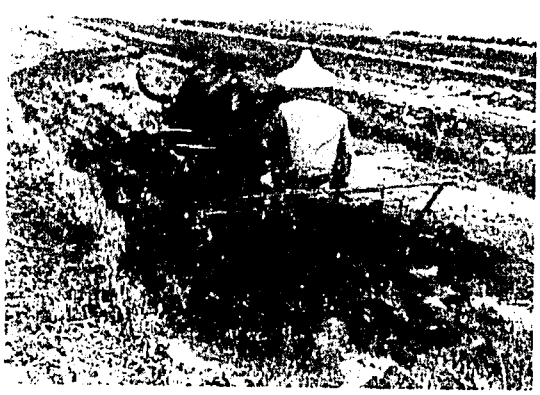
The major projects undertaken during the year involved the development of machines for improving farmers' traditional practices to enhance cropping intensity, increase income, and reduce the drudgery of farm labor.

LAND PREPARATION

Lowland areas. *Ground-driven rotary tiller.* We designed an animal-drawn, ground-driven rotary tiller (Fig. 1) having two tandemly mounted tined rotors, connected with a chain sprocket transmission so that the rear rotor is driven at about three times the speed of the front rotor. Skids control tillage depth and prevent excessive sinkage in soft soils.

The machine was tested under different soil conditions to determine draft power requirements and field capacity. The maximum draft of 56.6 kg was required in unplowed soils (T1), and the minimum draft of 34.7 kg in very soft soil (T4) (Table 1). The mean draft for all tillage treatments was 47.4 kg, which is well within the capability of average Philippine carabaos.



1. Ground-driven rotary tiller. IRRI, 1986.

Table 1. Test results on lowland ground-driven rotary tiller. IRRI, 1986.

Treatment	Draft (kg)	Speed (m/s)	Power (hp)	Capacity (ha/h)	Slip (%)
T1	56.6	0.50	0.38	0.13	28.4
T2	49.3	0.51	0.34	0.14	27.1
T3	49.1	0.54	0.35	0.14	34.0
T4	34.7	0.50	0.28	0.16	32.1
Mean	47.4	0.51	0.34	0.14	30.4

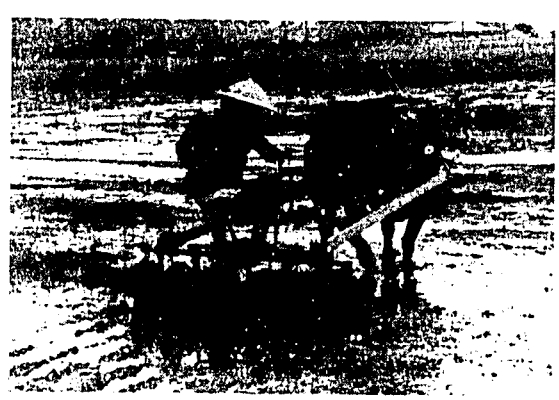
Animal-drawn cono puddler. The animal-drawn conical puddler was modified further to simplify its design. Instead of two rows of ganged conical rotors, only one was used, to reduce cost. Two wooden beams with a yoke replaced draw ropes to provide more stability and permit the operator to ride on the machine (Fig. 2).

The new design is much lighter and requires less draft, even though the operator rides on it. Compared with traditional comb harrows, the cono rotary puddler is more effective in breaking soil clods and in burying and incorporating crop residues in the soil. Its field capacity is about twice that of the comb harrow. The machine has been well received, and many farmers in different parts of the Philippines have purchased this puddler from local manufacturers.

Power tiller-attached cono puddler. The cono puddler was adapted to the power tiller. It consists of a single gang of six cono rotors mounted on a tool bar, which is attached to the power tiller through a hitch adapter (Fig. 3).

The rotors are identical to those of the animal-drawn puddler and are individually coupled to the tool bar. The hitch adapter will easily fit in most power tiller models and allows free swinging movement on both horizontal and vertical planes to facilitate turning and crossing of levees.

The implement is especially suited to secondary tillage and puddling of soft ricefields. The blades on the conical rotors create a horizontal back-and-forth action in the top 10-cm layer of the soil, requiring less energy input. The rolling action of the cones pushes and buries surface weeds and



2. Animal-drawn cono puddler. IRRI, 1986.

3. Power tiller-attached cono puddler. IRRI, 1986.

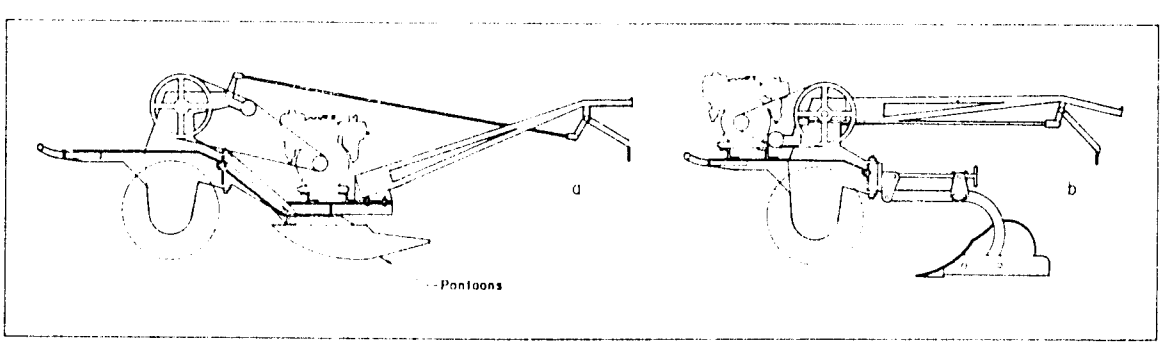
trash in the mud and leaves a well-puddled, level soil surface.

Based on field tests in farmers' fields, the average capacity of the power tiller-attached cono puddler is 1.26 ha/d, with 2 passes in lengthwise and crosswise directions — about twice the capacity of the comb harrow commonly used for secondary tillage. The farmers commented that the implement is convenient and light to handle, enabling them to operate it for longer hours.

Convertible tiller. A power tiller that combines several of the best features of the Ministry of Agriculture and Food (MAF)-IRRI hydrotiller and the traditional Filipino power tiller was developed by the MAF-IRRI Program. As described in the Annual report for 1985, the hydrotiller is an improvement of a locally designed floating tiller that has gained popularity for land preparation on rice farms in waterlogged areas. The hydrotiller is far more economical than the traditional tiller, even for fields with normal soil and water conditions. However, it does not have the versatility of the traditional tiller, i.e., it cannot be used to pull a trailer and is not capable of normal plowing, harrowing, and leveling operations. The convertible tiller can easily be converted from a traditional tiller to a quasi hydrotiller simply by adding two pontoons behind the cage wheels and moving the engine from the normal forward position to a position over the pontoons (Fig. 4). The conversion may be made in less than half an hour and increases the price of the unit by less than US$100. This tiller has all of the capabilities of the traditional tiller while having the very high field capacity of the hydrotiller, except in waterlogged areas. During 1986, the convertible tiller was promoted among interested manufacturers in the Philippines through the MAF-IRRI Program.

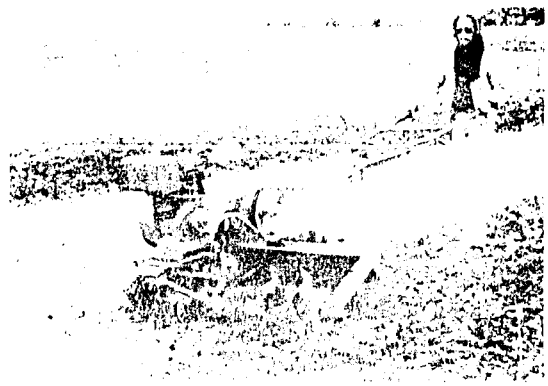
Waterlogged areas. *Conversion of PT-5 power tiller for soft soil tillage.* In many countries, soft, waterlogged soil is a common problem. This soil is not strong enough to support a conventional power tiller. Two attachments were developed to improve ground support for the IRRI PT-5 power tiller to retain its versatility in conventional operations such as plowing, harvesting, and transport: cono rotors (Fig. 5) and flotation skids (Fig. 6). Field tests in Santa Cruz, Laguna, were satisfactory. In very soft soils, the cono rotors performed slightly better than the flotation skids, partly because of the rolling traction of the roots.

Upland areas. *Power tiller conversion for upland tillage.* Conventional 4-wheel tractors are used for land preparation on larger farms in some upland areas. Such tractors, however, are beyond



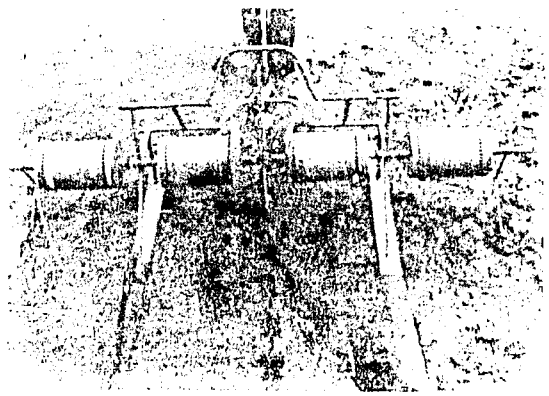
4. The convertible tiller (a) is obtained from the traditional power tiller (b) by adding pontoons and moving the handle bars to a rearward position. IRRI, 1986.

5. Conversion of PT-5 to a lowland puddler with cono rotors. IRRI, 1986.



7. Rototiller for uplands. IRRI, 1986.

6. Conversion of PT-5 to a lowland puddler with flotation skids. IRRI, 1986.



8. Drum seeder. IRRI, 1986.

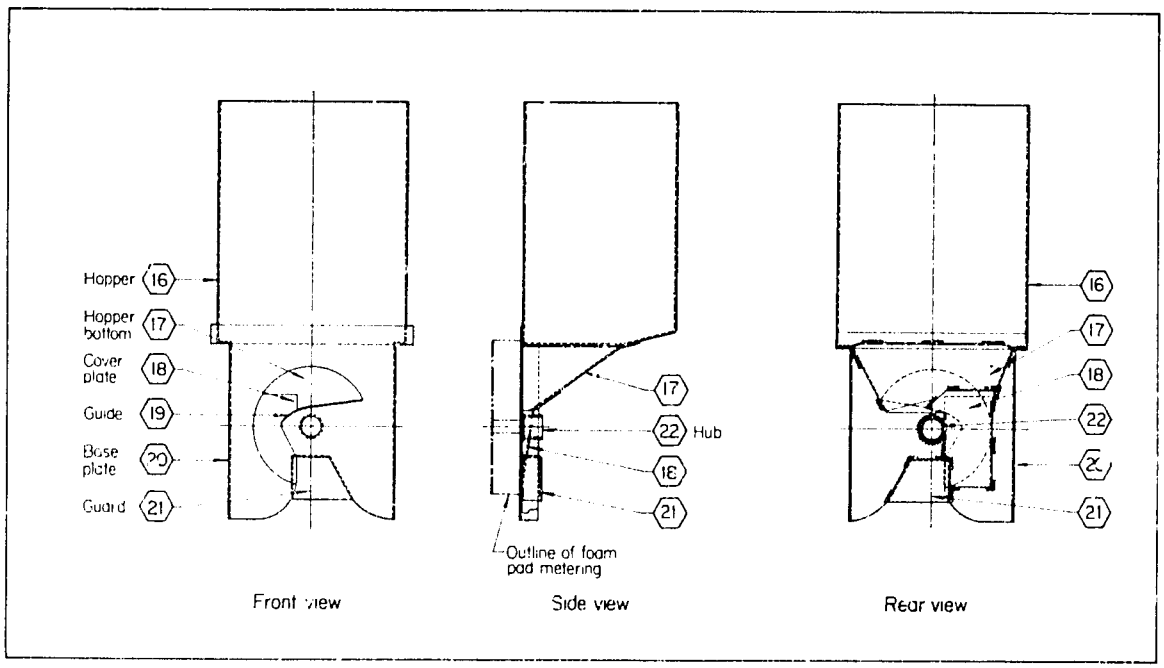
the means of the majority of upland farmers. A project was initiated to convert into an upland soil implement the standard 2-wheel power tiller popular in wetland farming. Cylindrical rotors with blades were fitted to the power tiller axle (Fig. 7). A tail wheel drive by the axle through a chain and sprocket controls forward motion. Initial tests indicate that the converted power tiller can be used for tilling upland soils. The prototype demonstrated a field capacity of 1.3 ha/d on light sandy soils and 1.6 ha/d on clayey soils.

CROP ESTABLISHMENT

Lowland areas. *Drum seeder for pregerminated rice.* The design of the drum seeder was further modified (Fig. 8) to eliminate problems encountered in tests in farmers' fields, which indicated that the 8-row unit has a field capacity of 1.2 ha/d with 2 men operating alternately. The average seeding rate of the modified machine ranges from 73 to 120 kg/ha, depending on the setting of the seed rate adjusting ring.

Many farmers, particularly in areas where direct seeding is practiced, have shown interest in the drum seeder. It is simple and easy to use. With this machine farmers can establish the crop in rows to permit the use of mechanical weeders to minimize, if not totally eliminate, herbicides. About 300 units have been fabricated by 20 manufacturers, and sales are increasing.

Upland areas. *Inverted-T seeder — modification of hopper base.* The original hopper base for the foam disk metering device for the inverted-T seeder came from New Zealand. It is made of molded plastic and is expensive to produce if not manufactured in large volume. The design was simplified so that the base can be made by small shops out of sheet metal, using a simple cut-and-weld process (Fig. 9).



9. Sheet metal hopper base for foam disk-type seed metering device. IRRI, 1986.

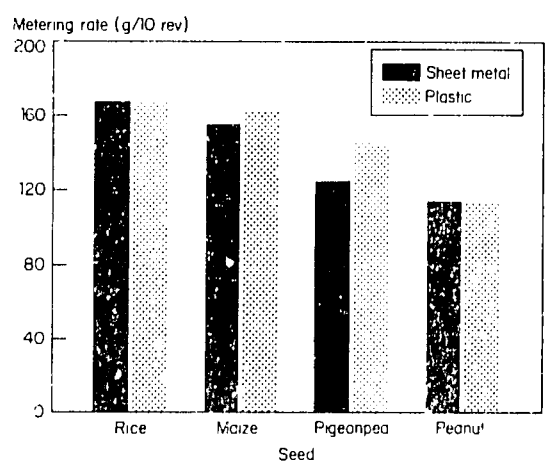
The design incorporates the same hopper shape and size as the original plastic version, but the semicircular seed groove was simplified to a uniform-slope rectangular groove. The seed hopper was also incorporated into the hopper base as a single assembly.

Laboratory tests compared the metering performance of the sheet metal foam disk and that of the original plastic version, with rice, maize, pigeonpea, and peanut seeds at three rotational speeds. In all cases, the metering rates of the two devices did not significantly differ (Fig. 10). In most of the tests, the sheet metal version had less deviation that the original plastic hopper base.

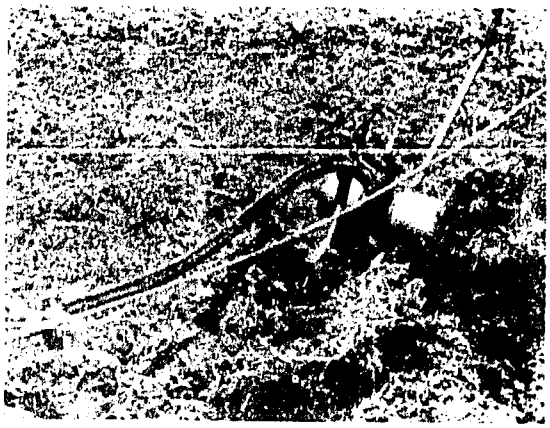
We have received numerous inquiries regarding the inverted-T seeder. The design drawings have been released to interested manufacturers, and commercialization is in progress.

Other seeder designs for uplands. Upland seeders are important devices for proper crop establishment and for increasing the productivity of rice-based farming systems. Work on the development of the following seeders was initiated.

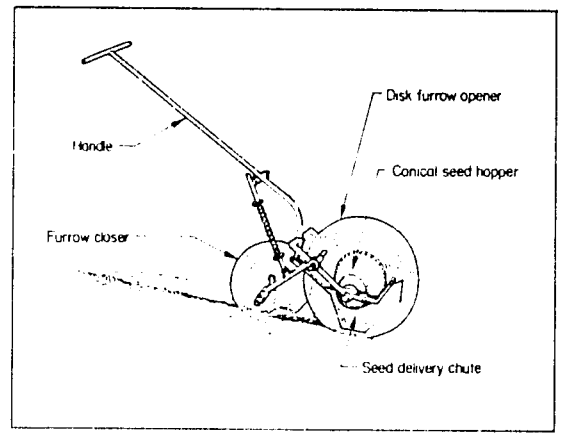
- Plow seeder and fertilizer applicator (Fig. 11). This machine is a simple, low-cost attachment for native plows for seeding rice and other crops. It has two perforated drums mounted on each side of the plow and is driven from a single ground wheel. As the wheel rotates, seeds are discharged from one drum and fertilizer from the other.
- Rolling dibbler (Fig. 12). This is being developed to overcome the clogging problems of the rolling injection planter when used on wet and sticky soils. The important feature of



10. Comparative metering performance of sheet metal vs plastic foam disk. IRRI, 1986.



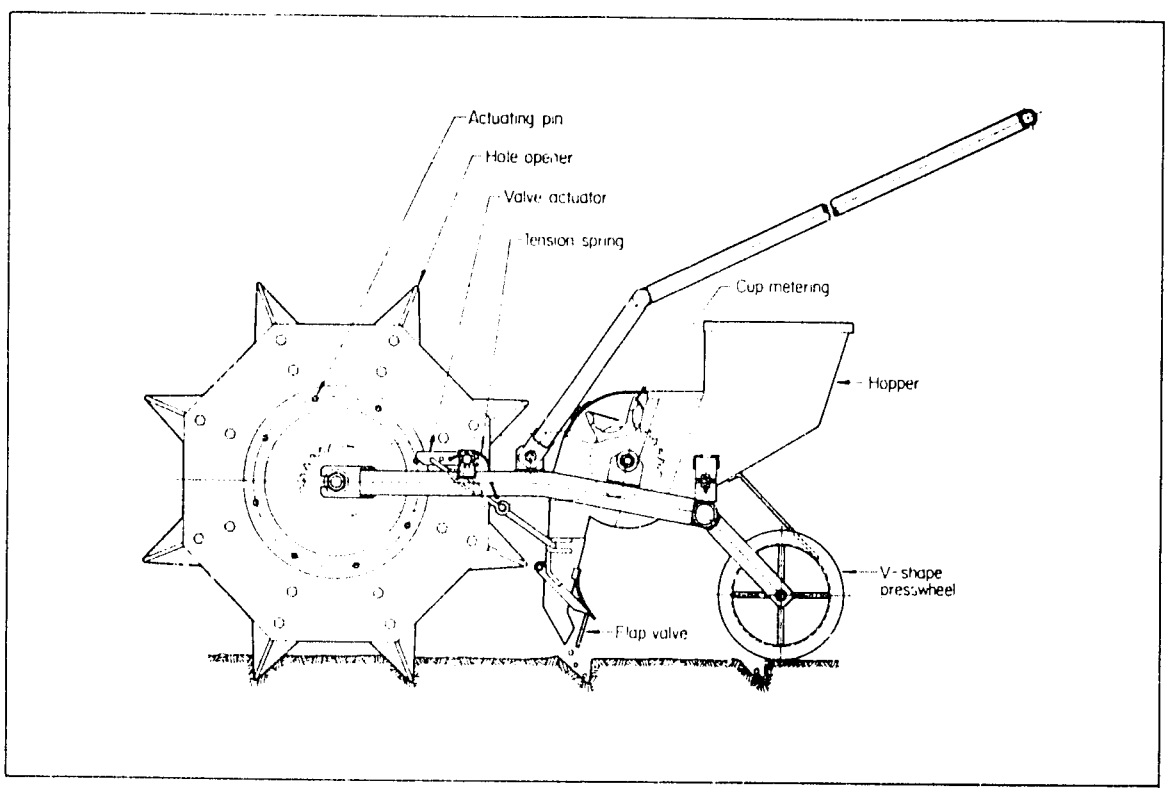
11. Plow seeder and fertilizer applicator. IRRI, 1986.



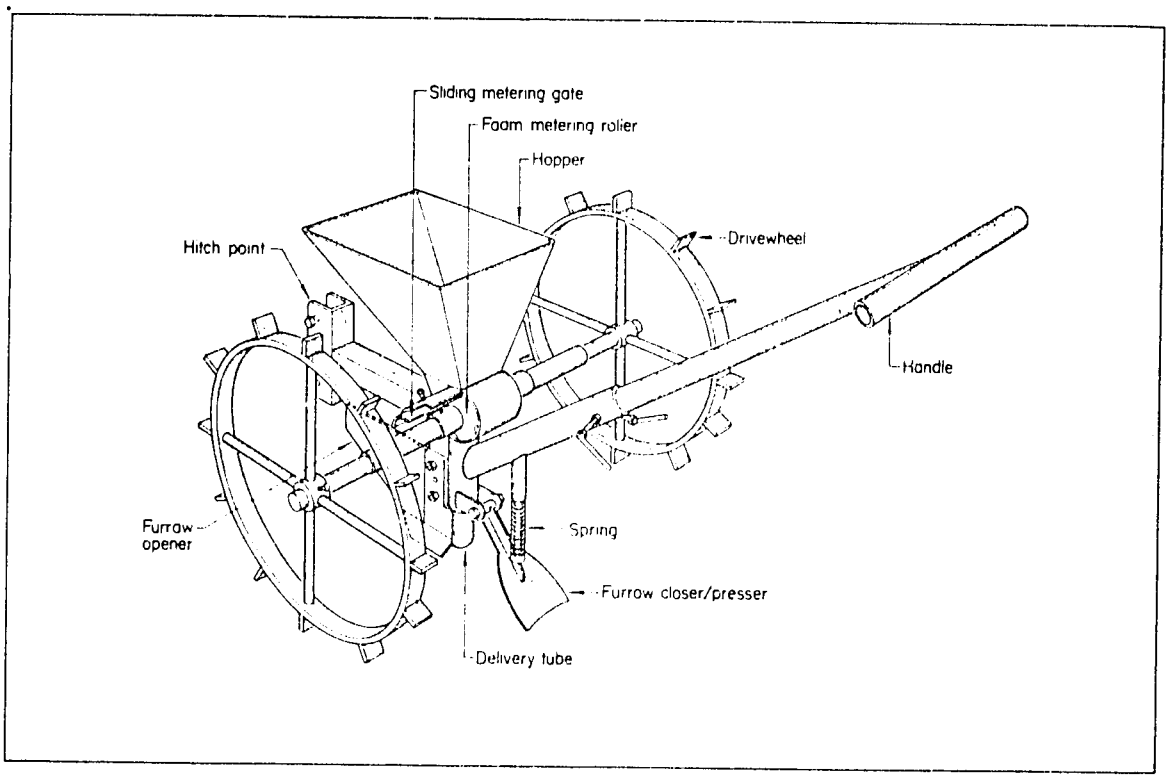
13. Seeder for relay cropping. IRRI, 1986.

the new design is the separation of the seed delivery system from the wheel on which the hole punches are mounted. Seed drop is indexed with the punched holes by an indexing mechanism to avoid clogging of the seed delivery passage.

- Seeder for relay cropping (Fig. 13). This manually operated device sows legume and maize seeds between rows of rice a few days before its harvest, when soil moisture is still available. It has a tapered disk furrow opener, a drum metering hopper, and a furrow closer.



12. Rolling dibbler planter for seeding upland crops after rice. IRRI, 1986.



14. Direct-drive animal-drawn seeder with foam metering roller. IRRI, 1986

A prototype is being tested jointly with the Physics Unit.

- Foam roller seeder (Fig. 14). This utilizes an inexpensive foam roller metering device at the bottom of a hopper containing the seeds. As the roller rotates, seeds are discharged beneath it. The machine is being developed for both animal and power tiller operation.

WEED CONTROL

Conical weeders. About 300 units of the conical weeder (Fig. 15) developed last year have been sold to farmers in Laguna, Central Luzon, and Bicol. This weeder is easier to operate than conventional rotary weeders, as it requires less than one-half the power. It is available in single- and double-row units with provision for adjusting the working width to conform to crop row spacing. Design drawings have been released to interested manufacturers through our international liaison network. A second cono weeder design was developed. It uses the existing frame structure of

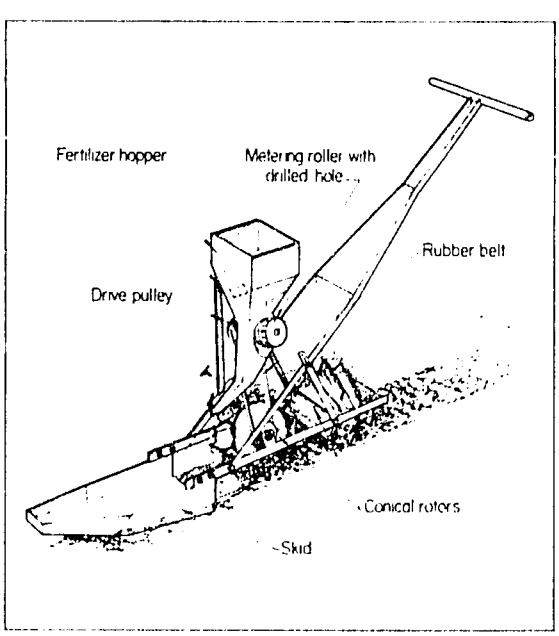
15. Conical weeder. IRRI, 1986.

conventional Japanese prototype weeders, thus facilitating production in shops that are used to producing conventional push-type weeders.

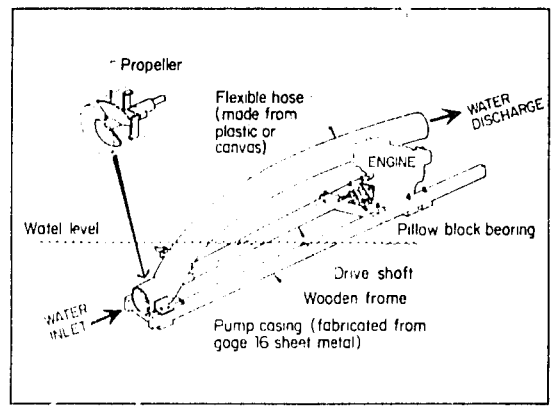
Conical weeder with fertilizer applicator. A fertilizer metering device (Fig. 16) was added to the single-row conical weeder to combine weeding and fertilizer application in one operation. A rubber belt made from a discarded tire tube drives the fertilizer metering roller. Two metering rates can be obtained by changing the orientation of the metering roller, which is provided with two different sets of metering pockets. The prototype is being tested in farmers' fields.

IRRIGATION

Simplified axial-flow pump. The MAF-IRRI Program continued to promote the low-cost *sipa* pump in the Philippines (Fig. 17). Close collaboration with local manufacturers aimed to provide designs suitable for a wide range of applications requiring different pump diameters, propeller pitch angles, and discharge columns. The manufacturers are now able to respond to customers' varying needs regarding lift, capacity, and available power source. In addition to being well received by rice farmers, the *sipa* pump has been enthusiastically



16. Conical weeder with fertilizer incorporator. IRRI, 1986.



17. Sipa pump. IRRI, 1986.

accepted for prawn production, which is one of the fastest growing agro-aqua ventures in the Philippines. Prawns are raised in brackish water; thus, the pump must be fabricated from stainless steel.

***Tapak-tapak* pump.** The *tapak-tapak* pump was developed in Bangladesh and modified by the MAF-IRRI Program for the Philippines. It is a human-powered pump having two cylinders and may be easily fabricated from sheet metal by small shops. It has been initially accepted by small farmers in a rainfed area (northwestern Luzon) where vegetables, legumes, and tobacco are frequently grown during the dry season after rice harvest. However, farmers indicated that the pump would be more acceptable if the price could be reduced below the present level of US$50-75. To reduce the cost it was decided to adapt a recent modification from Bangladesh that eliminates the pulley and minimizes materials for the framework and treadles.

POSTHARVEST EQUIPMENT

Sun-drying research. A study conducted at IRRI and in three major rice-producing regions of Luzon — the Cagayan Valley, Central Luzon, and Bicol — investigated the effects of rice layer thickness and mixing time interval on the physical qualities of sun-dried grain. Moisture content reduction with time and solar radiation intensity was measured. All rice samples were dried to 13-14% moisture content (wet basis) and then milled.

At the 5% level of significance, both thickness and mixing interval affected total milling recovery,

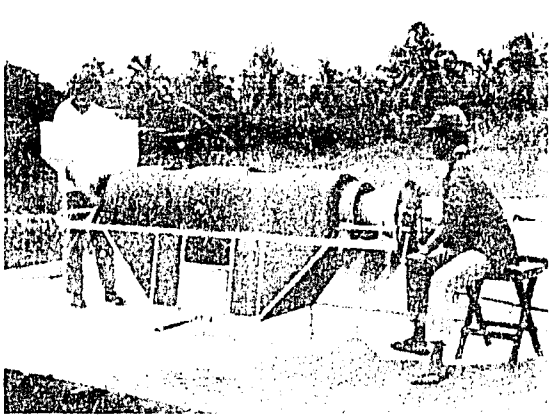
head rice recovery, and uniformity of moisture content after drying. Total milling recovery of 69-70% and head rice recovery of 88-90% (based on the milled sample) were attained at a thickness of 2-4 cm and a mixing time interval of 30 min. Frequent mixing resulted in more uniform moisture content after drying. Uniformity of moisture content decreased when thickness was increased.

Multicrop predryers. The batch-type rotary dryer (Annual report for 1985) was modified into a continuous flow-type (Fig. 18) to increase its capacity and efficiency.

The dryer operates by conduction and is designed for rapid, high-temperature drying. The grains come in contact with the hot drum surface as they traverse the drum from the feed hopper to the discharge section.

The drum is made of an ordinary oil drum or rolled sheet metal mounted on two pairs of ring supports and rollers. Baffles are provided inside the drum at critical angles and intervals to ensure proper control of the flow rate.

A rice straw-mud plaster is used as insulation for the drum and the furnace for higher heat utilization efficiency. The drive mechanism consists of a bicycle chain and sprocket that can be operated manually or connected to a variable-speed electric motor. The dryer is simple to operate and maintain, and requires minimal machining of parts, making it affordable.



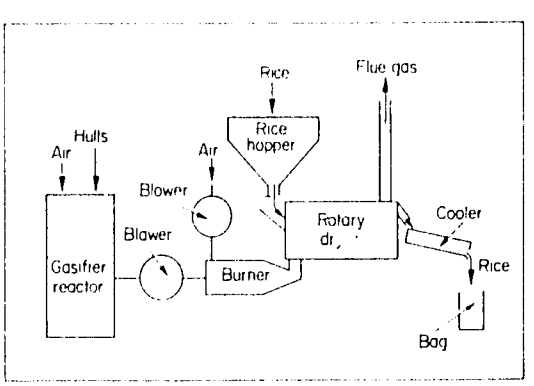
18. The continuous flow-type rotary drum predryer for rapid, high-temperature drying of high-moisture grains and other crops. IRRI, 1986.

The dryer has a continuous throughput capacity of 500 kg/h with moisture reduction of 3-5%/pass, depending on initial moisture content. The retention time of the material inside the dryer can be regulated by varying the inclination of the drum.

It is recommended to add a cooling section after the dryer to hasten the drying rate and to allow the material to cool from 60 to 30 °C before bagging. Predried materials can be dried further using mechanical dryers or by sun-drying on a later day without fear of deterioration. Milling tests of predried rice showed consistently high recovery compared with shade-dried or sun-dried samples. The dryer also works for maize, peanut, and other grains.

Rotary rice dryer with rice hull gasifier. The MAF-IRRI Program, in collaboration with local manufacturers and a rice miller, continued testing and improving a rotary dryer for partial drying of rice in areas where clouds and rain delay sun-drying and thereby lead to deterioration of grain quality. Three types of rice hull furnaces were tested. The best was a simple gasifier based on a Chinese design and modified by the University of California at Davis. Gas produced by rice hull gasification is burned to obtain hot flue gases for heating the dryer (Fig. 19). The flue gases pass through a gap between the rotating cylinder and the stationary shell around the dryer. The rotating cylinder has longitudinal vanes and is slightly tilted to provide axial movement to the rice. A vibrating screen with a blower cools the rice so that it may be directly bagged.

Results obtained with a prototype unit demonstrated that freshly harvested rice may be dried to



19. Rotary dryer with gasifier. IRRI, 1986.

17-19% moisture content in a single pass through the dryer, requiring only about 100 s. The rice leaves the dryer at a temperature of 80-90 °C but is cooled to about 40 °C before being bagged. The prototype's capacity is about 1 t/h, and its estimated price is US$3,000-4,000. The size of the system may be adjusted to give higher or lower capacities, according to users' preferences. Both the dryer and the reactor are easily fabricated from sheet metal, using tools and techniques readily available in small- and medium-scale metalcraft shops throughout the Philippines. IRRI economists and engineers are collaborating to determine the economic viability of the dryer.

Pliers-type moisture and hardness tester. Ordinary pliers were modified to be used as a moisture-hardness sensing device (Fig. 20) for individual grains. The device is connected to a resistance-type moisture meter and an oscillograph, which show a record of the determinations.

Simultaneous measurement of grain moisture and hardness is accomplished by placing a single kernel between the tips of the jaws and crushing it. The moisture content is measured by the electrodes mounted on the jaws and is read through the moisture meter digital display. Hardness is measured by a strain gage bonded to the jaw surface. When the grain is being crushed, the strain developed on the jaws is monitored through a strain amplifier and recorded on an oscillograph. An optional computerized measurement can be obtained using a microcomputer with analog port.

The device finds practical application in field or laboratory measurements of individual kernels and has a high degree of accuracy within a wide range of moisture content. It will be useful in recording data needed by plant breeders, plant physiologists, and agricultural processing engineers.

20. The pliers-type moisture and hardness tester for individual grains, suitable for field and laboratory determinations. IRRI, 1986.

INDUSTRIAL EXTENSION

In the Philippines, four major projects were accomplished during the year under the MAF-IRRI Program. The IRRI reaper, threshers, and transplanter were introduced in India under the Central Institute of Agricultural Engineering-IRRI Program. In Bangladesh, assistance was provided to the Bangladesh Rice Research Institute in modifying the PT-3 power tiller with a rotary tiller attachment to suit local conditions. Various IRRI machines were introduced in Madagascar. See the section on Cooperative Country Projects for more details.

Training programs

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The Institute offers a variety of research training and educational programs designed to meet the needs of various levels of scientific personnel. The programs constitute a primary linkage to the international research network that complements IRRI's global research programs. Through its training and professional advancement programs, IRRI has helped to develop a cadre of about 5,000 well-trained research scientists from more than 75 countries all over the world.

RESEARCH-ORIENTED PROGRAMS

Visiting scientists and postdoctoral scientists. IRRI's visiting scientist and postdoctoral scientist program serves as a reorientation for senior scientists of national research organizations and agricultural universities from developing countries to learn new research methodologies and pursue in-depth research on production- and research-related problems. The studies they undertake are related to the research programs of both their respective countries and IRRI.

The visiting scientists work together with IRRI scientists, using modern facilities and equipment, then return to their organizations, enriched by their intensive and extensive research experience at IRRI. They continue to serve as important links between IRRI and national programs all over the world.

In the selection of candidates, major consideration is given to their affiliation with research or educational institutions associated with rice and rice-based farming systems. All of them come from developing countries. Occasionally, IRRI selects candidates who are not associated with national organizations but possess research expertise complementary to that of the IRRI scientific staff.

During 1986, there were 17 visiting scientists from India, the Philippines, Thailand, and Sri Lanka; and 28 postdoctoral scientists from 10 countries in Asia, Africa, and Latin America (Table 1, 2). Eighteen completed their fellowships during the year.

Collaborative research scientists and fellows. IRRI has collaborative research programs with research laboratories and agricultural universities in developed countries with which it pursues special projects. Normally, these projects are funded by a sponsor with provisions for young scientists to spend 1-2 yr at IRRI to conduct parts of the overall research program. These scientists maintain their grants while at IRRI, and IRRI provides them research facilities and laboratory space.

Funding organizations and research laboratories in developed countries also sponsor research fellowships for candidates from developing countries. These candidates are accepted in line with existing collaboration between IRRI and the sponsoring agencies.

During the year, there were 11 collaborative research scientists from Europe, 10 from Asia, and 2 from Africa. Ten of them completed their fellowships during the year (Table 1, 2).

Degree scholars and fellows. For middle-level rice research scientists, IRRI offers degree training programs at the MS and Ph D levels to prepare them for responsibilities in research and management operations. To facilitate the implementation of its graduate education program, the institute has collaborative graduate programs with about 30 agricultural universities all over the world. The scholars complete their course requirements at these universities and later come to IRRI to conduct their thesis and dissertation research. IRRI scientists are officially appointed affiliate members of the graduate faculties of the respective universities and serve as chairmen, cochairmen, or members of the graduate advisory committees of the scholars and fellows in accordance with the rules and regulations of the home universities.

In the selection of candidates, priority is given to candidates of organizations that have collaborative agreements with IRRI. A small number of nominees of other organizations in developing countries that are major rice producers are also accepted, depending on the availability of space and resources. Candidates who intend to work on research topics that are directly related to the research programs of IRRI are given preference.

During 1986, 69 Ph D students and 85 MS students were in residence at IRRI (Table 1, 2). Of these, 35 completed their degree requirements during the year.

Among the degree candidates, 32 Ph D students and 19 MS students were nominated by their university professors to pursue their dissertation or

Table 1. Visiting scientists, postdoctoral scientists, collaborative research scientists and fellows, research fellows, and research scholars by region and country. IRRI, 1966.

Country	Visiting scientists	Postdoctoral scientists	Collaborative research scientists and fellows	Ph D fellows	MS scholars	Nondegree	Total
			Asia				
India	9	12	3	11	1	–	36
China	–	–	2	7	18	4	31
Bangladesh	–	2	–	9	15	2	28
Philippines	4	6	–	6	7	1	24
Thailand	2	1	1	5	11	2	22
Burma	–	–	–	–	11	2	13
Vietnam	–	–	3	1	2	5	11
Korea, Republic of	–	–	1	7	1	1	10
Pakistan	–	1	–	3	3	2	9
Nepal	–	–	–	5	1	–	6
Sri Lanka	2	–	–	1	–	3	6
Indonesia	–	1	–	2	–	2	5
Japan	–	2	–	2	–	–	4
Bhutan	–	–	–	–	1	–	1
Iran	–	–	–	–	1	–	1
Taiwan, China	–	–	–	1	–	–	1
Subtotal	17	25	10	60	72	24	208
			Africa				
Ghana	–	1	1	–	1	–	3
Sierra Leone	–	–	–	1	1	–	2
Tanzania	–	–	–	1	–	–	1
Somalia	–	–	–	–	–	1	1
Zaire	–	1	–	–	–	–	1
Egypt	–	–	1	–	–	–	1
Kenya	–	–	–	–	1	–	1
Madagascar	–	–	–	–	–	1	1
Nigeria	–	–	–	–	–	1	1
Subtotal	–	2	2	2	3	3	12
			North America				
United States	–	–	–	2	–	–	2
Canada	–	–	–	1	1	–	2
Subtotal	–	–	–	3	1	–	4
			Latin America				
Brazil	–	–	–	–	1	–	1
Cuba	–	–	–	–	–	1	1
Mexico	–	1	–	–	2	–	3
Guyana	–	–	–	–	1	–	1
Subtotal	–	1	–	–	4	1	6
			Europe				
United Kingdom	–	–	3	–	–	–	3
Belgium	–	–	1	–	–	–	1
Germany, Federal Republic of	–	–	4	3	–	–	7
Netherlands	–	–	2	–	5	–	7
Switzerland	–	–	1	–	–	–	1
Subtotal	–	–	11	3	5	–	19
			Oceania				
Australia	–	–	–	1	–	–	1
Total	17	28	23	69	85	28	250

Table 2. Visiting scientists, postdoctoral scientists, collaborative research scientists and fellows, research fellows, and research scholars by research department, IRRI, 1986.

Department	Visiting scientists	Postdoctoral scientists	Collaborative research scientists and fellows	Ph D fellows	MS scholars	Nondegree	Total
Plant Breeding	1	3	4	13	13	1	35
Plant Pathology	3	1	2	10	9	7	32
Plant Physiology	3	4	2	5	4	6	24
Entomology	1	1	3	6	8	3	22
Agronomy	–	3	2	7	7	1	20
Agricultural Economics	1	1	1	6	8	1	18
Multiple Cropping	2	2	2	2	5	2	15
Rice Farming Systems Program	2	2	–	7	1	1	13
Soils	2	2	3	2	3	–	12
Soil Microbiology	–	3	3	3	2	1	12
International Rice Germplasm Center	1	–	1	–	4	2	8
Agricultural Engineering	–	1	–	–	6	–	7
Water Management	–	1	–	2	4	–	7
Statistics	–	2	–	1	2	–	5
International Rice Testing Program	1	1		2	–	–	4
Training and Technology Transfer	–	–	–	2	2	1	5
Cereal Chemistry	–	1	–	–	1	1	3
Communication and Publications	–	–	–	–	1	–	1
Library and Documentation	–	–	–	–	–	1	1
Others	–	–	–	1[a]	5[b]	–	6
Total	17	28	23	69	85	28	250

[a]Affiliated with Training and Technology Transfer Department. [b]Affiliated with Agricultural Economics, Agricultural Engineering, and Entomology Departments.

thesis research at IRRI after completing their course requirements at their universities (Table 3).

The linkages among agricultural universities, ministries of agriculture, and IRRI in support of the institute's degree programs not only have strengthened institutional collaboration among these agencies but also have focused greater attention on national problems as the subject of student research.

During the year, IRRI formalized agreements with seven agricultural universities: Zhejiang Agricultural University, China; Chonnam National University, Republic of Korea; Thammasat University, Thailand; Sokoine University of Agriculture, Tanzania; Universidad Sokonoma de Nueva Leon, Mexico; Universidade de São Paulo, Brazil; and Louisiana State University, United States.

The agreement with Universiti Pertanian Malaysia, originally established in 1981, was renewed for another 5 yr. A new graduate training program was initiated among the Bangladesh Rice Research Institute (BRRI), IRRI, and the Bangladesh Agricultural University (BAU), emphasizing farming systems. The scholars will complete their course requirements at IRRI and conduct research at BRRI, IRRI, or both locations.

Research and nondegree fellows. In response to requests from national programs, the Institute offers apprenticeship-type training for middle-level research personnel to develop their skills in research instrumentation, methodology, and other research support services such as computer management, library and documentation, and farm management operations.

During the year, 28 individuals completed this training program at IRRI (Table 1, 2).

REGULAR NONDEGREE PROGRAMS

Regular courses are offered every year. In 1986, IRRI offered 11 regular courses (see following descriptions and Table 4), 1 of which was new. The courses are highly oriented to research method-

Table 3. Ph D and MS students conducting dissertation or thesis research at IRRI, by country and university, 1986.

Institution	Ph D	MS	Total
Philippines			
University of the Philippines at Los Banos	5	9	14
University of the Philippines, Diliman	2	–	2
Visayas State College of Agriculture	–	1	1
Central Luzon State University	–	1	1
India			
Indian Agricultural Research Institute	7	–	7
Andhra Pradesh Agricultural University	2	–	2
Jawaharlal Nehru Krisni Vishwa Vidyalaya	2	–	2
University of Madras	1	–	1
Korea, Republic of			
Chonnam National University	1	–	1
Kyungpook National University	1	–	1
Japan			
Kyushu University	1	–	1
University of Tsukuba	1	–	1
Sri Lanka			
Post Graduate Institute of Agriculture	–	1	1
Vietnam			
Cantho University	–	1	1
Indonesia			
University of Gadjah Mada	1	–	1
United States			
Cornell University	2	–	2
Kentucky University	1	–	1
University of California, Berkeley	1	–	1
University of California, Davis	1	–	1
Germany, Federal Republic of			
Justus-Liebig University	1	–	1
Tropinstitut Phytopathology und Anguw Entymologie	1	–	1
University of Giessen	1	–	1
Netherlands			
Agricultural University, Wageningen	–	5	5
Canada			
McGill University	–	1	1
Total	32	19	51

ology and production. Half of the time is spent in lectures on basic aspects and half in the field and laboratories working on practical problems.

Agricultural Engineering (AEC). This 3-wk course was initiated in 1975 to complement IRRI's on-farm machinery development work. 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. Participants attend lectures and do field and practical work on the assembly of the machines to develop competence in their operation and maintenance. The 2 sessions in 1986 were attended by 31 trainees.

Cropping Systems Training Program (CSTP). In addition to increasing yields, increasing cropping intensity is another method to produce additional economic benefits. An intensive, diversified multiple cropping program is also advantageous in circumventing the single-crop risk factor and generating additional commodity markets. For over 10 yr, CSTP has developed human resources proficient in developing new rice-based cropping patterns and component technologies. In

Table 4. Participants in regular nondegree training courses[a] by region and country, IRRI, 1986.

Country	Participants (no.)													
	AEC		CSTP	EdPub		FSSR	GEU	IPM	INSFFER	IWM	SPCAAR	T3C[b]	WS	Total
	I	II		I	II									
Africa														
Ethiopia					1									1
Liberia				1										1
Madagascar	1		1			2	2	2	2					10
Mauritania										1				1
Nigeria		1			1									2
Tanzania					1			2		1				4
Asia														
Bangladesh		1	2	3		1				2				9
Bhutan		2										5		7
Burma												4		4
China	1	1	2	1	1	4	3	3	4		1		1	22
India	3	4	3		1	2	3	1	2	2	1			22
Indonesia			1	2		4	2				2	4	1	16
Korea			1					1			1			3
Malaysia			1	1					1	1	1			5
Nepal	1		1					3		3	1			9
Pakistan			1											1
Philippines	1	5	4	1	1	3	1		2	4	1		2	25
Sri Lanka	2	2	1			4		3				2	1	13
Thailand	1	1	5			1	1	1	2	2	3		1	18
Vietnam		1	1	1	1	4	2	2	2	1	1			16
Latin America and Caribbean														
Barbados					1									1
Chile	1													1
Cuba							1		1					2
Jamaica								1						1
Mexico		1								1				2
Surinam						1								1
Others														
Fiji	1													1
Iran	1						1							2
Papua New Guinea					1									1
Total	13	18	24	10	9	26	16	19	16	18	12	15	6	203

[a]AEC = Agricultural Engineering Course, CSTP = Cropping Systems Training Program, EdPub = Editing and Publication, FSSR = Farming Systems Socioeconomic Research, GEU = Genetic Evaluation and Utilization, INSFFER = International Network on Soil Fertility and Fertilizer Evaluation for Rice, IPM = Integrated Pest Management, IWM = Irrigation Water Management, SPCAAR = Statistical Procedures and Computer Applications in Agricultural Research, T3C = Training and Technology Transfer Course, WS = Weed Science. [b]New in 1986.

1986, a 2-wk component on research management was introduced in collaboration with the Research Management Center of the University of the Philippines at Los Baños (UPLB). Another modification to this course was the increase in interaction time among trainees, farmers, and extension workers through an expansion of the field practical component. The course was attended by 24 trainees from 13 countries.

Editing and Publication (EdPub). Two sessions were given, involving 19 trainees from 13 countries in the Caribbean, Africa, Asia, and Oceania. Teaching materials were refined, and the course was successfully compressed from 16 to 14 wk. Emphasis continued on problem-solving and practical projects in editing, design, illustration, and production of both scientific reports and more general publications popularizing scientific results. An alumni newsletter was initiated as a classroom exercise and to encourage an international network of graduates. The course is designed to be adopted by national programs, adapted to local needs, and given in national languages; the first experiment along these lines was given in November by the Central Research Institute for Food Crops in Bogor, Indonesia, a 3-wk course in Bahasa Indonesia; two more courses there will follow in 1987, all funded by the International Development Research Centre (IDRC) of Canada.

Farming Systems Socioeconomic Research (FSSR). On-farm research with a farming systems perspective is an efficient tool for designing agricultural technology and adapting it to small farmers' conditions. This course also integrates humanistic or social science aspects of the small farmers' circumstances in evaluating the suitability of new agricultural technology. It emphasizes on-farm research but also covers methodologies for economic evaluation of research station experiments and assessment of the broader impact of increased agricultural productivity. The course was attended by 26 trainees.

Genetic Evaluation and Utilization (GEU). The skill-oriented GEU training course is intended for young, dedicated, and enthusiastic agricultural scientists from the rice-growing countries of the world who are either involved or expected to become actively involved in rice germplasm improvement efforts in their countries. The training course complements IRRI's GEU program. During 1986, the 17th course since 1975 was offered, with 16 participants from 9 countries. The trainees were given a general orientation to the GEU-related activities of the IRRI research departments. They studied the different GEU problem areas, learned the screening techniques used by GEU scientists, and observed entries in different nurseries. Based on their countries' breeding goals, they produced F_1 seeds that, along with requested seeds of different cultivars, they took home for further evaluation and utilization. Each of them conducted a special project under the guidance of a GEU scientist and presented the results in a seminar.

Integrated Pest Management (IPM). A major cost in rice production is often incurred by reliance on chemical tactics for pest protection. The IPM course promulgates the integration of 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. In 1986, 19 trainees attended the course.

International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER). In rice production, inorganic fertilizers as well as biofertilizers generally constitute a major input expenditure. Therefore, the INSFFER course encompasses the concepts in related sciences that explain the differences in crop response to soil fertility and fertilizer. The course also emphasizes integrated nutrient management through the proper combination of organic and inorganic fertilizers, and considers cropping systems. Practical and theoretical training focus on scientific experimentation, site characterization, soil fertility and fertilizers, biological N_2 fixation, and data analysis and interpretation. The 1986 INSFFER training course was attended by 16 participants representing 13 organizations in 8 countries.

Irrigation Water Management (IWM). Water in the right amount at the right time is an important requirement for producing high yields and subsequent economic gains. This course enhances the engineering, agronomic, economic, socio-institutional, and communication knowledge and skills

associated with sound irrigation development and management. This 6-wk course was attended by 18 trainees in 1986.

Statistical Procedures and Computer Applications in Agricultural Research (SPCAAR). This 2-mo course familiarizes participants with the use of the microcomputer and appropriate software for conducting statistical analyses and managing agricultural research data. In addition, it updates the trainees on new statistical procedures and techniques with application to agricultural research. The course was attended by 12 trainees.

Training and Technology Transfer (T3C). National programs need to transfer information and technology to the end user, be it the researcher, extension agent, or farmer. One major form of assisting national programs to meet this need is to develop proficiency in the training and subsequent technology transfer process. This new 12-wk course was designed for professionals employed in training or technology transfer programs and addresses the latest concepts and skills utilized in developing human resources and disseminating technology. The course was taught twice: a regular course was attended by 15 trainees composing training teams from Bhutan, Burma, Indonesia, and Sri Lanka; and a special course was held for training teams associated with FSSR (see T3C-FSSR under Special Courses).

Weed Science (WS). The second 10-wk rice weed science training course in 1986 was attended by 6 trainees. It covered all aspects of weed control in rice. Emphasis was placed on the integration of weed control practices to ensure maximum weed control, economic stability, and environmental protection. The course had been classified as a special course in 1985 but was included among the regular courses in 1986. It will be offered biennially.

SPECIAL COURSES

Special courses are offered on an ad hoc basis. The following were given in 1986 (see Table 5).

Cowpea-Soybean Production (Cow-Soy). The International Institute of Tropical Agriculture and the United Nations Development Programme, in collaboration with IRRI, the Department of Agriculture of Thailand, and the University of Khon Kaen, Thailand, conducted the 6-wk course in Khon Kaen. It was designed for research workers assigned to cowpea and soybean improvement programs, extension supervisors, and specialists responsible for testing of new improved lines of these crops in Asian countries. Sixteen trainees attended.

Cropping Systems On-the-Job Training (CSOJT). Three courses associated with the cropping systems program were offered. The 4-wk Insect Management (IM) course exposed 2 trainees to current rice insect research at IRRI and to cropping systems outreach research. The 18-wk Legume Varietal Improvement for Rice-Based Cropping Systems (LVI) course, conducted in cooperation with the Institute of Plant Breeding of UPLB, focused on techniques for varietal improvement of upland crops; the course, attended by four trainees, culminated in an observational tour in Thailand. The 4-wk Varietal Testing of Upland Crops for Intensive Rice Farming Systems (VT) course provided 12 participants with actual experience in the techniques of testing upland crop cultivars for rice-based farming systems.

Farm Management (FM). The 2-wk course, designed primarily for farm and research station managers, covered several aspects of farm management such as farm machinery, labor distribution, control of crop pests, rice production, seed multiplication, lowland and upland irrigation, postharvest management, and care and maintenance of the experiment station. Six trainees attended.

Genetic Resources Conservation and Management (GRCM). Lasting from Oct 1985 to Sep 1986, this was the first training course on crop genetic resources to combine scientific principles with hands-on practice. The course consisted of 4 components: 1) field collection by trainees in their home countries, 2) the 2-wk training on rice production, 3) the 3 1/2-mo GEU course, and 4) 5 mo of lectures and practicals on genebank operations and management. The field planting, characterization, documentation, and storage of seeds collected in the participants' home countries were a special feature of the course. Twelve participants from eight Asian and two African nations participated in the course. They received the diploma of Associateship of IRRI in Genetic Resources Conservation and Management, the first ever conferred by the institute.

Table 5. Participants in special nondegree training courses,[a] by country. IRRI, 1986.

Country	Participants (no.)															
	Cow-Soy	CSOJT			FM	GRCM	MonSus	PTR	SASRP	T3CFSSR	DWRPMM	VDD	Others			Total
		IM	LVI	VT									RSPT	GO	REF	
Africa																
Ethiopia						1										1
Ghana						1										1
Asia																
Bangladesh	1			2				1								4
Burma			2			1										3
China				2		2	1	1						6	3	15
India	2					2		1	8		12					25
Indonesia			1	1	2	1		1	4	5						15
Malaysia						1			4							5
Nepal	2															2
Pakistan				1				1								2
Philippines	2			2		1		1	8	3						17
Sri Lanka	2	1		1	4	1		2	4			1				16
Thailand	7	1	1	3				2	4	3		1				22
Vietnam						1	1	1					2			5
Others																
Asian Development Bank								1								1
Italy								1								1
Total	16	2	4	12	6	12	2	13	32	11	12	2	2	6	3	135

[a]Cow-Soy = Cowpea-Soybean Production, CSOJT = Cropping Systems On-the-Job Training, IM = Insect Management, LVI = Legume Varietal Improvement for Rice-Based Cropping Systems, VT = Varietal Testing of Upland Crops for Intensive Rice Farming Systems, FM = Farm Management, GRCM = Genetic Resources Conservation and Management, MonSus = Monitoring Susceptibility Levels of Rice Pests to Insecticides, PTR = Prosperity Through Rice, SASRP = Systems Analysis and Simulation for Rice Production, T3CFSSR = Training for FSSR In-country Trainers, DWRPMM = Deepwater Rice Pest Management Methods, VDD = Virus Disease Diagnosis, RSPT = Rice Seed Production and Testing, GO = Genebank Operations, REF = Refrigeration Engineering Course.

Monitoring Susceptibility Levels of Rice Pests to Insecticides (MonSus). The Food and Agriculture Organization (FAO), Sri Lanka, India, Bangladesh, Thailand, Vietnam, Indonesia, Malaysia, China (Beijing), Taiwan, Republic of Korea, Japan, and IRRI started this project in 1985. Data on brown planthopper, green leafhopper, and leaffolders were received from 4 countries. Two scientists (1 each from China and Vietnam) were trained at IRRI for 2 wk.

Improving Income and Employment in Rice Farming Systems or Prosperity Through Rice (PTR). The IRRI-UPLB-Asian Development Bank Prosperity Through Rice Project emphasizes improvement of rice yields at lower cost by using multiple and mixed cropping to maximize resources and returns and using the whole rice plant to augment farm income. A 2-ha farm demonstrates opportunities for maximizing income and employment for small rice farmers through an integrated farming system involving crops, livestock, fish, and rice by-products. An 11-d orientation-training program for senior planning officers of ministries of agriculture enabled them to replicate in their own countries demonstration farms along the concept of Prosperity Through Rice. The course was composed of lectures, field demonstrations, and field trips and covered 1) basic plant, soil, water, air, and sunlight resources and their relation to production; 2) management of factors of production; 3) design of rice farming systems based on consideration of ecology, economics, and employment generation; 4) harvesting and postharvest processing; 5) biomass utilization; and 6) project management and implementation. In 1986, 13 participants attended the course.

Systems Analysis and Simulation for Rice Production (SASRP). In a cooperative effort of the Centre for Agrobiological Research and the Department for Theoretical Production Ecology of the Agricultural University, Wageningen, Netherlands, and IRRI, a special course was prepared to train small interdisciplinary teams from agricultural universities and research institutes in Asian countries in systems analysis and crop growth simulation. The aim of the course was to increase the applicability of scientific knowledge to different environments and particularly to the more complex environment of rice production. The initial part, lasting 8 wk, was held in Wageningen, and was attended by 8 teams of 4 persons from India (2 teams), Indonesia, Malaysia, Philippines, Sri Lanka, Thailand, and IRRI. The core of the course consisted of the modeling of central issues concerning crop growth, climate, soil water, pests, and diseases, including their interactions. A case study was formulated by each team to apply the new skills to relevant problems in their own research. Nine months were needed for subsequent modeling and interdisciplinary experimental activities. Teams were given a personal computer to execute their simulations effectively.

Training for FSSR In-Country Trainors (T3CFSSR). IRRI is now moving to transfer not only technology but also training expertise to national programs. The FSSR training course has been offered yearly since 1981 at IRRI. It is realized that it will considerably increase the pace, quality, and relevance of training socioeconomic workers in national farming systems programs if the national programs acquire the capability to conduct the training course for their own workers. Therefore, this 8-wk course, attended by 11 trainees, aimed to develop a corps of in-country trainors in FSSR and subsequently transfer training expertise in FSSR to national programs.

Deepwater Rice Pest Management Methods (DWRPMM). This 1-wk course, jointly organized by IRRI, the Government of India, and the Government of West Bengal, was held at the Ramakrishna Mission, Narendrapur, Calcutta. It trained entomologists, plant pathologists, and agronomists from five Indian states in methods of pest management in deeply flooded ricefields.

Virus Disease Diagnosis (VDD). This 14-wk course provided 2 participants practical experience in applying serology and other diagnostic techniques for virus epidemiology and resistance research.

Others. In response to requests of international funding agencies, IRRI conducted courses that addressed the specific needs of national organizations in developing their human resources. A 4-mo course on Rice Seed Production and Testing

(RSPT) was conducted for 2 Vietnamese at the request of FAO. A total of 9 Chinese workers for the new Chinese genebank in Beijing were given special training under the Rockefeller Foundation Project: 6 technicians underwent a 4-wk course on Genebank Operations (GO) supervised by the International Rice Germplasm Center, and 3 engineers attended an 8-wk course on Refrigeration Engineering (REF) at the Technological University of the Philippines, ending with a 2-wk session in Genebank Operations and Maintenance Training at IRRI.

INSTRUCTIONAL RESOURCES

The generation of courseware that documents content information in the form of self-learning materials has intensified. Manuals of performance objectives are being produced for each nondegree course. A series of pictorial booklets portraying field and laboratory skills in rice production and evaluation and use of genetic resources has been made available. Slide-tape programs in rice production, cropping systems, and socioeconomic research for farming systems are in various stages of production.

A project sponsored by IDRC and a donation by Hewlett-Packard have provided resources to develop databases specifically for training, using the computer as a storage and retrieval device.

A computer management program is being constructed to assist in the management of personnel, programs, finances, and correspondence inherent in administering training programs.

ACADEMIC COUNCIL

The IRRI Academic Council met on 19 Feb and 27 Aug in 1986. It welcomed a new member, Vice Chancellor G.R.V. Mmari of the Sokoine University of Agriculture, Tanzania.

The Council endorsed a proposal to IDRC to develop microcomputer-based instructional materials for nondegree training. It lauded the offering of the first international course on azolla in China in April 1987.

VISITING SCIENTISTS, POSTDOCTORAL SCIENTISTS, RESEARCH SCHOLARS, AND RESEARCH FELLOWS WHO COMPLETED TRAINING IN 1986

An asterisk (*) indicates completion of the M. degree and two asterisks (**) the Ph D degre during the year.

Agricultural Economics

Mubarik Ali**. Pakistan. Research fellow. Th determinants of inefficiency in Basmati ric production in Pakistan Punjab: frontier prof function approach.

S. B. Mathema**. Nepal. Research fellow. Adop tion and effects of technologies generated b the cropping systems program in Nepal.

T. Jatileksono**. Indonesia. Research fellow Equity implication of technology changes i the Indonesian rice economy.

E. J. van Aart*. The Netherlands. Researc scholar. Progress in rice technology in a unchanging institutional framework: a geo graphical and historical comparison betwee two neighboring villages in Iloilo, Philippines

Taufiqul Arif*. Bangladesh. Research scholar Dynamics of farm-level irrigation manage ment; the effects on resource use efficiency labor employment and income distribution i Northwest Bangladesh.

M. L. Bobbink*. The Netherlands. Researc scholar. The organizational difficulties of tubewell irrigators' association in Nueva Ecija Philippines.

Els M. M. Hart*. The Netherlands. Researc scholar. Progress in rice technology in a unchanging institutional framework: a geo graphical and historical comparison betwee two neighboring villages in Iloilo, Philippines

Zhang Linxiu*. China. Research scholar. A economic analysis of rice-based croppin systems in Southern Jiangsu Province, China

Agricultural Engineering

Thanya Kiatiwat*. Thailand. Research scholar Determination of optimum design parameter of the IRRI-designed axial-flow fan.

Zhang Luhong*. China. Research scholar. Forc analysis of corn kernel detachment.

Bibiano Ramos*. Philippines. Research scholar. Power requirement of the axial-flow thresher.

U Than Shein*. Burma. Research scholar. Evaluation of the different metering devices for multicrop seeding.

Agronomy

A. K. Pathak. India. Postdoctoral scientist. 1. Effect of dry season tillage on *Cyperus rotundus* L. in upland rice. 2. Effect of herbicide and moisture on *Cyperus rotundus* in upland rice (*Oryza sativa*). 3. Weed growth in lowland rice under moisture stress condition.

Indira Ekanayake**. Sri Lanka. Research fellow. Water stress effects on spikelet sterility in rice at anthesis: morphophysiological aspects and mechanisms of drought tolerance.

Wang Kairong. China. Nondegree research fellow. Nitrogen nutrition and fertilizer management in lowland rice.

Cereal Chemistry

Olusola Tinu Bobade. Nigeria. Nondegree research fellow. Physicochemical properties of parboiled Nigerian rice.

Percy A. Tennakoon. Sri Lanka. Research scholar. Storage properties of parboiled rice in Sri Lanka.

Communication and Publications

Mahfuzul M. Huque**. Bangladesh. Research fellow. The effectiveness of two rice extension publications in English and Cebuano among Philippine change agents.

Entomology

Supanee Pimsamarn**. Thailand. Research fellow. Selective toxicity of some insecticides to rice hoppers and their natural enemies.

Mostak Ahmed Chowdhury. Bangladesh. Research scholar. Monitoring susceptibility levels of rice pests to insecticides.

Ma Hongsu*. China. Research scholar. Biochemical basis of resistance in rice to stem borer larvae.

Nguyen Van Huynh. Vietnam. Research scholar. Varietal resistance to insect pests.

Nguyen Thi Me. Vietnam. Research scholar. Monitoring susceptibility levels of rice pests to insecticides.

Water Management

Rolando Bello*. Philippines. Research scholar. Optimal allocation of limited irrigation water.

International Rice Germplasm Center

Liwayway M. Engle. Philippines. Visiting scientist. Served as Deputy Coordinator of the Genetic Resources Conservation and Management Training Course.

Ian Roy Denton. United Kingdom. Collaborative research scientist. Field collection of wild rices.

Le Ba Duc. Vietnam. Research scholar. Seed production technology.

Phan Van Tuong. Vietnam. Research scholar. Seed production technology.

International Rice Testing Program

Shafiul Bashar Siddique**. Bangladesh. Research fellow. Variability in seed dormancy and tolerance to accelerated ageing of seed in rice, *Oryza sativa* L.

Multiple Cropping

O. P. Meelu. India. Visiting scientist. Studies on *Sesbania rostrata*.

C. Smitobol. Thailand. Visiting scientist. Studies on tillage operations.

Andrew B. Dua. Ghana. Postdoctoral scientist. Effect of climate on rice crop phenology and yield.

Nguyen van Luat. Vietnam. Collaborative research scientist. Orientation on cropping systems program at IRRI.

Ah Mar Yi. Burma. Research scholar. Medium deepwater rice traits.

Plant Breeding

R. N. Kaw. India. Visiting scientist. Breeding for cold tolerance.

Ish Kumar. India. Postdoctoral scientist. Inheritance of amylose content in rice.

K. Govinda Raj. India. Postdoctoral scientist. Genetics of fertility restoration in rice.

Q. Song. China. Collaborative research scientist. Shuttle breeding.

R. Singh. India. Collaborative research scientist. Analysis of rice trisomics.

Jin Guo Hu**. China. Research fellow. Research on trisomics.

Quasi Azizul Haque*. Bangladesh. Research scholar. Measurement techniques and inheritance of submergence tolerance in rice (*Oryza sativa* L.).

Boniface D. Peiris**. Sri Lanka. Research fellow. Effects of types of saline composition on growth and yield of rice.

Banloo Ruangsook**. Thailand. Research fellow. Genetics of resistance to green leafhopper in some rice varieties.

Ram Kumar Sahu**. India. Research fellow. Inheritance of resistance to bacterial blight.

Jin Can Chen*. China. Research scholar. Inheritance of resistance to bacterial blight.

Zitong Lu. China. Research scholar. Shuttle breeding.

M. Mistadinata. Indonesia. Research scholar. Hybrid rice research.

Sunita Ranjhan*. India. Research scholar. Location of isozyme genes to rice chromosome through trisomic inheritance.

Ziming Wang*. China. Research scholar. Inheritance of partial resistance to blast.

Wenliu Zhang*. China. Research scholar. Morphological and genetic studies on different semidwarfs.

Plant Pathology

Serag El-Din M. Kamel. Egypt. Collaborative research scientist. Screening and testing of some rice varieties for resistance to blast.

Chuke Kenchang**. China. Research fellow. Population dynamics of *Pyricularia oryzae* Cav. in pure and mixed stands of rice varieties.

Amara Parejarearn**. Thailand. Research fellow. Evaluating tolerance of rice (*Oryza sativa* L.) varieties to ragged stunt virus.

N. Unnamalai**. India. Research fellow. Seedborne nature of *Xanthomonas campestris* pv. *oryzae*.

Joung Kuk Ahn**. Republic of Korea. Research fellow. Enhanced grain yield potential in rice.

Thomas Duve**. Germany. Research fellow. Geographical epidemiology of rice blast in Korea.

Wang Mansi. China. Nondegree research fellow. 1. Anther culture of hybrid rice. 2. Somatic embryogenesis in indica rice, wild rices and *Echinochloa glabrescens*.

Witsuda Balaveang. Thailand. Research scholar. Rice virus diagnoses.

Henneke Buill*. The Netherlands. Research scholar. Histology of bacterial leaf blight infection.

John von der Gouw*. The Netherlands. Research scholar. Evaluation of scoring methods for leaf blast.

Kithsiri Wimal Jayasena. Sri Lanka. Research scholar. Rice virus diagnoses.

Pham Van Kim. Vietnam. Research scholar. Bacterial blight and blast diseases of rice.

Khin Maung Oo. Burma. Research scholar. Studies on some important rice diseases at IRRI.

Irma Jinadarie de Zoyza. Sri Lanka. Research scholar. Disease control in cropping systems.

Plant Physiology

S. T. Mercy. India. Visiting scientist. Histological analysis of the initiation and development of androgenesis in rice using different media, growth regulators, and amino acids.

M. S. Naik. India. Visiting scientist. Role of photorespiration and dark mitochondrial respiration in net carbon assimilation in rice plants.

B. Venkateswarlu. India. Visiting scientist. Enhanced grain yield potential in rice by increasing the number of high density grains.

Junko Yamagishi. Japan. Postdoctoral scientist. Varietal differences in the maintenance of respiration.

Siranut Lamseejan. Thailand. Collaborative research scientist. Effects of radiation on callus induction, cell proliferation and plant regeneration through rice somatic cell culture.

Ana Adelfa Hernandez Lopez. Cuba. Research scholar. Nutritional status of rice plants on sheath blight.

Xian-Xiang Jiang*. China. Research scholar. Assessment of cold tolerance in rice (*Oryza sativa* L.).

Pierre Rasolofo. Madagascar. Research scholar. Screening of 181 cultivars from Madagascar for low temperature tolerance at different stages of growth.

Rice Farming Systems

Arsenio D. Calub. Philippines. Visiting scientist. Crop-livestock systems research.

Chukree Senthong. Thailand. Postdoctoral scientist. Drought resistance in soybean.

N. P. U. Kuruppu. Sri Lanka. Research scholar. Mushroom production.

Soils

Muhammed Shah. Pakistan. Visiting scientist. Effects of Ca and Na/K ratios in saline and saline-sodic soils on the growth, mineral nutrition and salt tolerance of some rices.

Virandra Pal Singh. India. Postdoctoral scientist. Screening of rice varieties and management aspects in different adverse soils.

Keith Duncan Shepherd. United Kingdom. Collaborative research scientist. Water and nitrogen balances of crops grown after rainfed upland or rainfed lowland rice.

Le Quang Xang. China. Collaborative research scientist. Management of clay soils for upland crops.

Soil Microbiology

Dhirandra Kumar Painuli. India. Postdoctoral scientist. Physical and micromorphological aspects of rice-soil puddling.

P. M. Reddy. India. Postdoctoral scientist. Studies on algal inoculation in microplot and field experiment.

Nguyen Than Dat. Vietnam. Collaborative research scientist. Practical study on research on streptomyces in the soil around rice plant (*Oryza sativa* L.) roots.

Frank Kumaga. Ghana. Collaborative research scientist. Serological diversity of potential *Sesbania* rhizobia.

Maribel Cabildo. Philippines. Research scholar. Technique of ^{15}N analysis.

Training and Technology Transfer

Ahmed Mohamed Haybe. Somalia. Research scholar. Rice production.

Md. Abdur Rashid*. Bangladesh. Research scholar. Influence of variety, seedling age and nitrogen level on the growth and yield of rice grown on saline soil.

Water Management

Rolando Bello*. Philippines. Research scholar. Optimal allocation of limited irrigation water.

PARTICIPANTS IN REGULAR COURSES

Agricultural Engineering I (AEC I)
(26 May-13 Jun 1986)

Chile
Jorge Segundo Riquelme Sanjueza
China
Shan Yu Qing

Fiji
Prakash Chand

India
Chandore Jairam Vithoba
Mahendra Prakash Sharma
Nandkishor Khandelwal

Iran
Shahram Joharchi

Madagascar
Antoine Theodore Zafera

Nepal
Haldhar Prasad Deo

Philippines
Juanito R. Alba

Sri Lanka
Wimal Padmasiri Gopaluwewa
R.M.R.N. Bandara

Thailand
Songyos Juntaramanit

Agricultural Engineering II (AEC II)
(17 Nov-5 Dec 1986)

Bangladesh
Md. Abdul Baqui

Bhutan
Thinley Wangchuk
Thomba Singh Ghalay

China
He Zhongling

India
Maruthachalam Panneer Selvan
Prafulla Chandra Senapati
T. V. Job
Anil Kumar Dutta

Mexico
Ramon Jimenez Regalado

Nigeria
Mathias Nonyelu

Philippines
William V. Contillo
Romeo F. Florestes
Jecela A. Demegillo
Nicholas Lizares
Benjamin D. Varella

Sri Lanka
Ratnayake Mudiyanselage Bandara Karunaratne
Maldeniyage Shantha Mannapperuma

Thailand
Sugree Nuntasukon

Vietnam
Phan Nhuan Thai

Cropping Systems Training Program (CSTP)
(3 Feb-27 Jun 1986)

Bangladesh
Nasiruddin Khan
Md. Gias Uddin

China
Mu Yue
Wang Xinying

India
Rajendra Prasad Awasthi
Sudhir Ranjan Baroova
Sri Arabinda Sen Gupta

Indonesia
Ahmad

Korea
Gun Woo Song

Madagascar
Rabarimandimby B. Andriantsalama

Malaysia
Wan Jusoh Bin Wan Mahmood

Nepal
Naval Kishor Yadav

Pakistan
Jamaluddin Gilal

Philippines
Roger O. Bagaforo
Romulo C. Cambaya
Salvador Z. Reburiano
Lorenzo R. Salvador

Sri Lanka
Bamanayeke Pahirannahelage Maindapala

Thailand
Apsronsawan Arwatchanakarn
Narisern Kajonpon
Penbharkkul Sitha
Chaiwat Sittibush
Tachaboon Vitat

Vietnam
Mai Van Quyen

Editing and Publication I (EdPub I)
(17 Feb-23 May 1986)

Bangladesh
Hasan Shareef Ahmed
Bimal Kanti Guha
Khandkar Md. Enamul Kabir

China
Cai Jiangfeng

Indonesia
Yuswadi
Yusmichad Yusdja

Liberia
Augustine Akotoye

Malaysia
Sumangala Pillai

Philippines
Naomi Tangonan

Vietnam
Mai The Phung

Editing and Publication II (EdPub II)
(21 Jul-23 Oct 1986)

Barbados
Violet Eudine Barriteau

China
Chen Aiguo

Ethiopia
Simeret Kinfe

India
Rajanikent M. Jantrania

Nigeria
Gabriel Thompson

Papua New Guinea
Bing Sawanga

Philippines
Demetria Cornelio

Tanzania
Mbunda Msokile

Vietnam
Tran Van Hoa

Farming Systems Socioeconomic Research (FSSR)
(13 Oct-12 Dec 1986)

Bangladesh
Md. Rais Udin Akanda

China
Erda Wang
Ya-Fu Yu
Wang Zengyuan
Quan Zhongyu

India
Mangal Sain
Ram Villas Pandey

Indonesia
Sunihardi
Syam Amiruddin
Anoesyirwan Moeins
Rante Karambe

Madagascar
Fidelis Justin Andrianilana
Abel Henri Lucien Ratovo

Philippines
Leila Pagalilauan
Perfecto Ranchez
Gregorio Sangalang

Sri Lanka
Javawardena Manatunga Mudiyanselage
Shanti Indira Miulasie Ranjinie Abeysekera
Arumugam Nadarajah
Marcus Hulangamuwa

Surinam
John Kromodimedjo

Thailand
Withaya Atipanan

Vietnam
Nguyen Vo Dinh
Bui Thi Thai
Nguyen Duy Trang
Bui Huy Tuong

Genetic Evaluation and Utilization (GEU)
(3 Feb-23 May 1986)

China
Cheng Zhen Bang
Liang Bo Wen
Zhang Xian-Guang

Cuba
Jorge Luis Hernandez Concepcion

India
Suhardan Lal Sharma
Harpal Singh
Jai Bhagwan Tomar

Indonesia
Allidawati Bambang-Surono
Sri Widowati

Iran
Masomian-Mohammad Karim

Madagascar
Velomora Bienvenue Razanandraina
Mbolarinosy Rasoafalimanana

Philippines
Sergio C. Mancao

Thailand
Ankana Leungsirorat

Vietnam
Do Khac Thinh
Le Thi Thuc

Integrated Pest Management (IPM)
(21 Jul-19 Nov 1986)

China
Deng Xiong
Shi Aoxiang
Lou Dingfeng

India
Rajesh Kumar

Jamaica
Robinson Dalton Alexander

Korea
Chung Gyoo Park

Madagascar
Andriatsimalona Rabemananjara Dodelys
Gerson David Rakotovoalavo

Nepal
Shashi Adhikari
K. B. Shrestha
A. L. Shah

Sri Lanka
E.M.W.G.D.B. Ekanayake
Walter T. Huruggamuwa
Colamba Muhandiramge Donald Dharmasena

Tanzania
Joyce Samaka Edward Shigazu
Wilbrord Mosha

Thailand
Rachanee Suvaparp

Vietnam
Dang Thi Binh
Buong Dinh Tuan

International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER)
(3 Feb-23 May 1986)

China
Zhang Qinglong
Liu Guoping
Shuxin Tu
Lin Yi Cheng

Cuba
Roberto Cabello Martinez, Jr.

India
K. Krishna Murthy
B. Roy

Madagascar
Bruno B. Andrianaivo
Aime Lala Razafinjara

Malaysia
Minhad Bin Salleh

Philippines
Teodoro R. Bersabe
Conrado Mercado

Thailand
Kripol Limsomwong
Wijai Chaiyong

Vietnam
To Thi Quy
Nguyen Thi Hoai An

Irrigation Water Management (IWM)
(25 Aug-2 Oct 1986)

Bangladesh
Bishnu Pada Halder
Md. Fazlur Rahman

India
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Statistical Procedures and Computer Applications in Agricultural Research (SPCAAR)
(31 Mar-30 May 1986)

China
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Training and Technology Transfer (T3C)
(6 Oct-12 Dec 1986)

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Dhan Bahadur Gurung
Tika Thapa
Sonam Dorji
Damber Kumar Ghalay

Burma
Daw Nwe Nwe Hla
Daw Khin Than Myint
Daw Khin San Myint
Daw Ohn Kyi

Indonesia
Suparman Hamid
Sulaiman Achmad
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Weed Science (WS)
(21 Jul-26 Sep 1986)

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Prescilla Manalang

Sri Lanka
M.M.A.S.K. Megasooriya

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Pakorn U-Thaiphun

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Cowpea-Soybean Production (Cow-Soy)
(4 Aug-10 Sep 1986)

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Cropping Systems On-the-Job Training in Insect Management (IM)
(6-31 Oct 1986)

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Cropping Systems On-the-Job Training in Legume Varietal Improvement for Rice-Based Cropping Systems (LVI)
(20 Oct 1986-20 Feb 1987)

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Cropping Systems On-the-Job Training in Varietal Testing of Upland Crops for Intensive Rice Farming Systems (OJT)
(24 Nov-19 Dec 1986)

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Farm Management (FM)
(21 Jul-1 Aug 1986)

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Genetic Resources Conservation and Management (GRCM)
(1 Oct 1985-30 Sep 1986)

Burma
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Tadesse Dadi

Ghana
Richard Akromah

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Krishan Lal Hakim
Rajendar Kumar Saxena

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Athula Somakumara Udagama Liyanage

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Monitoring Susceptibility Levels of Rice Pests to Insecticides (MonSus)
(1-11 Oct 1986)

China
Liang Tian-Xi

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Nguyen Thi Me

Improving Income and Employment in Rice Farming Systems or Prosperity Through Rice (PTR)
(20-31 Jan 1986)

Asian Development Bank
Pin Yathay

Bangladesh
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China
Fang Hui

India
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Systems Analysis and Simulation for Rice Production (SASRP)
(3 Feb-28 Mar 1986)

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Training for FSSR In-Country Trainors
(5 May-27 Jun 1986)

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R. L. Limosinero
F. R. Rañola

Thailand
P. Panomatmonton
S. Mantana
P. Duangpiboon

Deepwater Rice Pest Management Methods (DWRPMM)
(25-30 Aug 1986)

India
Y. Rathaiah
B. R. Yien
S. Mazumdar
S. Banerjee
D. Nayak
S. K. Ghosh
S. S. Prasad
S. K. S. Chauhan
G. S. Raychaudhury
A. K. Das
B. K. Maity
R. Singh

Virus Disease Diagnosis (VDD)
(Aug-Nov 1986)

Sri Lanka
Jayasena

Thailand
Witchuda Balaveang

Rice Seed Production and Testing (RSPT)
(Jan-Apr 1986)

Vietnam
Le Ba Duc
Phan Van Tuong

Genebank Operations (GO)
(24 Feb-19 Apr 1986)

China
Junkai Zhao
Weigao Hou
Feng Liang
Zhen Chen
Fengqiu Liu
Congshu Cui

Refrigeration Engineering (REF)
(24 Feb-24 Mar 1986)

China
Zhenhua Tao
Jian Wang
Xing Hai

Cooperative programs

International Rice Testing Program

International Rice Testing Program

1985 NURSERY RESULTS 528
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The International Rice Testing Program (IRTP), established with funding from the United Nations Development Programme for the worldwide exchange and evaluation of elite genetic materials, completed its 11th year of activity in 1986. The following sections summarize 1) the results of the 1985 nurseries, for which data were received in 1986 (detailed results published separately in the IRTP annual nursery reports), and 2) the activities in 1986.

1985 NURSERY RESULTS

IRTP composed 1,707 sets of 28 types of nurseries in 1985 and distributed material to 49 countries cooperating in the network. A new nursery, the International Rice Ufra Screening Set (IRUSS), was initiated during the year in response to the need for identifying varieties and breeding lines resistant to this important nematode problem in deepwater rice. Another nursery, designated the International Rice Salinity Tolerance Yield Nursery (IRSTYN), was composed to assess the yield performance of breeding lines and varieties found tolerant of salinity stress in earlier salinity observational nurseries. The yield nursery for rainfed shallow water lowland conditions was divided into two maturity groups — early and medium.

Yield nurseries. Top ranking entries for the three maturity groups of irrigated rice — International Rice Yield Nursery-Very Early (IRYN-VE), -Early

Table 1. Best performing entries in the 6th International Rice Yield Nursery-Very Early (IRYN-VE) based on overall and regional mean yield, 1985.

Region and number of trials	Designation	Origin	Days to flowering	Yield (t/ha)
Overall, 38	IR50	IRRI	85	5.1
	IR25924-51-2-3	IRRI	87	4.9
	IR32429-47-3-2-2	IRRI	86	4.9
	UPR103-80-1-2	India	83	4.8
East Asia, 8	IR50	IRRI	93	6.3
	UPR103-80-1-2	India	90	6.3
	IR32429-47-3-2-2	IRRI	94	6.0
	IR25884-94-3-2	IRRI	92	5.9
Southeast Asia, 13	IR25890-82-5-3	IRRI	75	4.1
	IR25924-51-2-3	IRRI	76	4.1
	IR32429-47-3-2-2	IRRI	76	4.1
	IR50	IRRI	76	4.1
South Asia, 10	TKM9	India	84	4.9
	IR28128-45-2	IRRI	81	4.8
	IR50	IRRI	83	4.8
	IR25924-51-2-3	IRRI	84	4.6
	IR29692-65-2-3	IRRI	84	4.6
	IR32429-47-3-2-2	IRRI	83	4.6
West Asia and North Africa, 3	UPR103-80-1-2	India	101	7.4
	IR28128-45-2	IRRI	104	7.3
	RNR1429	India	104	6.9
	Palghar 31-2-9-3	India	102	6.8
Sub-Saharan Africa, 2	Palghar 31-2-9-3	India	106	6.3
	RNR1429	India	106	6.3
	AS688	India	99	5.8
	IR50	IRRI	106	5.8
	UPR103-80-1-2	India	103	5.6
Latin America, 2	TKM9	India	80	5.7
	HAU16-20-3	India	84	5.6
	IR25884-94-3-2	IRRI	73	5.6
	IR25890-82-5-3	IRRI	73	5.6

(IRYN-E), and -Medium (IRYN-M) — are given in Tables 1, 2, and 3. Some rices performed well in several regions. The nursery reports, published separately, show yield and yield components by site and region. 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 top yielding entries for the two maturity groups of upland rices — early (IURYN-E) and medium (IURYN-M) — are shown in Tables 6 and 7.

Observational nurseries. The outstanding entries in the observational nurseries (IRON, IURON, IRRSWON, IRDWON, IFRON, and IFPRON) as determined by their overall phenotypic acceptability ratings are shown in Table 8. Several entries were resistant to or tolerant of one or more important stresses at trial locations.

Nurseries for specific stresses. Tables 9 and 10 list the best performing entries in nurseries established for specific stresses. Insect nurseries were those for brown planthopper (IRBPHN),

Table 2. Best performing entries in the 13th International Rice Yield Nursery-Early (IRYN-E) based on overall and regional mean yield, 1985.

Region and number of trials	Designation	Origin	Days to flowering	Yield (t/ha)
Overall, 34	Chianung sen yu 26	Taiwan, China	100	5.3
	KAU1727	India	96	5.3
	C662083	Taiwan, China	92	5.0
	IR13240-108-2-2-3	IRRI	94	5.0
	Si-pi 692033	Taiwan, China	95	5.0
	IR36	IRRI	92	5.0
East Asia, 5	Chianung sen yu 26	Taiwan, China	112	7.5
	C662083	Taiwan, China	104	7.1
	IR13240-108-2-2-3	IRRI	113	6.8
	IR13524-21-2-3-3 2-2	IRRI	111	6.7
	IR36	IRRI	110	6.7
Southeast Asia, 13	KAU1727	India	89	5.1
	Chianung sen yu 26	Taiwan, China	91	4.9
	BW295-5	Sri Lanka	97	4.9
	MTU5410-14	India	90	4.9
	IR13240-108-2-2-3	IRRI	85	4.9
	IR31868-64-2-3-3-3	IRRI	85	4.9
South Asia, 12	Chianung sen yu 26	Taiwan, China	106	5.0
	BW295-5	Sri Lanka	112	5.0
	KAU1727	India	103	4.9
	SKL17-67-11	India	97	4.7
	IR64	IRRI	100	4.6
	C1321-9	Philippines	100	4.6
	MTU5410-14	India	105	4.6
	PDR76-D10-D8-D1	Pakistan	103	4.6
	Si-pi 692033	Taiwan, China	102	4.6
	S287b-39-1-3	Indonesia	99	4.6
West Asia and North Africa, 1	AD9246	India	97	8.9
	IR29692-99-3-2-1	IRRI	96	8.7
	IR29725-22-3-3-3	IRRI	99	8.1
	KAU1727	India	108	8.0
Latin America, 2	Chianung sen yu 26	Taiwan, China	87	5.8
	BW295-5	Sri Lanka	95	4.9
	Si-pi 681032	Taiwan, China	78	4.9
	S287b-39-1-3	Indonesia	79	4.8
Oceania, 1	IR64	IRRI	74	5.6
	IR35546-52-3-3-2	IRRI	74	4.9
	IR13240-108-2-2-3	IRRI	72	4.6
	KAU1727	India	75	4.5

whitebacked planthopper (IRWBPHN), and stem borer (IRSBN). Disease nurseries were those for ufra (IRUSS), bacterial blight (IRBBN), rice blast (IRBN), and rice tungro (IRTN). Nurseries for other stresses included those for salinity and alkalinity (IRSATON), acid upland and acid lowland soils, and cold tolerance (IRCTN).

Table 3. Best performing entries in the 13th International Rice Yield Nursery-Medium (IRYN-M) based on overall and regional mean yield, 1985.

Region and number of trials	Designation	Origin	Days to flowering	Yield (t/ha)
Overall, 25	BG380-2	Sri Lanka	100	5.2
	BR153-2B-10-1-3	Bangladesh	103	5.2
	IR21820-154-3-2-2-3	IRRI	101	5.2
	IR28118-138-2-3	IRRI	108	5.1
Southeast Asia, 8	IR28118-138-2-3	IRRI	100	5.2
	RTN16-2-1-1-1	India	105	5.0
	IR21820-154-3-2-2-3	IRRI	93	4.9
	BG379-2	Sri Lanka	95	4.8
	IR29723-143-3-2-1	IRRI	102	4.8
South Asia, 16	BG380-2	Sri Lanka	103	5.8
	BR153-2B-10-1-3	Bangladesh	108	5.5
	IR21820-154-3-2-2-3	IRRI	104	5.4
	BW293-2	Sri Lanka	109	5.2
	BG379-2	Sri Lanka	109	5.1
Sub-Saharan Africa, 1	OR447-20	India	96	6.0
	S512b-199	Indonesia	100	6.0
	IR42	IRRI	98	5.9
	BW293-2	Sri Lanka	102	5.8
	IR21820-154-3-2-2-3	IRRI	98	5.6
	IR25604-99-1-3-2-2	IRRI	103	5.6
	IR28118-138-2-3	IRRI	108	5.6
	PAU50-B-25-1	India	101	5.6
	Si-pi 692106	Taiwan, China	95	5.6

Table 4. Best performing entries in the 5th International Rainfed Rice Shallow Water Yield Nursery-Early (IRRSWYN-E) based on overall and regional mean yield, 1985.

Region and number of trials	Designation	Origin	Days to flowering	Yield (t/ha)
Overall, 14	IR21567-9-2-2-3-1-3	IRRI	108	4.0
	IR21178-39-P1	IRRI	100	3.9
	CR213-1002	India	113	3.8
	IR21188-87-3-3-2-2	IRRI	118	3.8
	IR28941-164-1-5	IRRI	105	3.5
	IR4829-89-2	IRRI	106	3.5
Southeast Asia, 10	IR21188-87-3-3-2-2	IRRI	107	4.1
	IR21567-9-2-2-3-1-3	IRRI	101	4.1
	CR213-1002	India	107	4.0
	IR21178-39-P1	IRRI	96	3.9
	IR28941-164-1-5	IRRI	102	3.7
South Asia, 4	IR21178-39-P1	IRRI	108	3.7
	IR21567-9-2-2-3-1-2	IRRI	124	3.7
	IR4829-89-2	IRRI	122	3.7
	CR213-1002	India	128	3.3

Table 5. Best performing entries in the 5th International Rainfed Rice Shallow Water Yield Nursery-Medium (IRRSWYN-M) based on overall and regional mean yield, 1985.

Region and number of trials	Designation	Origin	Days to flowering	Yield (t/ha)
Overall, 13	OR142-99	India	118	3.9
	RP1045-25-2-1	India	117	3.9
	BR51-74-6/J1	Bangladesh	118	3.8
	RP975-109-2	India	119	3.7
	BR11	Bangladesh	115	3.6
	IR9884-54-3-1E-P1	IRRI	116	3.6
Southeast Asia, 7	BR51-74-6/J1	Bangladesh	112	4.1
	RP1045-25-2-1	India	113	4.1
	RP1057-184-5-3-2	India	123	4.1
	IR19083-22-2-2	IRRI	105	4.0
	IR21037-2-1-2E-P1	IRRI	110	4.0
	IR9884-54-3-1E-P1	IRRI	107	4.0
	OR142-99	India	113	4.0
South Asia, 6	OR142-99	India	122	3.3
	BR51-74-6/J1	Bangladesh	124	3.5
	CN540	India	123	3.5
	RP1045-25-2-1	India	122	3.5
	RP975-109-2	India	123	3.5
	BR11	Bangladesh	123	3.5

Table 6. Best performing entries in the 11th International Upland Rice Yield Nursery-Early (IURYN-E) based on overall and regional mean yield, 1985.

Region and number of trials	Designation	Origin	Days to flowering	Yield (t/ha)
Overall, 17	BG367-4	Sri Lanka	85	2.4
	HPU741	India	72	2.1
	IR10198-66-2	IRRI	81	2.0
	IR19793-25-2-2	IRRI	77	2.0
	IR9729-67-3	IRRI	69	2.0
	IR9761-19-1	IRRI	79	2.0
Southeast Asia, 6	BG367-4	Sri Lanka	82	2.3
	IRAT109	Ivory Coast	68	2.0
	IR10198-66-2	IRRI	78	2.0
	IR19793-25-2-2	IRRI	76	2.0
	IR9761-19-1	IRRI	79	1.9
South Asia, 9	BG367-4	Sri Lanka	87	2.5
	HPU741	India	73	2.4
	IR9729-67-3	IRRI	70	2.4
	IR19793-25-2-2	IRRI	77	2.2
	NDR119	India	73	2.2
Sub-Saharan Africa, 1	IR9761-19-1	IRRI	71	1.7
	IR19793-25-2-2	IRRI	72	1.6
	NDR102	India	73	1.5
	RAU4004-105	India	65	1.4
Latin America, 1	BG367-4	Sri Lanka	98	2.6
	NDR80	India	98	2.4
	HPU741	India	75	2.3
	OR164-5	India	88	2.3
	RP1899-1689-98	India	87	2.3

Table 7. Best performing entries in the 11th International Upland Rice Yield Nursery-Medium (IURYN-M) based on overall and regional mean yield, 1985.

Region and number of trials	Designation	Origin	Days to flowering	Yield (t/ha)
Overall, 18	B2997c-Tb-60-3-3	Indonesia	91	2.8
	B3623g-Tb-49	Indonesia	88	2.8
	IR12979-24-1 (brown)	IRRI	87	2.8
	UPLRi-7	Philippines	88	2.8
	B3622e-Tb-5-4-4	Indonesia	89	2.7
	IR10781-75-3-2-2	IRRI	111	2.7
Southeast Asia, 13	IR12979-24-1 (brown)	IRRI	87	2.9
	UPLRi-7	Philippines	88	2.8
	B2997c-Tb-60-3-3	Indonesia	91	2.7
	B3623g-Tb-49	Indonesia	87	2.7
	IR10781-75-3-2-2	IRRI	112	2.7
South Asia, 4	B2997c-Tb-60-3-3	Indonesia	86	3.3
	UPLRi-7	Philippines	84	3.3
	B2997c-Tb-4-2-1	Indonesia	86	3.1
	B3016b-Tb-260-3-2-1-1-3	Indonesia	87	3.1
	B3622e-Tb-5-4-4	Indonesia	89	3.1
	B3623g-Tb-49	Indonesia	87	3.1
Latin America, 1	IR18189-42-2-3	IRRI	110	4.0
	IR10781-75-3-2-2	IRRI	110	3.8
	IR4829-89-2	IRRI	110	3.5
	C894-7	Philippines	110	2.8
	IR43	IRRI	110	2.8

Table 8. Entries that received phenotypic acceptability ratings in the 1985 observational nurseries.

Nursery and number of trials	Designation	Mean phenotypic acceptability score	Mean days to flowering
International Rice Observational Nursery (IRON), 21	C702015	4.4	93
	IR25840-81-3-2	4.5	97
	IR22107-14-2-1	4.6	100
	IR31787-85-3-3-3-2	4.6	89
	IR31802-48-2-2-2	4.6	88
	IR21820-154-3-2-2-3	4.6	107
	IR29692-34-1-3-2-2	4.7	87
	IR28128-45-2	4.8	85
	B5322b-PN-1-SM-83	4.8	98
	ADT36	4.9	90
	B5322b-PN-1-MS-1-KP-1	4.9	98
	IR13429-150-3-2-1-2	4.9	100
	IR29692-117-1-2-2	4.9	89
International Upland Rice Observational Nursery (IURON), 26	UPLRi-5	4.4	99
	Plah Sew 1	4.6	99
	UPLRi-7	4.6	88
	IR5420-1-1-2-3	4.7	97
	IR6023-10-1-1	4.7	98
	IR43	4.7	99
	B3622f-Tb-14-4	4.8	95
	IR3646-9-3-1	4.8	94
	B3623g-Tb-48	4.9	94
	IR10147-113-5-1-1-5	4.9	97
	IR12979-24-3-4	4.9	95
	IR13260-100-1E-P2	4.9	103

Continued on opposite page

Table 8 continued

Nursery and number of trials	Designation	Mean phenotypic acceptability score	Mean days to flowering
International Rainfed Rice Shallow Water Observational Nursery (IRRSWON), 20	BKN6721-5-7-4	4.4	118
	RTN15-2-1-1-1	4.4	128
	RP975-109-2	4.6	124
	BR4	4.7	120
	CN540	4.7	124
	CR1022	4.7	122
	IR21064-48-2-1E-P1	4.7	118
	MW80-137	4.8	115
	BR51-120-2	4.8	113
	IR13149-43-2-P1	4.8	128
	IR33238-25-2-3-2	4.8	120
	IR4819-77-3-2	4.8	110
	RD21	4.8	110
	IR21178-39-P1	4.9	108
	BRB11-448-1-4	4.9	124
	BR51-282-8-HR83	4.9	120
	BR51-315-4	4.9	110
	IR19672-140-2-3-2-2	4.9	116
	IR5873-9-1	4.9	108
International Rice Deepwater Observational Nursery (IRDWON), 11	HTA7403-110-1-1-3-0	4.6	121
	BKNFR78023-38-1K-1-1	4.7	128
	IR21038-77-P2-5-2-3-1-1	5.0	114
	Jalamagna	5.0	131
International Floating Rice Observational Nursery (IFRON), 5	Leb Mue Nahng 111	3.0	173
	BKNFR76043-7-2-1-1	3.8	168
	SPR7411-72-1	4.4	171
	SPR7410-0-256	4.8	173
	Baisbish	4.6	139
	HTAFR77012-3	5.0	167
	HTAFR77068-2	5.0	173
International Tide-Prone Rice Observational Nursery (ITPRON), 2	CN540	2.0	121
	BRB20-3B-17	2.5	138
	BR111-140-1-1	3.0	108
	Hogla Pata (Acc. 37104)	3.0	–
	BKN6986-66-2	3.5	110
	B1043d-Sm-28-6-1-1	3.5	110
	B1050d-Kn-59-3-1-2-5-3	3.5	120
	B2791b-Mr-196-2-3-1-3	3.5	105
	Garcha	3.5	135

Table 9. Best performing entries in the 1985 insect and disease nurseries.

Nursery[a] number of trials	Entries rated resistant	Nursery[a] number of trials	Entries rated resistant
RBPHN, 19	PTB33, Rathu Heenati (Acc. 11730), BG367-2, BG379-2, IR13540-56-3-2-1, IR25587-133-3-2-2-2, IR25603-20-2-1-3-2, IR27325-111-2-1, IR29692-65-2-3-3, IR35323-93-1-3-1, PTB19 (Acc. 6107), Sinna Sivappu (Acc. 15444)	IRWBPHN, 8	ARC 10239, IR13475-7-3-2, IR2035-117-3, IR15527-21-2-3, IR27316-6-2-2, Sufaida 172 (Acc. 28298), WC1240 (Acc. 13742), IR25587-67-1-3-3-3, Rathu Heenati (Acc. 11730)

Continued on next page

Table 9 continued

Nursery[a] number of trials	Entries rated resistant
IRSBN	
Vegetative stage, 1	CO18, IR19735-5-2-3-2-1, IR19743-25-2-2, IR19774-42-2-1-3-2, IR56, IR8608-75-3-1-3, Kalinga 2 (Acc. 39473), MTU15, Taichung sen 10, TNAU (AD) 103, IR13429-287-3, W1203 (Acc. 11057), IR19743-46-2-3-3-2, IR21015-80-3-3-1-2, IR5857-4-1E-3, IR9129-169-3-2-3-3, KAU1675, RP825-71-4-10, TKM6 (Acc. 237), TNAU9426-7
Heading stage, 5	IR15314-43-2-3-3, IR56, IR9288-B-B-52-1, Taichung sen 10, IR15795-151-2-3-2-2, IR8608-75-3-1-3, IR9830-26-3-3
IRUSS, 3	Ba Tuc, Bazail 65, Rayada 16-011, Rayada 16-013, Rayada 16-05, Rayada 16-06, Rayada 16-07, Rayada 16-08, Rayada 16-09
IRBBN, 12	DV85, IR13423-17-1-2-1, IR22082-41-2, IR26717-1-1-2-1-1, IR27325-63-2-2, IR29295-70-1-1-1-1-3-1, IR29341-85-3-1-3, IR40, IR54, IR8192-166-2-2-3, IR9830-26-3-3, RP633-76-1
IRBN, 18	Tetep, Huan-sen-goo, Ta-poo-cho-z, SR3044-78-3, IRAT109, IRAT113, IRAT134, IRAT147
IRTN, 4	Boteswar, ARC11554, Kachamota, Naria Bachi, Pankhari 203

[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 10. Best performing entries in the 1985 IRTP soil and low temperature stress screening nurseries.

Nursery[a] and number of trials	Entries rated tolerant
IRSATON	
Salinity, 5	Bhurarata 4-10, IR9129-285-3-1-2-3, IR9209-163-2, RP975-109-2
Alkalinity, 5	IR4630-22-2-5-1-3, IR8073-231-3-3, IR4595-4-1-13, Pokkali, BR51-282-8, IR13149-43-2, IR8073-231-3-3
Acid Upland, 8	IR12979-24-1 (brown), Azucena, IRAT104, M55, GH305, IR43, IR6023-10-1-1
Acid Lowland	
4 WT, 5	BG374-1, IR13146-45-2-3, IR4227-109-1-3-3, IR5741-73-2-3, IR8192-31-2-1-2, Khao Tah Haeng 17, Mahsuri
8 WT, 5	BW271-1, IR13610-72-2-2E-P2, IR4227-109-1-3-3, Mahsuri, P1369-4-16M-1-2M-4
IRCTN, 17	Ouella-Inia, Lien-Chan-Ze-Tnou, Ta-Mao-Tao

[a]IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery, Acid Upland = Acid Upland Soils Screening Set, Acid Lowland = Acid Lowland Soils Screening Set, IRCTN = International Rice Cold Tolerance Nursery, WT = weeks after transplanting

1986 NURSERY DISTRIBUTION

A total of 1,464 sets of 29 types — 17 for cultural type and 12 for stress tolerance — of IRTP nurseries were composed and distributed to 51 countries in the IRTP network (Table 11). Sources of test entries appear in Table 12. A total of 1,484 entries were distributed around the world. In Asia, 1,034 sets went to national programs. Sub-Saharan Africa received 277 sets, 53 of which went to the West Africa Rice Development Association (WARDA) for distribution to member countries. Forty-six nursery sets went to the national programs in West Asia and North Africa. Ninety-five nursery sets went to 14 countries in Latin America, 7 sets to 3 countries in Europe, and 5 sets to the Solomon Islands.

USE OF IRTP ENTRIES

National rice improvement programs continued using IRTP materials. Outstanding entries in stress screening nurseries were often used as donors in hybridization programs (Table 13). Fifty-nine IRTP nursery entries were utilized for further yield testing in different countries (Table 14). Eight

Table 11. IRTP nurseries dispatched from IRRI in 1986.

Region and country	Nurseries for 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-F	IURON-M	IRRSWON-E	IRRSWON-M	IRDWON	IFRON	ITPRON	IRCTN	IRSATON	Acid Lowland	Acid Upland	IRBN-Upland	IRBN-Lowland	IRBBN	IRTN	IRBFHN	IRWBPHN	IRSBN	IRUSS	
East Asia																														
China	6	6	3	3	3	3		7	7	5	3	3	1	1	1			3	4	1	1	1	1	6		8	5	4		86
Japan																		2				1	1							4
Korea	1							2	2	2								2	2			4	4	1		1	1			22
Taiwan, China	2							1														1	2			2	1			9
Southeast Asia																														
Burma		1	1	1		1	1				1		1	1	2			1	2	1	1	2	1	2		1	1	1	1	24
Indonesia	1	1						1	1	1	1	1			1		1	1		2	1	3		2	2					20
Malaysia	2	4	4		2		3					2		1						1			1	1	1	1	1	1		25
Philippines	7	7	5	14	14	5	6	4	4	4	12	12	6	6	1	1	3	4	6	1	3	1	1	1	1	1	1	1	1	133
Thailand	8	8	2	5	1	9	9	6	6	6	5	1	9	9	6	4	2	5	4	6	2	6	6	5	3	2	1	3		139
Vietnam	7	7	4	2	1	7	4	5	5	4	2	1	2	4	2	1	3	1	3	4	1	2	4	3	1	6	3	2	3	90
South Asia																														
Bangladesh	6	6	5				4	2	1	1	4			2	3	2	1	4	5		1	2	1	3	3	1			1	58
Bhutan	1	2	1			1	1	1	1	1	1			1				4												15
India	24	20	13	13	7	2	6	15	11	10	7	7	3	6	10	4	2	18	11	1	3	14	15	12	10	13	8	11	1	277
Nepal		3	3	1	4		3	2	2	1	2	2		3				2				3	3	3		2	1	4		44
Pakistan	7	6	5	1	1	2	2	4	3	3		2	1	1	1			2	7				1	1			3	3		56
Sri Lanka								3	2	1	4	1	1	1	1		1	3	2	2		3	2		1	1	1	2		32
West Asia and North Africa																														
Egypt	2	2						2	2	2									2				2							14
Iran	3			1	1			3	3	3									2			3	3							22
Saudi Arabia				1	1																									2
Turkey	3							2											1				2							8
Sub-Saharan Africa																														
Burundi	1	1	1	1	1			1	1	1	1	1						1												11
Cameroon	1	1	1						1									3												7
Ethiopia	1					1	1				1	1	1	1	1	1		1												10
Guinea Bissau																			1	1								1		3
Kenya											1	1																		2
Liberia (WARDA)[b]				1	1			2	2	2	1		3	3	3	3	3	3	5	4		3	8	4				2		53
Malagasy Republic																				1										1
Mozambique								1	1	1			1	1				1	1											7
Nigeria – IITA[c]	2	2	2	2	3	2	2	10	10	10	10	10	10	10				2		3	10	3	3	3						109
– NCRI[d]	1	1	1	1				1	1	1					1			1			1	1	1							12
Sierra Leone		1											1	1	1		1		2	1		1	1							10
South Africa	1																													1
Tanzania	3	3	3	1	1	1		1	1	1	2	2	3	2	2			2				1	1							30
Zaire				3	3						1	1										4						4		16
Zimbabwe	1	1																1	1	1										5

Continued on next page

Table 11 continued

Region and country	Nurseries for 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-Upland	IRBN-Lowland	IRBBN	IRTN	IRBPHN	IRWBPHN	IRSBN	IRUSS	
Latin America																														
Argentina										1																				1
Brazil	1										1	1						5	2	1		2	2							15
Chile																		1												1
Colombia								1	1	1	1	1	1							1	1	1	1					1		11
Dominican Republic	1	1						2	2	2	1	1							3											13
Ecuador															1				1											2
El Salvador	1																													1
Haiti																			1											1
Honduras																						1	1							2
Mexico	2	1		1	3		1	1	1	2	2	4		1	1			3	4	1		5	5							38
Panama								1	1	1	1											1								5
Peru		1			1																1									3
Surinam		1																												1
Uruguay																		1												1
Europe																														
Hungary											1							1												2
Italy																						1	1							2
Spain	1							1			1																			3
Oceania																														
Solomon Islands	1	1						1		1																1				5
Total	98	86	54	52	48	30	43	82	72	68	67	56	44	55	38	16	17	78	72	33	26	70	74	47	22	40	27	40	7	1464

[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 Nursery-Medium, IRRSWYN-E = International Rainfed Rice Shallow Water Yield Nursery-Early, IRRSWYN-M = International Rainfed Rice 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 Rainfed Rice Shallow Water Observational Nursery-Early, IRRSWON-M = International Rainfed Rice 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-Upland = International Rice Blast Nursery-Upland, IRBN-Lowland = International Rice Blast Nursery-Lowland, 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 Ultra Screening Set. [b]West Africa Rice Development Association. [c]International Institute of Tropical Agriculture. [d]National Cereals Research Institute.

IRTP entries were released in 1986: three in Indonesia (IR11288-B-B-118-1 [PAD3], IR11141-6-1-4 [PAD4], and SPR7232-2-3-1 [PAD6]), three in Tanzania (BG400-1, Taichung sen 10, and BIET360), and two in Malaysia (IR8192-200-3-3-1-1 and P901-22-11-2-6-1-1B [Ohundus]).

Table 12. Origin and types of entries in the 1986 IRTP nurseries dispatched from IRRI.

Nursery	Sets dispatched (no.)	Entries (no.)	Entries (no.) from			
			National programs		IRRI	
			Improved (no.)	Traditional (no.)	Improved (no.)	Germplasm bank (no.)
Yield						
Irrigated						
IRYN-VE	98	23	7	0	16	0
IRYN-E	88	24	11	0	13	0
IRYN-M	54	22	13	0	9	0
Rainfed Upland						
IURYN-E	52	16	12	0	4	0
IURYN-M	48	16	8	0	8	0
Rainfed Lowland						
IRRSWYN-E	30	17	2	0	15	0
IRRSWYN-M	43	16	7	0	9	0
Observational						
Irrigated						
IRON-VE	82	31	0	0	31	0
IRON-E	72	76	19	0	57	0
IRON-M	68	64	32	0	32	0
Rainfed						
IURON-E	67	49	35	2	10	2
IURON-M	56	53	40	1	12	0
IRRSWON-E	44	26	7	0	19	0
IRRSWON-M	55	100	47	3	50	0
IRDWON	38	80	41	2	37	0
IFRON	16	21	16	2	2	1
ITPRON	17	44	22	1	17	4
Stress screening						
Diseases						
IRBN-Upland	70	20	15	1	4	0
IRBN-Lowland	74	170	72	5	92	1
IRBBN	47	97	39	3	55	0
IRTN	22	79	17	3	59	0
Insects						
IRBPHN	40	96	11	0	79	6
IRWBPHN	27	50	7	3	35	5
IRSBN	40	22	4	0	17	1
Nematode						
IRUSS	7	14	13	1	0	0
Problem soils						
IRSATON	72	64	15	1	48	0
Acid Lowland	33	61	14	1	45	1
Acid Upland	26	45	23	1	21	0
Temperature tolerance						
IRCTN	78	88	41	3	17	27
Total			590	33	813	48

Table 13. Utilization of 1986 IRTP nursery entries.[a]

Region and country	Used for		
	Hybridization	Yield testing	
		Local	National
East Asia			
China	16	5	
Korea	26		
Southeast Asia			
Indonesia	16		16
Thailand	23	10	
Vietnam		5	
South Asia			
India	5	4	
Nepal		9	
Pakistan	5		
Sri Lanka	1		
Latin America			
Dominican Republic			14
Europe			
Hungary	2		
Total	94	33	30

[a]Based on data received as of 12 Jan 1987.

Table 14. 1986 IRTP entries utilized for further yield testing in various countries.[a]

BR1354-18-1-1	IR29725-109-1-2-1
BR1356-16-1-1	IR29725-3-1-3-2
BR1356-32-1-3	IR31785-58-1-2-3-3
BR203-26-2	IR31802-48-2-2-2
BR308-B-2-3	IR31805-20-1-3-3
BR319-1	IR31868-64-2-3-3-3
BR4-9-16-3-1	IR32307-107-3-2-2
BR9-17-4-2	IR32429-47-3-2-2
B2992B-TB-73-4-2-3-3-3-2	IR32429-68-3-3-3
B3623G-TB-49	IR32712-2-2-1-1
Chianung sen yu 26	IR32720-138-2-1-1-2
C662083	IR34583-19-3-3
C894-7	IR34615-4-2-3
IR10206-29-2-1	IR35350-126-2-1-3
IR12979-24-1 (Brown)	IR39422-19-3-3-3-3
IR13524-21-2-3-3-2-2	IR39422-75-3-3-3-2
IR13754-5-2	IR64
IR19743-40-3-3-2-3	IR7805-22-3-1
IR21820-154-3-2-2-3	IR8608-75-3-1-3
IR22083-105-3-3-3-3	IR9859-6-3-3
IR22107-14-2-1	Lu Chao 1
IR25884-94-3-2	NDR-97
IR25916-41-3-1	PR106
IR26717-1-1-2-1	Rathu Heenati (Acc. 11730)
IR28	RPCB-2B-849
IR28150-84-3-3-2	Si-pi 692033
IR28154-101-3-2	SPRLR76102-26-1-1
IR28228-119-2-3-1-1	S2878-39-1-3
IR28238-109-1-3-2-2	TNAU6464
IR29519-157-1-2-1	

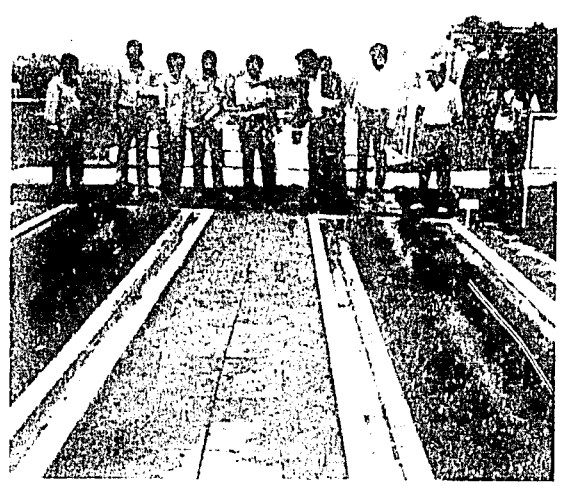
[a]Based on data received as of 12 Jan 1987.

MONITORING VISITS AND WORKSHOPS

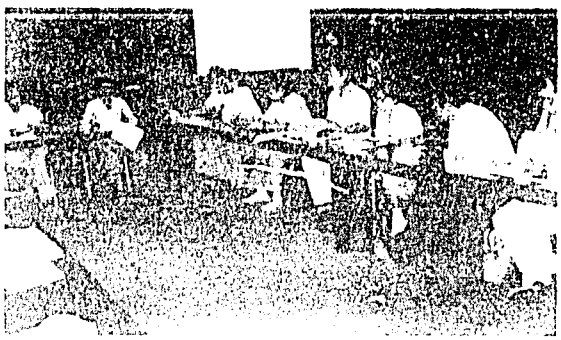
The IRTP monitoring program continued to play an important role in forging interactions among the world's rice scientists involved in varietal improvement. The following monitoring tours were organized in 1986

- Monitoring tour in Madagascar and Tanzania, 10-20 Mar
- South American monitoring tour in Brazil, Uruguay, Argentina, Paraguay, and Chile, 9-20 Mar
- Cold tolerant rice monitoring tour in Pakistan, India, Nepal, and Korea, 1-12 Sep (Fig. 1)
- Upland rice monitoring tour in Ghana, Sierra Leone, and Senegal, September and October
- Rice disease and insect resistance monitoring tour in India, Bangladesh, Thailand, Malaysia, and the Philippines, 18 Oct-4 Nov (Fig. 2)

The observations and recommendations relative to these pest monitoring tours are published separately.



1. Participants in IRTP Cold Tolerant Rice Monitoring Tour (Sep 1986) observing the screening trials in Chuncheon, Korea, for low temperature tolerance at the seedling stage.



2. IRTP Rice Disease and Insect Resistance Monitoring Tour (Oct–Nov 1986) participants at a planning meeting at IRRI on the concluding day of the tour.

IRTP IN AFRICA

IRTP activities in Africa in 1986 continued to focus on providing national programs with improved germplasm to overcome major constraints. In addition to global nurseries, nurseries specific to the region were distributed. An IRTP regional program was initiated in East Africa with headquarters at the Sokoine University of Agriculture, Morogoro, Tanzania.

One hundred eighty-three nursery sets were dispatched to different African countries (Table 15). These included 99 for 3 upland nurseries (AURAT, AURON, and AURPSS) and 87 for 3 irrigated nurseries (AIRAT, AIRON, and AIRPSS). The nurseries were supplied to Burundi, Kenya, Malawi, Rwanda, Tanzania, and Zambia in East Africa and to the WARDA member countries and Cameroon in West Africa. The promising entries from the 1985 IRTP trials in Africa are listed in Table 16.

IRTP IN LATIN AMERICA AND THE CARIBBEAN

In 1986, 95 sets of IRTP global nurseries were sent to various countries in Latin America. Promising entries from different nurseries tested in Latin America are listed in Table 17.

The Caribbean Rice Research Network was initiated in February 1986. During the year, 561 entries were evaluated under field conditions at the network headquarters at Juma, Dominican Republic (Table 18). Two hundred twenty-eight entries were selected for grain quality tests. They

Table 15. Dispatch of 1986 IRTP-Africa nurseries.

Country	Nurseries dispatched[a] (no.)						
	AURAT	AURON	AURPSS	AIRAT	AIRON	AIRPSS	Total
Burkina Faso	1	1		1	1		4
Burundi	2	1	1	3	1		8
Cameroon	1	2	2	2	1		8
Congo	1	1		1	1		4
Ghana	2	2	1				5
Ivory Coast	10	10	2	3	3	1	29
Kano	3	2					5
Kenya	2	1		2	1		6
Liberia	2	2	2	2	2	2	12
Malawi	1	1		2	2	1	7
Nigeria	4	4	2	4	4	2	20
Rwanda	1	1	1	4	3	1	11
Senegal	2	2	1	6	6	2	19
Tanzania	2	2	1	4	4	1	14
Togo	4	2	1				7
Uwani				1	1		2
Zaire	1			1			2
Zambia	4	4	2	4	4	2	20
Total	43	38	16	40	34	12	183

[a]AURAT = African Upland Rice Advanced Trial, AURPSS = African Upland Rice Preliminary Screening Set, AIRON = African Irrigated Rice Observational Nursery, AURON = African Upland Rice Observational Nursery, AIRAT = African Irrigated Rice Advanced Trial, AIRPSS = African Irrigated Rice Preliminary Screening Set.

Table 16. Promising entries in Africa based on 1985 IRTP trials.

Nursery and number of trials	Entries
IRYN-VE, 2	Falghar 31-2-9-3, RNR1429, AS688, IR50, UPR103-80-1-2
IRYN-M, 1	OR447-20, S512b-199, IR42, BW293-2, IR21820-154-3-2-2-3, IR25604-99-1-3-2-2, IR28118-138-2-3, PAU50-B-25-1, Si-pi 692106
IURYN-E, 1	IR9761-19-1, IR19793-25-2-2, NDR102, RAU4004-105
IRON, 1	BG35-2, IR25588-32-2, IR29692-34-1-3-2-2, IR29708-113-3-2-3, BG367-4, BR203-70-B-1, BR203-70-B-2, BR316-15-4-4-1, BR51-120-2, BW288-1-3, B5322b-PN-1-SM-83
IRRSWON, 2	BR51-120-2, BR51-282-8-HR83, BR51-315-4, IR18152-CN-7-1-3-3, IR18848-35, IR21567-16-2-2
Acid Lowland, 1	BW100, IR13610-72-2-2E-P2, Mat Candu
IRBN, 1	BR1356-38-3, BR220-1-1, Tetep, DWCT156-1-B-B, IR25890-82-5-3, Milyang 68, Si-pi 681032

Table 17. Promising entries in Latin America based on 1985 IRTP trials.

Nursery and number of trials	Entries
IRYN-VE, 2	TKM9, HAU16-20-3, IR25884-94-3-2, IR25890-82-5-3
IRYN-E, 2	Chianung sen yu 26, BW295-5, Si-pi 681032, S287b-39-1-3
IURYN-E, 1	BG367-4, NDR80, HPU741, OR164-5, RP1899-1689-98
IURYN-M, 1	IR18189-42-2-3, IR10781-75-3-2-2, IR4829-89-2, C894-7, IR43
IRON (Rainfed), 1	IR25588-32-2, IR29725-11-3-2-2, IR58, IR29725-21-1-3-2, IR29725-22-3-3-3, IR29725-41-2-3-3, Caribe 1-4, C702015, ECIA136-C-2, ECIA66-133-3-1-1, IR29725-117-2-3-3, IR29725-128-3-1-2, IR29725-40-3-2-3, IR32307-107-3-2-2, MRC5720-3427
IURON, 3	IR13260-100-1E-P2, IRAT170, CICA8, Colombia 1, IR9852-18-1, 16863, IR43, IR13358-16-3-2, ITA117, KMP34, IR9761-40-3-2, Napa40 Krad ST-12

Table 17 continued

Nursery and number of trials	Entries
IRRSWON, 1	RTN90-4, CN506-147-14-2, CN540, CN836-3-9, CR1009, CR1022, GEU77042-0-4K-28, IR13259-153-5E-P2-3, IR13358-16-3-2, IR15810-260-1-3-1-3, IR17488-2-3-2, IR17491-5-4-3-3-P1, IR18152-CN-7-1-3-3, IR19382-42-3-3-2, IR21188-15-2-2-3-3, IR21586-R-31-1, IR28384-21-2, IR28932-9-3-2, IR33196-79-2-3-2
IRSATON (Alkalinity), 1	Bhurarata 4-10, CR1023, IR10198-66-2, IR4630-22-2-5-1-3, IR8073-231-3-3, PNL20-4-2-1, Pokkali, BKNBR1094-56-1-2, BR51-282-8, IR4595-4-1-13
Acid Lowland, 1	IR13146-45-2-3, IR13423-17-1-2-1, IR13610-72-2-2E-P2, IR19735-5-2-3-2-1, IR26, IR28228-119-2-3-1-1, IR2823-399-5-6, IR32, IR44, IR46, IR54, IR56, IR5741-73-2-3, IR58, IR9764-45-2-2, Mahsuri
IRBN, 3	Chokoto, H115-20-1-1, IR21015-72-3-3-3-1, IR21015-80-3-3-1-2, IR28154-101-3-2, IR32799-107-3-3-2, IR32843-92-2-2-3, IR35350-126-2-1-3, Ta-poo-cho-z, IR19670-57-1-1-3

Table 18. Germplasm evaluation at Juma, Dominican Republic, during 1986.

Nursery[a]	Source[b]	Entries (no.)	
		Evaluated	Selected[c]
VIOAL-1985	CIAT	90	46
VIOAL-1986	CIAT	140	99
UPLAND-SET	CIAT	19	19
Commercial varieties	CIAT	19	–
Promising entries	Guyana	4	4
IRSATON, 1986	IRRI	42	14
IRON-E	IRRI	41	11
IRON-VE, M[d]	IRRI	88	–
Promising early entries	IRRI	118	35
Total		561	228

[a]VIOAL = International Rice Observational Nursery for Latin America, IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery, IRON-VE, E, M = International Rice Observational Nursery-Very Early, Early, and Medium growth duration. [b]CIAT = Centro Internacional de Agricultura Tropical. [c]Selected entries of VIOAL-1985 were included in an observational nursery and dispatched to cooperators in September. Other entries constituted the elite material for distribution in early 1987. [d]Under evaluation.

Table 19. Highest yielding entries of the Caribbean Rice Research Network selected for seed multiplication and regional trials in the Dominican Republic, 1986.

Designation	Days to flowering	Yield (t/ha)	Disease reaction[a]					Iron toxicity
			BI	NBI	BS	LSc	GID	
P4729F2-2-2	105	9.8	3	3	6	2	2	7
P4721F2-10-6	113	9.0	4	3	3	5	3	5
P4034F3-3-5	106	8.8	4	2	2	5	3	4
F3709F4-13-1B	106	8.6	4	4	3	4	1	–
P3831F3-RH38-10-1M	108	8.5	2	3	3	4	3	5
P4743F2-65-1	108	8.4	3	3	2	3	3	5
P4729F2-34-2	108	8.3	3	3	4	3	2	9
P3844F3-23	106	7.6	3	3	4	5	3	–
P4134F3-22-1B	103	7.4	4	4	5	5	2	–
P4721F2-93-1	106	7.2	4	3	2	3	3	5
Checks								
CICA8	112	9.5	3	3	1	3	3	2
Oryzica 1	106	7.2	1	3	6	5	3	2
Juma 58	123	7.4	–	–	5	3	3	3
Juma 61	106	7.2	–	–	3	6	3	–

[a]Blast (BI), neck blast (NBI), Fe toxicity, leaf scald (LSc), recorded at CIAT-Santa Rosa, Colombia; brown spot (BS) and grain discoloration (GID) recorded at Juma, Dominican Republic; scale 0-9: 0 = resistant and 9 = susceptible.

will be entered in the Caribbean regional observational nurseries and regional trials in farmers' fields to be conducted in the Dominican Republic (Table 19).

From IRSATON, 14 lines with good plant type, long grain, and good milling recovery were selected for testing for salt tolerance in Laguna Salada, Dominican Republic, a hot spot for salinity screening under field conditions.

Cooperative programs

International Network on Soil Fertility and Fertilizer Evaluation for Rice

Agronomy Department

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NITROGEN FERTILIZER EFFICIENCY FIELD TRIAL IN IRRIGATED RICE

The sixth trial of the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) was continued at IRRI in 1986 dry season (DS) and wet season (WS). In both seasons, no fertilizer source-rate interaction was significant.

In DS, sulfur-coated urea (SCU) and urea supergranules (USG) produced significantly higher yields than did prilled urea (PU) applied either as local best split (BS) (1/2 topdressed at 10 d after transplanting + 1/2 topdressed at 10 d after panicle initiation) or as standard BS (2/3 broadcast and incorporated [B&I] without standing water + 1/3 topdressed at 5-7 d before panicle initiation) (Table 1).

In WS, USG yielded significantly higher than SCU, local BS, or standard BS. Yields with SCU and standard BS were comparable but significantly higher than those with local BS. In both seasons, increasing N levels significantly increased yields.

Table 1. Effects of source, rate, and method of N fertilizer application on average yield of IR64. Sixth international trial on N fertilizer efficiency in irrigated rice, International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER), IRRI, 1986.

Treatment[a]	Yield[b] (t/ha)	
	DS	WS
No fertilizer N	3.4	2.1
Source and application method		
PU local BS	4.7 c	2.6 c
PU standard BS	5.5 b	3.4 b
SCU	6.1 a	3.7 b
USG	6.1 a	4.1 a
N rate (kg/ha)		
29	–	2.7 c
58	4.9 c	3.6 b
87	5.7 b	3.9 a
116	6.2 a	–

[a]PU = prilled urea, BS = best split, SCU = sulfur-coated urea, USG = urea supergranules. PU local BS = 1/2 topdressed at 10 d after transplanting + 1/2 topdressed at 10 d after panicle initiation; PU standard BS = 2/3 broadcast and incorporated without standing water + 1/3 topdressed at 5-7 d before panicle initiation. [b]CV = 8% in DS and 12% in WS.

INTERNATIONAL TRIALS

In 1986, 158 sets of experimental fertilizers and fieldbooks were sent to 57 collaborators from 22 participating national programs, and 11 collaborative research trials were conducted: N fertilizer efficiency trials in 3 major rice environments, a long-term fertility trial in irrigated rice, P sources in flooded rice, azolla use in lowland rice, integrated use of inorganic and organic N fertilizers in lowland rice, comparison of hand- and machine-applied N fertilizers in lowland rice, 2 long-term fertility trials on soil fertility management of rainfed upland rice soils with pH <5 and pH 5-7, and an acid lowland nursery. The latter trials are more recent ones, in line with current research thrusts in rice research at IRRI; the last — the acid lowland nursery — is reported in the section on the International Rice Testing Program. INSFFER is placing increasing emphasis on integrated nutrient management through proper combinations of inorganic and organic fertilizers.

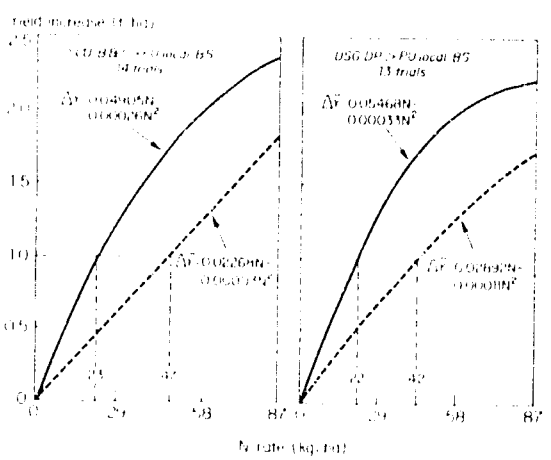
Nitrogen fertilizer efficiency trials. *Irrigated rice.* In 1985, 14 trials under the guidelines of the sixth international trial on N fertilizer efficiency in irrigated rice were conducted at 13 sites in 6 countries, bringing to 32 the total number of trials conducted since 1984, the sites to 24, and the participating countries to 7. Thirty-one of the 32 trials gave significant responses to N. The pooled statistical analyses of all the responsive trials showed that the yield responses of irrigated rice to B&I SCU and deep placed (DP) USG were identical and were higher than responses to local BS and standard BS PU, which were equally effective at all N rates during WS. In DS, USG DP at 87 kg N/ha performed the same as PU local BS at 116 kg N/ha.

Regression analysis using the multifertilizer response model (MRM) and the fertilizer testing model (FTM) showed that SCU B&I was superior to PU local BS in 47% of the N-responsive irrigated rice trials, to USG DP in 43% of the trials, and to PU standard BS in 7% of the trials (Table 2). For an initial yield increase of 1 t/ha over control, 51% less N was required if N were applied as SCU and 48% less N as USG during WS (Fig. 1). Although slow-release SCU has proven effective in rice, its use may be prohibitive because of its high production cost. However, deep-placed USG is promising, and so the national programs of India, Indonesia, and Thailand are presently conducting multilocation farm-level tests on deep placement of USG.

Table 2. Trials in 7 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 rice, INSFFER, 1984-85.

Country	Trials (no.)			
	Total	Response category[a]		
		SCU > PU local BS	USG > PU local BS	PU standard BS > PU local BS
Burma	2	1	1	0
Cameroon	1	0	0	0
India	16	8	7	1
Nepal	2	0	0	0
Pakistan	4	1	0	0
Philippines	5	3	4	0
Vietnam	2	1	1	1
Total[b]	32	14 (47)	13 (43)	2 (7)

[a]Fertilizer testing model (FTM) linear differential estimate of quadratic function was used to classify individual trials into response categories. [b]Values in parentheses are percentages of the 30 trials where positive N response was obtained.



1. Estimated average yield responses of irrigated 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 to PU. Sixth international trial on N fertilizer efficiency in irrigated rice, International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER), 1984-85 WS.

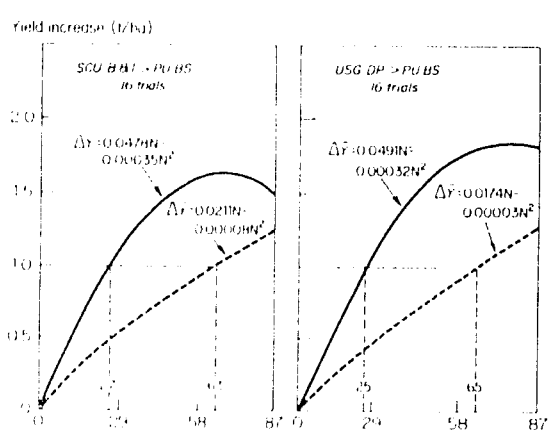
Rainfed lowland rice. In the third international trial on N fertilizer efficiency in rainfed lowland rice, MRM and FTM analysis of 51 trials at 31 sites in 9 countries from 1981 to 1985 showed that 49 trials had significant responses to applied N. Yield responses to SCU B&I and USG DP were significantly greater than responses to PU BS in 33% of the N-responsive trials (Table 3). An initial yield increase of 1 t/ha required 57% less N if applied as SCU and 62% less as USG (Fig. 2). The inclusion of 3 trials conducted in 1985 did not significantly affect the results obtained in the previous year.

Upland rice. Three trials on N fertilizer efficiency in rainfed upland rice were conducted at an acid upland site in Caliraya, Laguna, Philippines, from 1984 to 1986. Comparable yields were obtained

Table 3. Trials in 9 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, 1981-85.

Country	Trials (no.)			
	Total	Response category[a]		
		SCU > PU	USG > PU	No response
Bangladesh	4	2	0	0
Burma	5	2	2	0
India	23	5	5	0
Indonesia	3	1	1	0
Nigeria	1	0	0	1
Philippines	10	3	5	1
Sri Lanka	2	2	1	0
Thailand	2	1	1	0
Vietnam	1	0	1	0
Total[b]	51	16 (33)	16 (33)	2

[a]FTM linear differential estimate of quadratic function was used to classify individual trials into response categories. [b]Values in parentheses are percentages of 49 trials where positive N response was observed.



2. 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, 1981-85.

Table 4. Yield of 13 treatments tested in the first international trial on N fertilizer efficiency in acid upland rice under rainfed conditions. Calirayа, Laguna, Philippines, INSFFER, 1984-86.

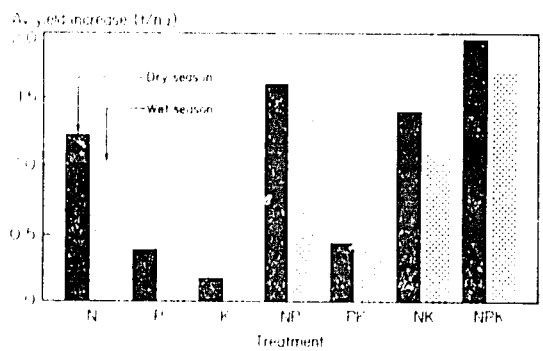
N source[a]	N rate (kg/ha)	Application method	Grain yield[b] (t/ha)		
			1984 WS	1985 WS	1986 WS
Control	0	--	1.0	1.1	1.2
PU	40	Basal, surface broadcast	1.1	0.9	1.3
PU	40	Recommended split[c]	1.1	0.8	1.4
PU + 10% DCD	40	Basal, broadcast & incorporated	1.3	1.0	1.4
PU + 10% DCD	40	Basal, surface broadcast	1.3	1.0	1.7
PU	40	Farmer's split[d]	1.2	0.9	1.5
AS	40	Basal, surface broadcast	1.2	0.8	1.4
AS	40	Recommended split	0.9	1.0	2.0
AS + 10% DCD	40	Basal, broadcast & incorporated	0.9	1.1	1.6
AS + 10% DCD	40	Basal, surface broadcast	1.1	1.1	1.4
SCU (forestry grade)	40	Basal, broadcast & incorporated	1.1	1.0	1.6
PU	80	Recommended split[c]	1.0	1.0	1.4
AS	80	Recommended split[c]	1.3	1.1	1.5
CV (%)			18	23	22

[a]DCD = dicyandiamide, AS = ammonium sulfate. [b]Values not significantly different at the 5% l by DMRT. [c]3/8 N 10 d after emergence (DE), 3/8 N 30 DE, and 1/4 N at panicle initiation (PI). [d]1/3 N at 30 DE, 2/3 N at PI.

from the different N sources and methods of application (Table 4). Yields of most treatments were lower in 1985 WS because of blast (Bl) disease during later growth stages. Average yield differences from the control in all seasons were mostly insignificant. Apparently, management of nutrient N is not the only factor in increasing yields in acid upland environments. Because of low participation among collaborators, this trial was terminated at the end of 1986.

Long-term fertility trial in irrigated rice. Significant responses of irrigated rice to application of N and combinations involving N were observed in most of the 139 trials since 1976. Responses to N were higher in DS than in WS, while responses to P, K, and PK were comparable in both seasons (Fig. 3). Significant response to N alone was observed in 105 trials, with an average yield increase of 1.4 t/ha in DS and 1.2 t/ha in WS (Table 5). P alone improved yields significantly by 0.8 t/ha in 23% of the trials, and K alone increased yields by 0.8 t/ha in 10% of the trials. In both seasons, responses to NP and NPK were significantly higher than to N alone, but NK was comparable to N alone.

At three Indonesian sites that have been conducting at least seven continuous croppings, N remains the limiting nutrient. Yield responses from NPK + Zn at suspected Zn-deficient sites were



3. Average yield increases with N, P, and K treatments in 62 DS and 77 WS trials. The international long-term fertility trial in irrigated rice, INSFFER, 1976-85.

either comparable or slightly lower than those from NPK alone. At one site, N alone performed as well as NP, NK, and NPK.

In the Philippines, the results of 19 croppings since 1976 in Luisiana and 17 croppings in Tanay showed that N continues to be the limiting nutrient. Eighty-five percent of all trials gave significant response to N alone, 98% to NP, and 100% to NPK. However, the percentage of trials responsive to P increased gradually to 36% by 1985.

Results from three sites in China showed that N alone or combined with P and K gave a significant response, especially during DS. P and K were effective only when combined with N. Yields from

Table 5. Significant yield responses to N, P, and K applied individually or in combination, averaged over number of responsive trials. International long-term fertility trial in irrigated rice, INSFFER, 1976-85.

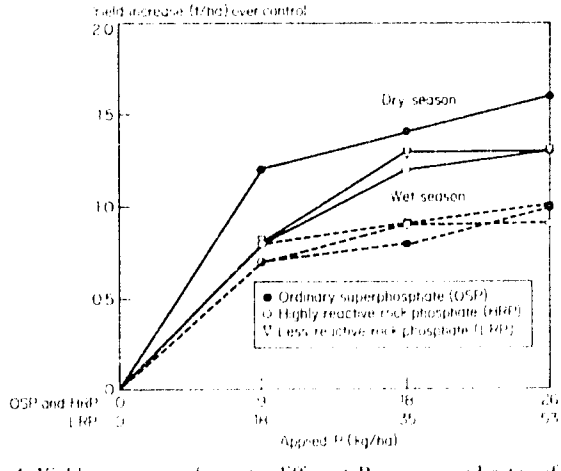
Treatment	Wet season			Dry season		
	Trials (no.)		Av yield response (t/ha)	Trials (no.)		Av yield response (t/ha)
	Total	Responsive to treatment		Total	Responsive to treatment	
N	77	54	1.21	62	51	1.40
P	76	19	0.72	62	13	0.90
K	76	9	0.84	62	5	0.74
NP	77	65	1.41	62	52	1.80
PK	75	23	0.84	62	22	0.87
NK	76	56	1.26	62	51	1.55
NPK	76	66	1.68	62	57	2.05
NPK + Zn[a]	22	15	1.61	16	9	1.94

[a] Additional treatment tested in suspected Zn-deficient sites.

N alone were comparable to those from NP, NK, and NPK.

N is also a limiting nutrient at two sites in India, especially in Pantnagar. In Dilip Nagar, NPK + Zn was more effective than NPK alone.

Sources of phosphorus. In the international trial on sources of P in flooded rice, average yield responses from 60 P-responsive trials at 29 sites in 12 countries from 1977 to 1985 showed that responses to P sources and rates of application were higher in DS than in WS except for rock phosphates at low P rate (Fig. 4). During DS, ordinary superphosphate gave higher yields than highly reactive rock phosphate (HRP) and less reactive rock phosphate (LRP). HRP and LRP produced similar yields. However, all P sources were equally effective during WS. This trial was terminated at the end of 1986.



4. Yield responses of rice to different P sources and rates of application. Data are averages of 18 P-responsive trials in DS and 42 in WS. International trial on sources of P in flooded rice, INSFFER, 1977-85.

Azolla. Seven trials in the fourth international trial on azolla use in rice at 7 sites in 5 countries in 1985 showed that azolla incorporated before or after transplanting at the rate of 15 t/ha can supplement as much as 30 kg N/ha from urea (Table 6). Compared with incorporation of azolla

Table 6. Average yield response of irrigated rice in the fourth international trial on azolla use in irrigated rice, INSFFER, 1985.

Treatment[a]	Grain yield[b] (t/ha)
No N, no azolla	3.7 (100)
30 N, all basal, broadcast and incorporated	4.2 (114)
30 N, all basal; incorporation of azolla is simulated at 3 wk AT[c]	4.3 (116)
60 N, 3 splits	4.5 (121)
30 N basal + 1.5 azolla incorporated BT	4.9 (131)
30 N basal + 1.5 azolla incorporated at 3 wk AT	5.1 (135)
30 N basal + 1.5 azolla applied (no incorporation) at 3 wk AT	4.4 (118)
Azolla grown and incorporated BT and again inoculated and incorporated at 3 wk AT	4.6 (124)
SE	0.2

[a] N was applied as urea in kg N/ha and azolla in kg fresh weight/m^2. AT = after transplanting, BT = before transplanting. [b] Average of 7 trials conducted at 7 sites in 5 countries. Numbers in parentheses are indexes; no N, no azolla taken as 100. [c] By disturbing the soil.

after transplanting, nonincorporation did not significantly improve rice grain yield. Soil disturbance had no significant effect on grain yield.

Integrated use of inorganic and organic N fertilizers. In the international trial on integrated use of inorganic and organic N fertilizers in lowland rice, the effectiveness of inorganic N fertilizers applied alone or in combination with either azolla or fresh straw was evaluated in 22 trials at 9 sites in 4 countries from 1984 to 1985. For combinations, N from organic materials was fixed at 29 kg N/ha and the inorganic N was applied as either PU in splits or USG DP.

A significant response to N was observed in all trials. The average yield responses across all sites for treatments involving pure inorganic N showed that USG DP yielded 21% more than PU BS at 58 and 87 kg N/ha (Table 7). Azolla combined with either PU or USG produced yields comparable to those with a pure inorganic source. The yield with fresh straw combined with PU was similar to that with pure PU and PU + azolla at both N rates. However, the combination of straw + USG yielded 0.3 t/ha less than pure USG at both rates of N.

A preliminary trial was conducted in 1986 WS in Los Baños, Philippines, to determine effective combinations and timing of application for inorganic N fertilizers and green manure. Results indicate that *Sesbania rostrata* incorporated into the soil at 40-50 d after emergence can provide as much as 40-140 kg N/ha (Table 8). *S. rostrata* alone produced a grain yield of 5.7 t/ha; yield was higher if it was combined with PU (Fig. 5).

Hand- and machine-applied N fertilizers. In the first international trial comparing hand- and machine-applied N fertilizers in lowland rice, the mean response to N was significant in 12 of the 15 trials conducted in 8 countries from 1984 to 1985. Of the 12 N-responsive trials, 7 were conducted in DS.

Hand-placed USG gave the highest mean yield response for both seasons. During DS, machine-

Table 7. Average yield increases of irrigated rice with application of PU and USG alone or in combination with azolla and straw at 2 N rates. First international trial on integrated use of inorganic and organic fertilizers in irrigated rice, INSFFER, 1984-85.

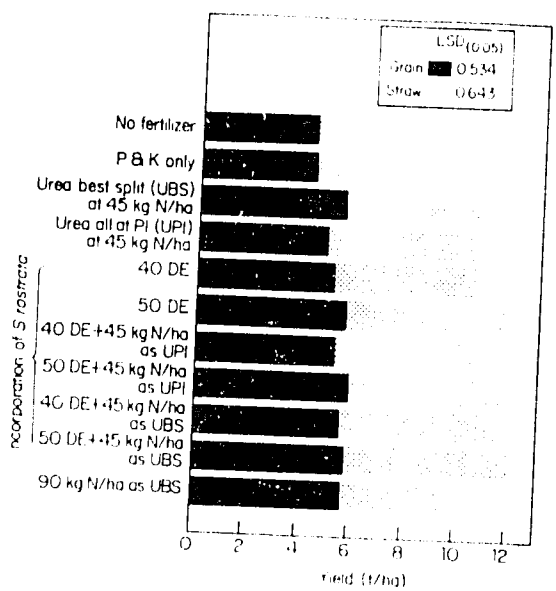
Treatment[a]	Yield increase[b] (t/ha)	
	58 kg N	87 kg N
PU	1.4	1.9
PU + azolla	1.3	2.0
PU + straw	1.1	1.9
USG	1.7	2.3
USG + azolla	1.6	2.4
USG + straw	1.4	2.0

[a]For combinations, organic N was fixed at 29 kg N/ha.
[b]The control (no fertilizer) yielded 3.4 t/ha. Yield increases over the control are the average of 22 trials at 9 sites in 4 countries. Yield increases from treatments with azolla and straw are the average of 19 and 22 trials, respectively.

Table 8. Biomass and N production of *Sesbania rostrata* as affected by age and cropping season.[a] IRRI, 1986 DS and WS.

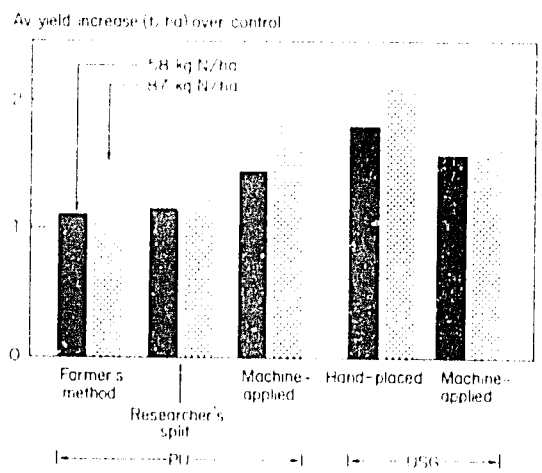
Age of *S. rostrata* (DE)[b]	Fresh biomass (t/ha)	N production (kg N/ha)
	Dry season	
40	9.6	43
50	22.2	128
	Wet season	
35	11.7	47
45	34.1	135

[a]All values are the average of 3 treatments and 4 replications. [b]DE = days after emergence.

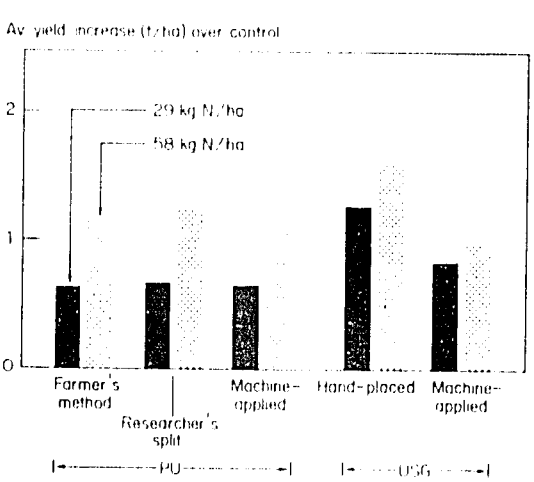


5. Grain and straw yields of IR64 as affected by inorganic N fertilizer and green manure, IRRI, 1986 DS. DE = days after emergence.

applied USG gave yields higher than those of machine-applied PU by 0.1 to 0.3 t/ha (Fig. 6). Machine-applied PU was also superior to PU standard BS by 0.3 t/ha at the lower N rate, although the trend was reversed at the higher N rate. Likewise, machine-applied USG and PU standard BS gave comparable yields. During WS, machine-applied PU gave comparable yields to PU local BS (Fig. 7). Machine-applied USG gave a lower yield than local BS or standard BS PU at the higher N rate. For the low N rate treatments in WS, the three application methods for PU gave comparable yield responses.



6. Significant yield responses of rice to PU and USG with different methods of application at 2 N rates tested at 7 N-responsive sites in 5 countries during DS. First international trial on the comparison of hand- and machine-applied N fertilizers in lowland rice, INSFFER, 1984-85.

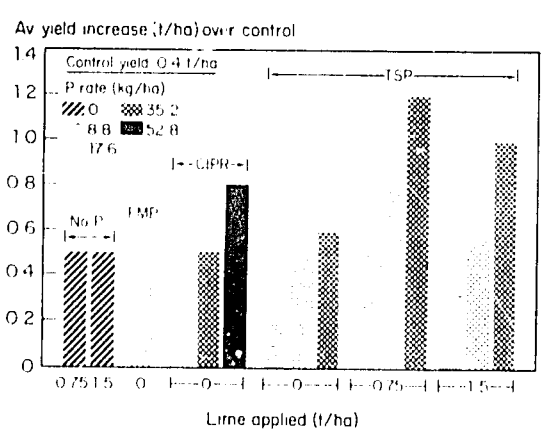


7. Yield response of rice to PU and USG at 2 N rates with different methods of application, tested at 5 N-responsive sites in 5 countries during WS. First international trial on the comparison of hand- and machine-applied N fertilizers in lowland rice, INSFFER, 1984-85.

Soil fertility management of acid upland soils. *pH* <5. Eight sets of fertilizers and fieldbooks were sent to five collaborators in four countries in 1985. Only the results of trials conducted by IRRI's Agronomy Department in an acid upland soil (pH 4.1) in Calirayа, Laguna, have been reported.

Three P sources — triple superphosphate (TSP), Christmas Island phosphate rock (CIPR), and fused magnesium phosphate (FMP) — and lime were tested in three consecutive WS trials in 1984-86. With lime, yield with TSP increased progressively with P applied, which may be attributed to the accumulation of P over the years (Fig. 8). Such accumulation may likewise explain the increase in yield with increasing CIPR rate. Without lime, TSP gave yields lower than those with lime by 0.4-0.6 t/ha. The application of 0.75 t lime/ha caused yield increases at all P levels. However, yield reduction occurred when lime was doubled. To obtain substantial yields from the less soluble FMP and CIPR, liming is necessary.

pH 5-7. Four sets of fertilizers and fieldbooks were sent to four collaborators in four countries in 1985. Only the results of trials conducted at the IRRI upland farm during 1985-86 WS were submitted and summarized.



8. Average yield response of rice in 3 trials conducted at an acid upland site (pH 4.1) in Calirayа, Laguna, Philippines, 1984-86 WS. First international trial on soil fertility management in acid upland soils (pH <5) for upland rice, INSFFER, 1986. CIPR = Christmas Island rock phosphate, TSP = triple superphosphate, FMP = fused magnesium phosphate.

Table 9. Yields of 8 treatments tested in the first international trial on soil fertility management of acid upland rice soils (pH 5-7). IRRI, 1985 and 1986 WS crops.

Treatment	Grain yield[a] (t/ha)			
	Site 1		Site 2	
	1985	1986	1985	1986
NPKS	2.5 a	3.2 abc	2.2 a	3.4 ab
PKS	2.2 ab	2.8 cd	2.1 a	2.7 bcd
NKS	2.4 ab	3.2 abc	2.3 a	3.4 ab
NPS	2.5 a	3.8 a	2.3 a	3.4 ab
NPK	2.7 a	3.4 ab	2.3 a	3.9 a
Control	2.2 ab	2.2 e	2.2 a	2.6 cd
Control	1.9 b	2.4 de	2.0 a	2.0 d
Control	1.9 b	2.6 de	2.4 a	2.0 d
CV (%)	13.5	11.4	13.3	17.1

[a]Sites 1 and 2 are adjacent.

Using the late-maturing upland variety UPLRi-5, 8 treatments were tested at 2 adjacent sites with pH 5.7. Except for the 1985 WS crop at site 2, the mean response to applied fertilizers was significant in all crops at both sites (Table 9). Yields from treatments involving N were not significantly different from each other in all crops. NPKS, NKS, NPS, and NPK produced significantly higher yields than PKS and the control plots, which had similar yields; this indicates that N remains the only limiting nutrient after two crops of rice and one crop of either sorghum or cowpea. Lower yields in 1985 WS crops were caused by rice BI during the last stages of growth.

SITE VISIT TOURS AND WORKSHOPS

An INSFFER site visit tour and workshop, sponsored jointly by the Chinese Academy of Agricultural Sciences and IRRI, was held in China, 11-26 Sep 1986. Among the 27 participants representing 12 countries, 20 were active INSFFER collaborators from 10 countries. The tour provided the group the opportunity for a close view of the production of rice and other important crops in the southeastern regions of China. Ongoing INSFFER trials were visited to observe their conduct, discuss existing problems, and share notable experiences encountered in the process of research. A 3-d planning meeting and workshop following the tour was devoted to discussing current research thrusts and accomplishments, identifying unresolved challenges, and evaluating and reviewing the results of INSFFER trials.

The INSFFER Advisory Committee met for the first time. Future plans for INSFFER were drawn up by the participating collaborators, using the guidelines set and recommendations made by the Advisory Committee.

The workshop papers as well as the discussions focused on integrated nutrient management in rice.

CHARACTERIZATION OF SOILS AT INSFFER SITES

The INSFFER program, jointly with collaborators from the rice-growing countries in Asia, initiated characterization and classification of soils of some INSFFER sites. *Soil taxonomy* (1975) and the Fertility Capability Classification (FCC) System are being used to stratify the soils into "homogeneous" groups for possible correlation between site characteristics and the inherent productivity of the sites and responses to specific management practices.

Soil characterization has been conducted mostly at the sites of the N fertilizer efficiency trials: 12 sites in Indonesia in 1982; 26 in the Philippines in 1983; and 16 in India, 10 in Thailand, and 17 in Indonesia in 1986. The soils at the 81 sites were classified under 7 soil orders of *Soil taxonomy* (Table 10).

The majority of the sites are on Inceptisols, followed by Alfisols, Vertisols, Mollisols, and Entisols. Only one wetland site is on Oxisols and one on Ultisols. The numbers of sites on Inceptisols

Table 10. Distribution of 81 sites by country and soil order. IRRI, 1986.

Soil order	Sites (no.)			
	India	Indonesia	Philippines	Thailand
Oxisols	1	3[a]	0	0
Vertisols	3	3	8	1
Ultisols	0	1	1[a]	0
Mollisols	3	2	7	0
Alfisols	4	6	1[a]	4
Inceptisols	5	13	8	4
Entisols	0	1	3+1[a]	1
Total	16	29	26	10

[a]Nonwetland soils or not normally used for wetland rice.

and Alfisols indicate the extent of ricelands on these soils. Ricelands on Vertisols are suspected to be more extensive than those on Mollisols.

The general pedon characteristics, associated landforms, and some salient physical and chemical properties of the soils according to soil order are given in Table 11. The ranges of fertility-related soil properties according to great group taxon are given in more detail in Table 12.

Except for the great groups under the Vertisols, which are all of the clayey textural class, soils classified under the six other orders have variable textural classes that are reflected in categories of the soil family. Low pH values are associated with the Oxisols (Gibbsiorthox and Haplorthox), the Ultisols (Plinthaquults and Palehumults), the Sulfaquepts, and the Sulfic Tropaquepts. The ranges of organic C content in the upper 50 cm depth of the soils show no consistent association with great group category. Neither can any relationship be established between great group category and the ranges of Bray P or exchangeable K. These fertility-related properties may have been modified by management practices over the periods that the soils were used for crop production. The surface 20 cm manifested higher P and K levels in some of the pedons than the 20-50 cm depth; this can be attributed to the addition of these nutrients, especially where the levels were low in the deeper horizons. Laboratory data have shown

Table 11. General characteristics of the soils at INSFFER sites, by soil order. IRRI, 1986.

Soil order	Pedon characteristics and landforms	Salient physical properties	Salient chemical properties
Oxisols	Horizon(s) of Fe and Al concentration (Oxic horizon) present; intensely weathered materials on highly stable level landforms and interhill valley	Slightly discernible structure; highly permeable, but surface water retained in the presence of indurated layer near the surface; good physical properties	Medium acid to near neutral; low clay and soil CEC; low nutrient reserves and weatherable minerals
Vertisols	Presence of deep wide cracks when dry; with tilted blocky peds and intersecting slickensides; level to undulating landscapes	Generally clayey with smectite clays; high swelling and shrinking properties; high surface water retention; hard when dry; sticky and plastic when wet	Medium acid to calcareous; high clay and soil CEC; high base saturation
Ultisols	Horizon(s) of clay accumulation present; intensely weathered and leached materials on old landforms; level to hilly landscapes	Variable texture; good physical conditions; argillic horizon aids in surface water retention	Strong to medium acidity; low clay and soil CEC; low base saturation; low weatherable minerals and nutrient reserves
Mollisols	Dark deep surface soil; may or may not have argillic horizon; on level to undulating relatively old landforms	Well aggregated and friable; water retention dependent on texture	Weakly acid to calcareous; medium to high clay and soil CEC; high base saturation and nutrient reserves
Alfisols	Argillic horizon present; on relatively stable landform; level to sloping landscapes	Argillic horizon aids in surface water retention; physical properties vary with type of clays and texture	Medium acid to calcareous to alkaline; medium to high clay and soil CEC; medium to high base saturation
Inceptisols	Moderately developed soils on slopes and slightly older depositional areas	Physical properties vary with texture and clay type, highly influenced by parent materials	Wide ranges of chemical properties dependent on texture and clay type and highly influenced by parent materials
Entisols	Weakly developed pedons on stratified materials on young depositional areas and manmade terrace systems	Physical properties vary with those of parent materials and their source	Variability associated with parent materials and their sources

Table 12. Ranges of some fertility-related soil properties of the upper 20 and 20-50 cm depths[a] of soils at the great group level of *Soil taxonomy* with the corresponding Fertility Capability Classification (FCC) System designations. IRRI, 1986.

Soil taxonomy and FCC designations[b]	Textural class	Soil pH	Organic C (%)	Bray P (ppm)	Exchangeable K (meq/100 g)	Base saturation (%)	Soil CEC (meq/100 g)
Gibbsiorthox (1) Sgedi	Loamy sand	5.5 / 6.0	0.6 / 0.4	8 / 3	tr / tr	40 / 67	3 / 2
Haplorthox (3) Celx	Clays	4.6–5.0 / 4.8–5.2	1.5–1.9 / 0.6–0.7	9–17 / 8–11	tr / tr	9–52 / 7–41	8–20 / 9–18
Chromusterts (5) 2 Cgvd; 3 Cgvdb	Clays	5.3–8.0 / 5.4–8.2	1.3–1.5 / 0.4–1.6	15–45 / 12–47	0.2–0.8 / 0.2–0.7	59–100+ / 94–100+	28–50 / 27–51
Pelluderts (2) Cgv & Cgbv	Clays	6.0–7.4 / 6.6–7.4	1.7–2.2 / 0.6–0.8	11–51 / 5–35	0.2–1.0 / tr–0.9	92–100+ / 100+	32–55 / 55–58
Pellusterts (5) 2 Cgvd, 3 Cgvdb	Clay to silty clay	5.3–8.0 / 6.6–8.2	0.8–1.9 / 0.3–0.6	12–51 / 5–35	0.2–0.6 / tr–0.9	92–100+ / 93–100+	32–60 / 39–47
Plinthaquults (1) Lgedai	Clay loam	4.8 / 4.6	0.7 / 0.4	6 / 6	tr / tr	45 / 26	12 / 14
Palehumults (1) Lhex	Loam	4.8 / 4.9	5.1 / 1.6	–	1.3 / 0.1	12 / 3	41 / 30
Haplaquolls (9) 2 Cdvqx; 2 Cgx Cgdb; Lgd; Lg Lgde; Lgdb	Loams to clays	5.5–8.2 / 6.2–8.7	0.8–3.4 / 0.5–1.5	13–113 / 12–44	0.1–0.6 / tr–0.6	57–100+ / 75–100+	16–47 / 9–48
Haplustolls (3) 2 Lgdb; Ldb	Loam to clay loam	6.8–7.9 / 7.3–8.0	0.7–1.0 / 0.3–0.7	5.7 / 5.3	0.1–0.2 / tr–0.1	96–100+ / 100+	29–51 / 40–52
Plinthaqualfs (2) Lgde & Cgd	Silt loam to clay	5.8–6.6 / 5.8–7.6	0.4–0.8 / 0.1–0.3	6–17 / 6–11	0.1–0.2 / 0.1–0.2	92–100+ / 74–100+	5–18 / 4–24
Tropaqualfs (5) 2Lgd; Lgde LCgd; Cgd	Sandy loam to silty clay	5.1–6.5 / 5.1–7.0	0.3–1.0 / 0.2–0.6	5–41 / 6–36	tr–0.3 / tr–0.3	72–100+ / 53–100+	3–39 / 14–43
Natrustalfs (2) Lgdn	Sandy loam to silt loam	6.2–8.4 / 6.7–9.0	0.3–0.6 / 0.1–0.3	4–5 / 4–6	0.1–0.2 / 0.1	100+ / 100+	5–13 / 4–14
Paleudalfs (1) Cgix	Clay	5.7 / 6.3	1.5 / 0.6	12 / 13	0.7 / 0.5	73 / 87	17 / 13
Tropudalfs (3) LC	Silt loam	5.8 / 5.5	0.6 / 0.4	4 / 7	0.2 / 0.3	77 / 47	14 / 30
Haplustalfs (3) Lgd; Lgdb; Lgdbe	Silt loam to clay loam	5.6–8.5 / 5.4–8.7	0.4–2.0 / 0.2–0.7	11–16 / 6–12	0.1–0.9 / 0.2–0.5	68–100+ / 62–100+	6–29 / 7–14
Ochraqualfs (1)	–	–	–	–	–	–	–
Sulfaquepts (1) Cgdvac	Clay	4.2 / 3.9	2.0 / 0.9	20 / 9	0.4 / 0.3	57 / 41	19 / 18
Halaquepts (1) Lgdn	Silt loam	8.1 / 8.7	0.8 / 0.2	78 / 19	0.2 / 0.2	100+ / 100+	13 / 14
Plinthaquepts (1) Lgdi	Clay	5.6 / 5.0	2.3 / 0.6	–	0.4 / 0.5	–	31 / 14
Tropaquepts (10) (Typic + Aeric) Lg; Lgd; 2 Cg Cgd; 2 Cgx; Lgdx 2 Lgde	Loam to clay	5.1–7.2 / 4.8–7.2	0.5–2.0 / 0.2–1.4	8–79 / 9–90	0.1–0.4 / 0.1–0.4	65–100+ / 71–100+	14–30 / 10–30

Continued on opposite page

Table 12 continued

Soil taxonomy and FCC designations[b]	Textural class	Soil pH	Organic C (%)	Bray P (ppm)	Exchangeable K (meq/100 g)	Base saturation (%)	Soil CEC (meq/100 g)
Tropaquepts (4) (Vertic) 2 Cgv; Lgdvb; LCgv	Clay	4.9–7.6	1.6–1.9	6–13	0.2–0.4	44–100+	9–32
		5.3–7.6	0.4–1.2	9	0.1–0.3	73–100+	22–38
Tropaquepts (2) (Sulfic) Cgdaicv	Clay	4.0–4.3	0.8–1.1	11–16	0.4–0.8	74–76	19–28
		3.8–4.2	0.5–0.9	6–10	0.3–0.5	58–65	18–26
Tropaquepts (3) (Fluventic) Lgde; 2 Cgd	Silt loam to silty clay	5.6–7.7	0.5–3.1	11	0.1–0.9	99–100+	8–14
		7.0–8.1	0.2–0.4	6	0.1–0.8	99–100+	12–34
Haplaquepts (1) Cgdb	Clay	8.0	1.2	55	0.4	100+	32
		7.7	0.5	53	0.4	100+	30
Andaquepts (1) Lgdx	Silt loam	7.1	0.5	70	0.1	98	18
		7.2	0.4	90	0.1	94	21
Vitrandepts (2) Lgdx; LSdxg	Sandy loam	6.5	0.7–0.9	100–205	0.2–0.3	100+	11–12
		6.5	0.2–0.8	150–203	0.2–0.3	82–100+	10–11
Eutrandepts (2) Lx; LSdx	Loam	5.7–5.9	1.0–2.8	24–78	0.5	59–71	12–14
		6.1–6.9	0.5–1.6	78–63	0.7	68–88	10
Ustochrepts (2) Ldvb; Ldv	Silt loam to clay loam	7.7–8.3	0.5–0.7	49–80	0.4–0.5	100+	8–24
		8.1	0.2	29	0.3	100+	25
Ustropepts (1) Sde	Loamy sand	4.3	0.5	25	tr	–	2
		4.8	0.4	20	tr		2
Fluvaquents (1) Cgv	Silty clay	5.5	2.4	–	0.4	88	33
		6.2	0.6		0.6	95	45
Tropofluvents (1) Lg	Silt	5.7	3.0	–	tr	81	52
		6.2	4.0		tr	85	53
Troporthents (1) Cg	Clay	4.9	1.5	–	0.3	47	26
		5.9	0.9		0.3	69	25
Ustifluvents (1) Ldge	Loamy sand	5.3	0.7	–	0.5	44	5
		5.6	0.4		0.1	54	4

[a]Figures above the lines are for the 0-20 cm, those below for the 20-50 cm depth. tr = trace, (–) = no data. [b]Explanation of FCC designations: S = sandy texture, L = loamy texture, C = clayey texture, LS = loamy over sandy texture, a = extremely acidic, b = with free carbonates, c = associated with cat clays, d = normal occurrence of long droughty periods, e = low CEC of soils, g = wet or poorly drained, i = Fe toxicity probable, n = sodic (ESP is 15% or more), v = poor tilth associated with vertic properties, x = detectable influence of amorphous minerals. Numbers in parentheses are number of pedons characterized for the great group.

that many of the sites have low levels of available P (<20 ppm Bray P) and exchangeable K (<0.2 meq/100 g soil) throughout the profiles, and emphasis on these nutrients in the fertility management of these soils becomes essential for increased production.

The base saturations were generally lower at the 20-50 cm depths than in the surface 20 cm in Oxisols, Ultisols, and some Alfisols. The base saturation levels of Oxisols and Ultisols were inherently lower than that of the Alfisols. Although CEC is dependent on the quantity of clay, the low CECs of the clayey Oxisols, Ultisols, and some Alfisols reflect the dominance of low activity oxide and kaolinitic clays associated with these soils.

The available information on the areas of these soil orders and their respective lower categories may be both incomplete and isolated. Extracting the available information requires strong cooperation and linkages among workers in the various

countries. Participating scientists may be motivated to allocate funds, time, and effort to extract these data if the present exercise shows positive indications for the use of *Soil taxonomy* or the FCC System in stratifying sites according to potential productivity, predictability of crop response to management, and the possibility of the most direct transfer of appropriate agronomic innovations among similar sites. The objectives of site characterization may be attained by superimposing other environmental factors (climate and weather), biological constraints (diseases and pests), and suitable genotypes over the more stable site characteristic, the soil.

Cooperative programs

Asian rice farming systems network

Rice Farming Systems Program, and Agricultural Economics and Communication and Publications Departments

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WOMEN IN RICE FARMING SYSTEMS 568

The Asian Rice Farming Systems Network (ARFSN) consists of Bangladesh, Bhutan, Burma, China, India, Indonesia, Madagascar, Malaysia, Nepal, Pakistan, Philippines, Republic of Korea, Sri Lanka, Taiwan (China), Thailand, and Vietnam. The network also involves national institutions and international centers to provide technologies for commodities in which IRRI has no expertise. The program continued the ongoing collaborative research on farming systems and development with emphasis on cropping pattern testing, varietal testing of upland crops, long-term cropping pattern and fertilizer trials, rice - wheat cropping systems, crop - livestock systems research, and women in rice farming.

Research methodology developed and refined by IRRI and network scientists is used in participating countries with some modifications to suit their organizational structure and available manpower and financial resources. Most of the sites in collaborating countries focus their work on cropping pattern testing in rainfed lowland, irrigated and partially irrigated lowland, and upland rice. Thailand, the Philippines, and Indonesia expanded their activities in other crop-based farming systems, particularly in maize, coconut, and cassava. Indonesia and the Philippines expanded their activities in hillside farming with emphasis on food crops and agroforestry. The Philippines, Thailand, Indonesia, Bangladesh, Burma, and Nepal included a livestock component in their cropping systems research activities.

National programs, such as those of Bangladesh, the Philippines, Nepal, Sri Lanka, and Thailand, expanded the preproduction (multilocation testing and pilot production) phase of the methodology. The Philippine Regional Integrated Agricultural Research System conducted several pilot production programs in villages where they had conducted cropping systems research. The Bangladesh Rice Research Institute (BRRI) and Bangladesh Agricultural Research Institute (BARI) expanded their multilocation testing in rainfed and irrigated rice areas, using data obtained from their cropping systems sites. BRRI, in collaboration with the Department of Agricultural Extension, established multilocation trials in 41 villages, and tested several cropping patterns from 5 cropping systems sites at 20 multilocation sites. In Sri Lanka, pilot production programs were conducted in two areas, using results from the Katupotha cropping systems site. Preproduction programs were implemented in Thailand in Chiang Mai, Phayao, Lampung, and Phrae using mungbean - rice and direct seeded rice alone. Production programs in Nepal in 1984-85 covered 35,000 ha in 17 districts in the terai. Yield increases of 15-20% were recorded in almost all districts. In 1986 the production program was expanded to cover 70,000 ha in 22 districts of 5 development regions. In Iloilo, Philippines, the special production program known as KABSAKA is now integrated into the regular production program of the province.

CROPPING PATTERN TESTING

Rice Farming Systems Program and Agricultural Economics Department

Collaboration on cropping pattern testing, which started in 1975, involves testing of crop sequences in different rice environments using the cropping systems research methodology developed and refined by IRRI and network scientists. There are 43 sites involved in the collaboration in Burma, Bangladesh, China, Indonesia, Malaysia, Nepal, Pakistan, Philippines, Republic of Korea, Sri Lanka, Taiwan (China), and Thailand. We monitored environmental factors and the crop and economic performance of cropping patterns. In most cases the focus at a site was to increase production, net income, and cropping intensity. At some sites we increased both the production of each crop in the pattern and the income of the total system. The sites represent rainfed lowland, partially irrigated lowland, irrigated lowland, and upland conditions.

Several cropping patterns were tested and compared with the farmers' dominant pattern at each site (Table 1). In most cases, the experimental patterns were better in total production and income than the farmers' patterns. However, production costs of the experimental patterns were high because of the large amounts of inputs. The promising cropping patterns indicated in Table 1 were agronomically and economically better than the dominant farmers' cropping patterns.

Table 1. Number of crops in farmers' predominant patterns and in the experimental pattern, and promising cropping patterns, 1986.

Site	Crops (no.) in		Promising cropping patterns
	Farmers' pattern	Experimental pattern	
		Rainfed lowland	
Bacnotan, Philippines	1	2-3	Green maize - rice - mungbean Rice - tobacco - maize
Tumauini, Philippines	1-2	2	Mungbean - rice Rice - rice
Wakema, Burma	1-2	2	Jute - rice - soybean Rice - sunflower
Padang Terap, Malaysia	1	2	Rice - watermelon
Siaton, Philippines	1-2	2	Rice - mungbean
Bireun Aceh, Indonesia[a]	1	2	Rice - soybean
Ratna Nager, Nepal[a]	1-2	2-3	Rice - chickpea + mustard
Maasin, Philippines	1-2	2-3	Rice - rice Rice - rice - mungbean
Phayao, Thailand[a]	1	2	Mungbean - rice Dry seeded rice + rice
Srisaket, Thailand	1	2	Sesame - rice Green maize - rice
Pumdi Bhumdi, Nepal[a]	2-3	2-3	Rice - wheat - maize Rice - mustard - wheat
Screepur, Bangladesh	1-2	2	Rice (local) - rice (BR11 or BR10)
		Partially irrigated lowland	
North Nawin, Burma	1	2	Rice - sunflower
Guimba, Philippines	1-2	2-3	Rice - maize - mungbean Rice - upland crop
Patheingyi, Burma	1	2	Cotton - rice Sesame - rice
Yezin, Burma	1-2	2-3	Peanut - rice - sorghum Maize - rice - cowpea
Ratna Nager, Nepal	2 + 3	2-3	Rice - mustard - maize
		Irrigated lowland	
Beijing, China	1-2	2	Wheat - dry seeded rice
Guangzhou, China	2-3	3	Wheat - rice - sweet potato Faba bean - rice - rice
Chengdu, China			Wheat - rapeseed Sweet potato - rice 6 crops in 2-yr rotation
Parsa, Nepal[a]	2-3	3	Rice - maize - mungbean Rice - chickpea + mustard
Shoaxing, China	2-3	2-3	Barley - watermelon - rice Barley - rice - green soybean
Ratna Nager, Nepal[a]	2	3	Rice - wheat - mungbean Rice - wheat - dhaincha
Kaoshung, China	2-3	2-3	Rice - sorghum - ratoon sorghum
Changhwa, China	2-3	3	Rice - green manure - maize Sorghum - ratoon sorghum - maize
Tainan, China	2-3	3	Rice - soybean - maize
Jeurbuk, Korea	1-2	2	Rice - garlic Sorghum - ratoon sorghum - maize
Daska, Pakistan	2	2	Rice - sunflower Rice - chickpea
Ubon, Thailand	2	3	Rice + fish - rice

Continued on next page

Table 1 continued

Site	Crops (no.) in		Promising cropping patterns
	Farmers' pattern	Experimental pattern	
Guimba, Philippines	2	3	Rice - rice - mungbean
Dipolog, Philippines	2	2-3	Rice - rice - mungbean
Compostela, Philippines	2	2-3	Rice - rice - rice Rice - mungbean - rice
Chungbuk, Korea	2	2-3	Rice - lettuce - sweet maize Rice - spinach - green pea
		Upland	
Trece Martires, Philippines	2-3	2-3	Banana + rice - green maize Banana + rice - peanut
Batumarta, Indonesia[b]	2-3	4	Rice + maize/cassava/ peanut or soybean
Manito, Albay, Philippines	2	2-3	Rice - sweet potato - mungbean
Claveria, Philippines	1-2	3-4	Mungbean - rice - peanut + sweet potato Maize - maize - grain legumes
Jaimindan, Philippines	1-2	4	Rice + maize - maize + peanut
Screepur, Bangladesh	1-2	2	Swamp cabbage - black gram Rice (BR20) - black gram

[a]Used for multilocation or pilot production program or both. [b]Used for multilocation testing.

VARIETAL TESTING

Rice Farming Systems Program

Entries in trials to test upland crop varieties before and after rice came from the breeding programs of the Institute of Plant Breeding (IPB) (Philippines), Field Crops Research Institute (Thailand), Central Research Institute for Food Crops (CRIFC) (Indonesia), International Institute of Tropical Agriculture (IITA), and other national programs and international centers like the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The breeding activities of the IPB and IRRI-IITA projects and the screening activities of IRRI are presented in the section on the Cropping Systems Program. Seeds of promising varieties from the projects were sent to IRRI for seed increase and distribution throughout the network. National programs also contributed a few promising entries from their breeding programs.

This collaboration encouraged national programs to establish their own breeding programs for upland crops in rice farming systems, particularly for the rainfed lowlands. The Philippines, Thailand, Indonesia, Nepal, Bangladesh, Sri Lanka, and Pakistan strengthened their breeding programs to include development of legume varieties for rice farming.

In 1986, we increased seeds of 13 mungbean (MB) varieties from IPB, Pakistan, Indonesia, and China; 7 wheat (W) varieties from IPB; 4 maize (M) varieties from IPB and Thailand; 10 sorghum (S) varieties from ICRISAT; 11 peanut (P) varieties from IPB and China; and 4 pigeonpea (PP) varieties from ICRISAT. We also received 5 soybean (SB) and 21 MB varieties from IPB, which were screened for high yield potential, acid soil tolerance, and drought tolerance. These varieties will be multiplied in the 1986-87 dry season (DS).

For the 1985-86 cropping pattern year, 183 trials before rice (46 MB, 37 cowpea [CP], 30 bush sitao [BSi], 16 SB, 13 P, 8 S, and 33 M) and 214 trials after rice (40 MB, 35 CP, 27 BSi, 34 SB, 23 P, 16 S, 33 M, and 6 PP) were distributed to Nepal, Burma, Bangladesh, China, Thailand, Vietnam, Indonesia, Madagascar, Sri Lanka, Taiwan (China), and the Philippines. Most of the trials were grown under rainfed lowland and irrigated lowland conditions. In the Philippines, a few trials were grown in the uplands.

Varietal trials after and before rice were conducted in eight countries in the 1985-86 cropping pattern year. The number of entries in each trial varied from 8 to 12. Two local checks were

included. From data received from the Philippines, Thailand, Indonesia, Nepal, Burma, Taiwan (China), and Vietnam, several promising varieties were identified. The most promising in terms of grain and fodder yields that were better than the check or highest yielding varieties are presented in Tables 2 and 3.

LONG-TERM CROPPING PATTERN AND FERTILIZER TRIALS

Rice Farming Systems Program

Sustainability of agriculture is now a major concern of most national programs, especially with the intensive use of cultivated land in heavily populated areas. Continued cultivation will result in rapid loss of fertility and consequent lower production. Network scientists decided to study the effects over at least 3 yr of continuous cropping using different crop rotations on the soil and crop performance, and the residual effects of fertilizer and other soil amendments on cropping pattern performance. Collaborators in Bangladesh, Indonesia, Burma, India, China, Nepal, and Taiwan (China) designed their experiments to suit their own environments cropping patterns and fertilizer treatments vary from location to location but use a uniform data format.

Nepal tried four cropping patterns with three fertilizer rates in Khumaltar; there is also an ongoing rice [R] - R - W cropping pattern with various fertilizer levels in Parwanipur. In Bangladesh in 1985, BRRI established long-term cropping pattern trials with four cropping patterns under irrigated conditions in Comilla and Joydebpur and three cropping patterns in rainfed lowlands in Joydebpur and Rajshahi. In Burma, long-term studies on fertilizer effects and cropping patterns are being conducted in Yezin; partial results indicate that N becomes limiting with continuous cropping, but crop residues of previous crops in the pattern may partially correct this.

In Indonesia, four experiments were begun at several locations: 1) effectiveness of partially acidulated phosphate rock in year-round cropping pattern at four research sites, 2) crop and soil response to time and P treatment in cropping patterns at four research sites, 3) controlled-release N fertilizers in upland cropping at five research

Table 2. Upland crop varieties better than the local check or highest yielding across locations in the Asian Rice Farming Systems Network (ARFSN) when planted before lowland rice, 1985-86 cropping pattern year.

Location	Mungbean		Cowpea		Bush sitao	Peanut		Maize	
	Grain	Fodder	Grain	Fodder	Fresh pod	Shelled bean	Fodder	Grain	Fodder
Philippines	IPB M79-9-82	IPB M79-13-29	IT 82D-892	IT 82E-18	83F-563-7	–	–	–	–
	VC 2768A	IPB M79-9-82	IT 82D-891	IT 82E-16	EG BS2				
	VC 1973A	Pag-asa 3	IT 82D-889	All Season	LG 17-23-2-2				
	IPB M79-13-60	IPB M79-13-60	CES 41-6	IT 82D-787	LBBS #1				
Indonesia	Pag-asa 1	IPB M79-22-62	–	–	–	–	–	XC #1	XC #1
	IPB M79-9-94	IPB M79-17-79						Early DMR	Early DMR
	IPB M79-22-62	IPB M79-9-94						Comp 1	Comp 1
	IPB M79-9-82	IPB M79-9-82						Pirsabak 7931	Tocumen 7931
Nepal	–	–	IT 82E-18	–	–	–	–	–	–
			All Season						
			IT 82E-16						
Burma	IPB M79-9-94	IPB M79-9-94	–	–	–	CES 2-25	CES 2-25	–	–
	IPB M79-13-60	IPB M79-17-79				Acc 12	Acc 12		
	M350	IPB M79-22-62				UPL PN-2	PI 118200		
	Pag-asa 3	IPB M79-9-82							

Table 3. Upland crop varieties better than the local check or highest yielding across locations in ARFSN when planted after lowland rice, 1985-85 cropping pattern year.

Location	Mungbean		Cowpea			Bush sitao		Soybean
	Grain	Fodder	Fresh pod	Grain	Fodder	Fresh pod	Fodder	Grain
Philippines	IPB M79-13-29 IPB M79-9-94 IPB M79-9-82 IPB M79-22-11	IPB M79-13-29 IPB M79-9-94 IPB M79-9-82	TVx 2724-01F EG #2 All Season TVx 1948-01F	TVx 2724-01F TVx 3381-02F TVx 3410-02J	TVx 4659-03E TVx 3381-02F TVx 3410-02J	BS_3(6-14RxAS) BS_3(6-14RxAS) IT-818-1228-14	BS_1(6-14RxAS) BS_7 IT-818-1228-14	Acc 2120 UPL SY-2 7207-1
Thailand	IPB M79-13-60 IPB M79-22-62 IPB M79-22-17	IPB M79-22-17 IPB M79-13-60 IPB M79-17-79				LBBS #1 BS_1(6-14RxAS) BS_3(6-14RxAS)	BS_1(6-14RxAS) BS_6 BS_7	7521-26-2 7207-1 30290-11-11
Burma			TVx 4661-7D Vita 7 TVx 289-4G	TVx 4678-03E TVx 289-4G TVx 3410-02J	TVx 4678-03E TVx 3381-02F TVx 4659-03E			7207-1 Clark 63 30290-11-11 UPL SY-2
Vietnam	Pag-asa 3 CES 11-2 IPB M79-13-45 IPB M79-9-82	Pag-asa 3 Pag-asa 3 IPB M79-13-29 IPB M79-9-94						

Location	Peanut		Sorghum			Maize	Pigeonpea		Sweet potato	
	Shelled bean	Fodder	Grain	Fodder	Grain	Fodder	Grain	Fodder	Roots	Fodder
Philippines	UPL PN-4 CES 2-25 CES 101	UPL PN-4 CES 101 CES 2-25	UPL SG-5 CS 100 CS 110	UPL SG-5 CES 1-0 CES 336	xC #1 EDC 1 Tocumen 7931	TFE 139 Tocumen 7931 xC #1	QPL 72 ICPL-87 ICPL-81	TCF 6-1-1 ICPL-6 QPL 87	V2-1 CI-93-9 Kinabakab	Kinabakab G 113-2b Timpay
Thailand	CES 101 CES 102 CES 2-25		CES 336 CS 182 CS 110 CS 346	CS 182 UPL SG 5 CS 346 CS 110	xC #1 Arun 2 Thai Comp Early Pirsabak 7930	Thai Comp Early TFE 139 Early DMR Comp 2				
Taiwan, China	Tainan No. 10 TF 9 Hong Mei-Chao IPB PN-2-25	Tainan IPB PN-48-90 EG PN-18 EG PN-11								
Indonesia	CES 2-25 UPL PN-2 M-10	CES 102 CES 101 CES 2-25	UPL SG-5 CS 346 CS 116 CS 110	CS 110 UPL SG-5 CS 405 CS 182	xC #1 Early DMR 2 Panjuna					
Burma	CES 2-25 CES 102 M-10	CES 101 CES 102 CES 2-25	CS 116 CS 346 CS 416	CS 110 CS 253 CS 182	Early DMR Comp 2 Tocumen 7931 xC #1 Panjuna	Tocumen 7931 Early DMR Comp 2 Early DMR Comp 1				

sites, and 4) evaluation of effects of crop residue management on soil and production of R and SB in year-round cropping patterns at three experiment stations. Some of the experiments in farmers' fields were discontinued. Studies in the upland system looking at crop responses to P and lime indicate general decreases in yield because of loss of organic matter and general soil fertility in some locations and no effect in other studies.

Most cropping pattern experiments in China are long-term trials of at least 3-6 yr, with rotation of cropping patterns. Long-term studies of 6 rotations in Guangdong showed that 2-yr combinations of W, R, P, pea, and green manure gave the highest net returns; in Sichuan, 2-yr combinations of W, rapeseed (RS), sweet potato (SP), and R gave the highest net returns. In Pintung, the District Agricultural Improvement Station is conducting long-term trials with three cropping patterns and three fertilizer rates. There were no appreciable changes in soil pH and no significant differences in organic content. Available P increased, and the available K in SB - R - M was higher than in other patterns.

In India, collaboration on integrated production trials in irrigated areas was undertaken at 14 research institutions in 1985. Each institution designed its cropping pattern and evaluated 2-8 patterns for at least 3 yr. Available data are only on cropping pattern performance. Each institution identified the most promising cropping patterns. No data on soil were reported.

RICE - WHEAT CROPPING SYSTEMS

Rice Farming Systems Program

IRRI, CIMMYT, and national programs agreed to start collaborative research to identify R and W varieties that will satisfy the crop rotation needs of farmers and to identify profitable R - W systems in different rice environments. Collaboration started on cropping pattern testing and international R - W integrated trials. Varietal trials were distributed to 13 countries involved in ARESN in 1984 and 1985. Several R varieties were identified as better than local checks in temperate, subtropical, and tropical countries, while the local W check varieties were generally better than introduced varieties. W yields were very low in tropical countries. In 1985, we discontinued the integrated variety trial and concentrated on cropping pattern testing using improved varieties from the national breeding programs, since they also get materials from the International Rice Testing Program and CIMMYT international nurseries.

Cropping patterns involving R - W and other upland crops are tested in Burma, Nepal, China, India, and Bangladesh. In Burma, R - W was evaluated with four other cropping patterns in Wakema and with five other patterns in Yezin. P - R - SB gave the highest net return ($700), and R - W the lowest ($87) in Yezin. In Wakema, R - W was comparable with the other cropping patterns with net returns of $323/ha.

In Ratna Nager, Nepal, R - W - dhaincha (D) gave higher grain production and net returns than the farmers' R - W pattern in the irrigated lowlands; under partially irrigated conditions, R - mustard [MS] - M was agronomically and economically better than R - W and R - W - D. In Parsa, R - chickpea [CH] - MS gave the highest net returns compared with the farmers' R - W and R - W - R. In Pumdi Bhumdi, the R - W - M using improved management was significantly better in production and income generation than the farmers' R - W - R pattern.

In Sichuan, China, the highest net returns were observed in combinations of W, RS, SP, and R in a 2-yr period, while in Beijing R - W gave a higher yield than barley - R or RS - R. In Guangzhou, the highest net returns were obtained from W - P - R followed by W - R - R, faba bean - R - R, and pea - R - R.

In India, R - W systems (2- and 5-crop systems) were compared with other cropping patterns in Jorhat, Assam; Ludhiana, Punjab; Modipuram, Uttar Pradesh; Bardhaman, West Bengal; Kanpur, Uttar Pradesh; Masodha, Faizabad; Indian Agricultural Research Institute, New Delhi; Jagtial, Andhra Pradesh; Chiplima, Orissa; Pharbhani, Maharashtra; and Basar, Arunachal Pradesh. Trials started in late 1985 at a few sites and 1986 at most other sites. Most of the sites do not have a complete year's data. In Chiplima, out of 6 cropping patterns tested, R - potato - sesame gave the highest net returns ($787), while R - W - MB gave $452. More intensive systems were evaluated in Kanpur. R - CH + linseed - M + CP (fodder) gave the highest net returns of $1,728, and R - W gave $948. In Masodha, 6 cropping patterns were tested; R - potato - blackgram showed the highest net return of $1,007, and R - W gave $751. In Pharbhani, R - W - MB was compared with some upland systems. Cotton - P gave the highest net returns of $994, while R - W showed $401. In Pantnagar, the most promising cropping patterns based on production were R - W - M + CP (fodder) and R - potato + W - CP (fodder).

CROP - LIVESTOCK SYSTEMS RESEARCH

Rice Farming Systems Program and Agricultural Economics Department

The collaborative crop - livestock research project consists of on-station research at the Philippine Institute of Animal Science (IAS), the Philippine National Crop Protection Center, and IRRI; on-farm research in the Philippines in collaboration with the Ministry of Agriculture and Food (MAF) and IAS; coordination of other key crop - livestock sites in Nepal, Indonesia, and Thailand; and sharing of research information among countries involved in crop - livestock research.

On-farm research. On-farm trials were conducted at two sites in Santa Barbara, Pangasinan, Philippines, under irrigated lowland (Malanay) and rainfed lowland (Carosucan) conditions, described previously (Annual report for 1985).

Cattle fattening trials in Carosucan showed small liveweight gains: 60 kg in the 1st year and 57 kg in the 2d year. Feeding was supplemented during the critical months of April and May with 2 kg rice bran/head per day to minimize weight loss. Feeding with *Leucaena* was minimal because *Heteropsylla* infestation made the fodder unavailable. Weight losses occurred during the summer (April-May) and at the peak of the rice harvest (November), when farmers could not give time to gathering fodder. Periodic weights of individual animals were correlated with feed availability. Some farmers improved feed quality by including MB straw at about 2 kg/head per day during the dry months. However, the overall contribution of MB straw was small, considering that the farmers planted only about 0.4 ha and shared the straw with their neighbors. Some farmers also provided cut-and-carry weeds even in the months of scarce supply, while others depended mostly on rice straw during those times. Farmers with slow gaining animals were those who did not adopt *Leucaena* feeding. Planting of *Gliricidia* to replace *Leucaena* was also tried by some.

In Malanay, after the farmers had sold their fattened cattle in year 2, they indicated a preference for breeding carabao because of their easier care and management in the flood-prone site and the better market for them than for fattened cattle. Breeding female carabao were provided to 13 cooperators along with 4 fattener cattle. The sharing arrangement was still guided by the *pa-iwi* scheme, i.e., 50:50 on incremental gains.

Breeding by artificial insemination using Murrah and Nilli Ravi frozen semen was done in collaboration with the Philippine Carabao Research and Development Center at the University of the Philippines at Los Baños (UPLB). The breeding objective was to produce hybrid progeny that are larger and more suitable for meat, draft, and milk, with dairy production the lowest priority. Female hybrid offspring are also expected to be better breeders because their improved milking capacity should cause their offspring to grow faster.

After 3 mo of artificial insemination work in collaboration with a MAF technician, no carabao females of 7 tested were pregnant. Rice bran supplement was given to breeding animals in October to improve their condition, since some had been used for draft in August-September.

Cropping pattern trials with R followed by either MB or CP were continued. Early-maturing IR60 yielded significantly more than IR36 and IR62, which the farmers were using. In heavier soils, IR42 gave a grain and fodder yield advantage with improved practices. The farmers' local R variety (Diket) and IR48 showed both a grain yield and a straw yield advantage. MB following R gave an additional net income of at least $150/ha.

In upland crop variety trials during 1985-86 DS, field legumes such as MB, CP, BSi, and P grown on residual soil moisture gave high yields. SB and PP had very poor yields. M and S gave no yields at all. CP varieties TVx 3381-02F and TVx 2724-01F gave significant grain yield advantages of 86% and 63%, respectively, over the farmers' local variety. TVx 4678-03F, which gave a grain yield of 0.55 t/ha, had the highest fodder yield. Three promising MB cultivars — IPB M79-13-29, IPB M79-9-74, and IPB M79-9-82 — yielded significantly better than Pag-asa 1 (variety for cropping pattern tests) and the farmers' local check. CFS TT-2 gave the highest fodder yield (6.07 t/ha). Bush sitao #7 and LBBS #1 significantly outyielded the farmers' local variety in both grain and fodder yield. The most promising P cultivars were PI-118200 and CFS 101.

Insect control trials on MB showed that spraying 0.51 kg ai monocrotophos/ha at 2 and 12 d after emergence followed by 0.015 kg ai decamethrin/ha at 10 d after flowering gave the highest marginal benefit-cost ratio of 186.

Component technology trials on the cultural management aspect of R and upland crops were further verified during 1985-86. Results of the variety trials for R during the 1986 wet season (WS) indicated that IR13540-56-3-2-1, C1786-13-2-2-1, and IR50 were the highest grain yielders (>4 t/ha) compared with IR42 (3.80 t/ha). In terms of straw yield, however, IR42, which is commonly planted by farmers, gave the highest yield of 4.8 t/ha.

To further reduce the cash cost of fertilizing the first rice crop, green manuring with *Sesbania rostrata* in combination with inorganic fertilizer and other legume species was tested; 40 kg N/ha alone (cropping pattern recommendation) gave the highest marginal rate of return (MRR) of 1310%.

Sesbania alone and in combination with inorganic fertilizer gave a lower net benefit because of the additional cost in land preparation and incorporation of sesbania.

Other legume species (MB and CP) as green manure were also compared with *S. rostrata*. A yield increase of at least 35% was attained with sesbania alone compared with no fertilizer. Sesbania, MB, and CP plus 30 kg N/ha produced a grain yield advantage of 57, 83, and 64% over no fertilizer. But 40 kg N/ha alone was the most economical treatment, with a MRR of 1341%.

IR65 (glutinous improved variety) was compared with the farmers' traditional glutinous varieties, collectively called Diket, under their own cultural practices. In terms of fresh and dry grain yield, IR65 outyielded Diket at no additional cost. The net return from growing IR65 was 16% higher than that from Diket. Agronomic characteristics of four distinct types of Diket — Imelda, Milagrosa, Miracle, and Waray — were compared with IR65. All the varieties matured later than IR65 (120 d) — Waray in 150 d and the others in 130 d. Although the plant height of IR65 is at least 53% less than Milagrosa's, straw yield is the same because IR65 has more tillers.

Component technology trials on variety and fertilizer were conducted in Malanay during the first rice crop. Variety MRC12379-927-7 (July planting) gave the highest grain (4.5 t/ha) and straw yields (6.72 t/ha), followed by IR32307-107-3-2-2 for grain yield and MRC14364-g-MRC12961-1576-1 for straw. The popular farmers' variety IR42 gave grain and straw yields of 3.14 and 6.06 t/ha, which were 43 and 11% lower than for the highest yielder. In the variety trials planted in January, IR64 gave the highest grain yield (6.46 t/ha) — followed by IR32307-107-3-2-2 and IR62 — and IR42 gave the lowest (4.55 t/ha). For straw yield, IR28178-111-1-2-3 and IR25587-133-3-2-2-3 were the top 2 yielders with 14.2 and 12.0 t/ha. Studies on rates of N per hectare showed that 40 kg N/ha was more economical than 80 kg N/ha, which gave a MRR of 1280%. The farmers' level of fertilizer use ranged from 60 to 80 kg N/ha.

Animal health. A research veterinarian from the Bureau of Animal Industry, MAF, assisted by an on-site research veterinarian from MAF in Dagupan City, conducted animal health research. The on-site veterinarian also served farmer cooperators, in addition to performing routine research monitoring functions.

All farm animals were observed: cattle, carabao, goats, swine, and poultry (mostly chickens). Health services were focused on the notifiable diseases, namely: foot and mouth disease (FMD), hemorrhagic septicemia (hemosep), brucellosis, leptospirosis (lepto), and helminthiasis (liver fluke and gastrointestinal worms).

Benchmarks were established on the seasonal occurrence of animal parasitization and infectious diseases by laboratory examination and serological tests on feces, blood, and skin scrapings. A monthly egg per gram (EPG) count chart was established, and deworming in March, June, and September is now recommended. Animals with EPG beyond tolerable limits are dewormed.

In 1985, preventive vaccination was done against FMD and hemosep. In 1986, hemosep vaccination was administered twice. No cases of FMD, CA, or lepto occurred in 1986. Some large animals had abortions because of poisoning, overwork, or malnutrition.

Some hog cholera cases were observed on 5- to 11-mo-old animals. Chicken chronic respiratory disease complex was frequently observed; birds with early symptoms were recommended for family consumption or market.

Economic analyses. Labor spent for livestock care at both sites peaked during the late rainy season (August to December) and was lowest during the dry months (February to June). The rice crop was ready for harvest in November-December. Almost all fields were planted, so farmers had to search for forage. Some fields were fallow even in Malanay, where a second rice crop is planted in January-February. This allowed more animal grazing.

On a per-day basis, labor for feeding management ranged from 0.41 to 0.51 h/animal. Other activities for animal care ranged from 0.24 to 0.58 h/animal. Farmers spent more time caring for cattle in Malanay (0.85 vs 0.69 h/animal for buffalo) and for carabao in Carosucan (1.06 vs 0.75 h/animal for cattle). The average daily labor spent was 0.80 h for each of the cattle and 0.88 h for each carabao. Carabao provided 85% of total draft power in Malanay and 74% in Carosucan. Use of

both species peaked during land preparation in June-July and December-January.

The returns to livestock enterprises consist of two items: the value of the animal sold and the value for renting out animals for draft services. The value of the animals sold in Malanay ($325) was higher than that in Carosucan ($214), but values reflected fattened animals in Malanay and cull cows in Carosucan. The variable costs included materials — the stock, concentrate feeds, mineral supplements, medicines, and rope — and family labor. The total variable costs were $192 for Carosucan and $296 for Malanay.

The fixed costs, which covered depreciation on the building, tools, and equipment and interest on the investment, amounted to $19 for Carosucan, and $24 for Malanay.

Both sites registered positive returns. The returns above variable cost were $25 for Carosucan, and $30 for Malanay. The net cash returns were $32 for Carosucan and $40 for Malanay, and the net returns were $6 and $16, respectively.

Combined cost and return analyses for rice crops and livestock done for both Malanay and Carosucan are in Table 4.

Case study of mungbean after rice. A study was conducted to determine the increase in MB hectarage caused by the project.

In 1985-86 DS, 67% of farmers in Carosucan planted MB after R. Before the project started in 1984, less than 20% of the farmers had planted upland crops or MB after R, partly because of the drought in 1983-84 DS. Although some farmers had previous experience with growing the crop, the more widespread MB cultivation in Urdaneta, the neighboring town, had not radiated to the village in 1984.

A R - MB or R - CP pattern was tested in 1984-85 with some cooperators and in trial plots. The encouraging results led to the decision of the project to provide up to 10 kg each of Pag-asa 1 MB seeds, good for about 0.5 ha, to 9 farmers, including 1 noncooperator. Farmers also purchased additional seeds of Miracle mungbean from the market to be able to plant a maximum of 0.71 ha. The minimum area planted was 0.16 ha.

One farmer lost the entire crop to loose carabao. The highest overall yield was 140 kg from 0.50 ha, roughly 0.28 t/ha. Pag-asa 1 outyielded the local variety.

Table 4. Cost and return analysis for rice crops and livestock in Carosucan and Malanay, Pangasinan, Philippines, 1985-86.

Item	Carosucan	Malanay
Av annual total returns	$1518	$1335
Av cash return	393	669
Av noncash return	1125	666
Total returns		
Livestock	995	642
Rice	523	693
Total expenses	570	853
Net farm income		
Cash	−38	−70
Noncash	1013	596
Total net farm income	948	482

Only five farmers saved seeds (Pag-asa 1) for the next year's planting.

The MB boom in 1985-86 may be attributed to four reasons:

- A noncooperator farmer planted an early-maturing IR60 R crop, then MB in September. The MB crop was very successful and attracted attention.
- Depressed job availability in Manila and scarce money for expenses forced farmers to stay and plant mungbean.
- Rainfall was more favorable, allowing cultivation after the rice harvest.
- Some farmers were provided seeds, so they planted them.

Research on data collection. Three data collection methods were used: intensive recording, periodic visits, and the recall method (one long survey at the end of each season). Questions were similar.

Periodic visits and intensive recording showed no significant difference between mean labor hours for nursery, land preparation, and fertilizer and insecticide application. The wider the gap between the time an activity was done and the date of interview, the less reliable the data became. However, harvesting and threshing labor hours significantly differed between the periodic and intensive methods on one hand and the recall method, which gave unusually low values.

The mean quantities of input use (fertilizer and insecticides) did not differ significantly among methods. Farmers remembered more accurately inputs in large quantities (e.g., kg, bag) than those in smaller ones (e.g., cc).

On yield estimates, results also showed no significant difference among the three methods, even when the plots were reorganized into different sizes. Also, there was no correlation between tenure arrangement and method of data collection. However, when yield estimates were compared with crop-cut yield, share-tenants had significantly lower yield estimates than the lease tenants.

On-farm research at other key crop - livestock sites. Research collaboration in crop - livestock systems research is being undertaken at key sites in ARFSN countries: in Santa Barbara, Pangasinan, Philippines; Ban Phai, Khon Kaen, Thailand; Batumarta, South Sumatra, Indonesia; and Pumdi Bhumdi, Nepal.

The project in Thailand is conducted in collaboration with the Ministry of Agriculture and Cooperatives through the Department of Agriculture, Department of Livestock Development, and Office of Agricultural Economics. Khon Kaen University also participates. The Farming Systems Research Institute acts as a core coordinating body to integrate the activities of these agencies. The results of a baseline survey indicated that the average size of landholding is 5.28 ha of rainfed area. Cropping pattern tests considered field crops like MB, green M, and CP. Green M seemed to be an outstanding crop for its market potential as well as for providing green crop residues that the animals liked. Under upland R conditions, P - green M gave positive returns. Other crops like CP provided additional residues for animal feed. All groups of farmer cooperators utilized backyard grasses, rice straw, and public land grasses (pastures, roadside forages). Considerable fluctuation in animal weights occurred, depending on the availability of forage or crop residues at certain times of the year. Crop residues resulting from the cropping pattern tests provided additional feedstuffs that prevented further weight loss. In terms of net cash farm income, the animal-based group had the highest, partly because of returns through buying and selling cattle and selling milk, as well as more off-farm income. Farmers in the area were convinced to raise dairy cattle with the use of artificial insemination to produce Holstein-Frisian-Brahman crossbred cows.

The crop - livestock project in Indonesia is situated in an upland transmigration area in South Sumatra. The project is undertaken by staff from the Department of Agriculture through the Agency for Agricultural Research and Development. The two institutes concerned are CRIFC and the Central Research Institute for Animal Science. The settlers are entitled to 5 ha of land. Four farming systems models were considered, and on-farm trials started in October 1985. Yields of M, upland R, and P as the first crops in the sequence were fairly good. Some lowland areas that were developed into lowland ricefields yielded 3 t/ha. The production value from cattle was higher than those from goats and local chickens. *Setaria* was planted, especially at the edges of the terraces, and *Gliricidia* was used as a border plant. These crops provided additional forage for the animals. Input-output analysis of WS data showed that the biggest portion (77%) of the total net value came from the food crop component. Livestock enterprises contributed 14%, while rubber, which was tapped for the first 6 mo (October-March), gave 9%. Improved models showed these trends.

In Nepal, the Agricultural Research and Production Program is collaborating with the activities of the Farming Systems Research Division, Ministry of Agriculture. Research in Pumdi Bhumdi, which was identified as one of the key sites for the crop - livestock research, considers cropping pattern tests on R - W - M, R - W/M/finger millet, and R - oats. The livestock component is mainly buffaloes for milk. Staff of the Department of Livestock Production and Animal Health are also involved.

The site in Sri Lanka has met difficulties in pursuing crop - livestock on-farm trials.

On-station research at the University of the Philippines at Los Baños. In year 3, 38 digestion trials were completed at UPLB. Four animals (2 cattle and 2 carabao) were used in 28 of the trials. Ten animals (five of each species) were acquired to replace older stock. With the use of the new animals, confirmatory tests were conducted

for some feed materials, especially for those with highly variable results.

Data on the digestibility and energy values of various fodder crops — fodder tree browse (leaves + pencil-sized twigs), grasses, field legumes, and crop residues — were compiled. Generally, the average digestibility for carabao was higher. However, the values were higher for cattle in the case of star grass (*Cynodon plectostachyus*), P, PP, and crop residues. Napier had the highest energy value among the grasses with 2,710 kcal digestible energy/kg and 61.7% total digestible nutrients (TDN).

Leucaena gave higher energy values than *Gliricidia* (3,014 kcal/kg and 70.9% TDN vs 2,553 kcal/kg and 68.5% TDN) for cattle and carabao. Digestible energy values were poor in acacia *Samanea saman* (578 kcal/kg) and PP (1,645 kcal/kg).

Rice straw yielded only 1,138 kcal digestible energy/kg and 41.1% TDN in carabao, and 1,907 kcal/kg and 50.0% TDN in cattle.

When 50:50 grass-legume combinations were fed, TDN values improved markedly. Napier + *Leucaena* had 70.2% TDN for carabao and 66.4% TDN for cattle.

The macronutrient and micronutrient compositions of various fodders were also investigated. The grasses and cereal grain residues contained low levels of Ca and P. Napier had 0.6% Ca and 0.36% P; guinea grass had 0.28% Ca and 0.33% P. Of the legumes, PP had 2.68% Ca and 0.19% P, similar to that of P (2.72% Ca and 0.21% P).

The microminerals Fe and Cu are often deficient in forages, especially mature materials. In all the fodders analyzed, even the crop residues contained comparable levels of the two minerals except for very low Cu in rice straw. The legumes and forage grasses also had similar Cu contents except guinea and Alabang-X *Dicanthium aristatum*.

Pesticide residues. A pesticide use survey was first done at the Pangasinan site, followed by a field trial at IRRI wherein insecticides were sprayed on rice to determine residue levels in the straw. Carbofuran and BPMC + chlorpyrifos were detectable at harvest. Carbofuran was later tested in a small-scale ricefield and fishpond. Fish were able to bio-accumulate carbofuran residues 110 times, and snails 10 times, the residue concentration in water. However, the residues were still within the acceptable daily intake level for man. Carbofuran-laced straw was fed to goats for 7 consecutive days. Rapid loss occurred through the urine (77%), a little (1%) through the feces, and a trace (0.5%) through the milk. Although residues were detectable in milk beyond the withdrawal period, such levels did not exceed 0.03 ppm of carbofuran equivalent. Some high levels of retention occurred in other goat tissues (e.g., liver) but were nontoxic metabolites as determined by thin layer gas chromatography.

Samples of MB straw were gathered from farmer cooperators' plots with known degrees of pesticide application (monocrotophos and decamethrin) and analyzed for residue levels. No residues of monocrotophos or decamethrin were detected on MB straw samples at harvest; thus, these straws are considered safe for animal feeding even immediately after harvest.

On-station research at IRRI. *Evaluation of forage crops.* As the main source of feed for livestock, forage crops can play a very significant role in the crop - livestock system. Improvement of forages both quantitatively and qualitatively should result in better condition of the animals and better income for the owners. Several forage crops can be grown in combination or in sequence with food crops to produce food and animal feed.

Since 1985, some introduced forage grasses have been evaluated at the rainfed upland site at IRRI, while both forage grasses and legumes have been evaluated on the bunds of irrigated lowland ricefields.

Evaluation of forage grasses in the rainfed uplands aims to select forage species and varieties with drought tolerance, high herbage yield, and better regrowth ability. Herbage yields of grasses in the first year of establishment (1985) were reported (Annual report for 1985). The accumulated dry matter yields from the first cut (March 1985) to the last cut (August 1986), in descending order, were as shown in Table 5.

Since it had been decided to cut each grass at about 30 cm, their cutting intervals were different, based on their rates of regrowth. *Pennisetum purpureum* had the fastest rate of regrowth, with an average cutting interval of 48 d, and *Setaria anceps* cv Kazungula was the slowest, with 98 d.

When the leaf-to-stem ratio was taken into account, *Andropogon gayanus* was the most leafy grass, giving the highest ratio of 5.03. It was followed by *Panicum maximum* cv Hamil (4.09), *P. purpureum* (4.01), *Paspalum plicatulum* (3.96), and *Panicum maximum* cv Guinea (3.84). The leaf-to-stem ratios of the other grasses ranged from 3.80 to 1.34, with *Cynodon plectostachyus* being the least leafy species.

In the lowland ricefield, 7 forage grasses and 5 forage legumes were established on bunds in June 1986 with a 5-m row and 3 replications for each species. The plants were cut at 10 cm cutting height at 30- to 45-d intervals. The data from two cuttings (August and October 1986) showed that *Echinochloa pieta* was the best yielding grass on the bund. It gave a total fresh weight of 1.7 kg/linear m with an average of 9.6 tillers/plant. The next highest yielding grasses were a *Setaria* hybrid from Bukidnon, Philippines, and *Brachiaria ruziziensis* with fresh weights of 587 and 300 g/linear m. *S. anceps* cv Nandi had more tillers (11/plant), but its forage yield was only 345 g/linear m. Among the legumes tested on ricefield bunds, *Clitoria ternatea* was the most promising in initial yield and regrowth, with a fresh weight forage yield of 0.9 kg/linear m in the first cut and 0.8 kg/linear m in the second cut. *Sesbania rostrata* had the highest forage in the first cut (1.4 kg/linear m), but its regrowth was rather poor, yielding only 0.4 kg/linear m in the second cut; no regrowth was observed thereafter.

Table 5. Accumulated dry matter yields of forage crops from first cut (Mar 1985) to last cut (Aug 1986). IRRI, 1985-86.

Species	Dry matter yield (t/ha)
Pennisetum purpureum	41.8
Andropogon gayanus	34.4
Paspalum plicatulum	34.2
Panicum maximum cv Hamil	28.9
Setaria anceps cv Nandi	27.9
Brachiaria mutica	26.3
Setaria anceps cv Kazungula	21.0
Panicum maximum cv Guinea	17.7
Brachiaria ruziziensis	16.9
Brachiaria decumbens	16.6
Cynodon plectostachyus	14.9
Dicanthium aristatum	14.0

For forages to plant beneath shrubs and trees, selection for shade tolerance is continuing. Six introduced forage grasses were established from stem cuttings at 25 × 25 cm spacing both under and outside the canopy of 7- to 8-mo-old *Leucaena* trees spaced at 1 × 1 m. The trees were cut to about 2 m height at the start of the experiment and developed to about 5 m at the termination. The grasses were cut periodically (30- to 45-d intervals) to determine herbage production. The average forage yield from the 6 cuttings are shown in Table 6.

Dry matter yields of all grasses grown in the shade were reduced. *S. anceps* cv Nandi, the highest yielding grass in the shade, also yielded high in the open. Setaria had 46 live tillers when grown in an open area and 32.3 live tillers when grown in the shade. *B. ruziziensis* had the highest forage yield, but it yielded much less in the shade.

Grain legume + forage legume intercropping. Intercropping of grain and forage crops can provide both human food and animal feed. Improved soil fertility has also been noted when a forage legume is used as an intercrop. At IRRI, one upland trial was conducted at the start of DS and another in the lowland after DS rice. Four grain legumes — MB IPB M79-13-29, CP TVx 4677-08E, CP TVx 2724-01F, and PP QPL 72 — were used as main crops in both trials. The intercrops were Siratro *Macroptilium atropurpureum* cv Siratro, Cook stylo *Stylosanthes guianensis* cv Cook, and *Stylosanthes guianensis* CIAT 136 in the upland. Centro *Centrosema pubescens* instead of Cook stylo was used in the lowland. The upland had thorough land preparation; the lowland had zero tillage with furrows only for seeding. Each crop combination was planted simultaneously in

Table 6. Average forage yield from 6 cuttings of 6 grasses. IRRI, 1986.

Grass	Dry matter yield/cut (kg/ha)	
	Shaded	Opened
Setaria anceps cv Nandi	919	2022
Andropogon gayanus	678	1399
Panicum maximum cv Hamil	675	961
Pennisetum purpureum	639	1876
Brachiaria ruziziensis	570	2658
Brachiaria mutica	528	1656

rows spaced 0.75 m apart in a 4- × 5-m plot replicated 3 times.

In the upland environment, the grain yield of mungbean significantly decreased from 1.0 t/ha as a monocrop to an average of 0.9 t/ha with intercropping. Except in the combination TVx 4677-08F with Cook stylo, CP grain yields ranged from 1.0 to 1.3 t/ha, which were not significantly affected by any forage legume intercrop. No grain yield was obtained from PP because of pod borer infestation. Siratro was the best intercropped species in terms of fodder dry matter yield, giving an average of 5.1 t/ha. Its highest fodder yield (6.6 t/ha) was obtained from the MB + Siratro intercropping. The total fodder yields (main crop + intercrop) of the combinations with PP as the main crop were much higher than the others, mainly because of the higher contribution from PP.

Both grain and fodder yields of the food - forage legumes intercropping under lowland conditions were lower than those in the upland. In monocropping, grain yields of MB, CP TVx 4677-08F, CP TVx 2724-01F, and PP were 0.5, 0.7, 0.9, and 0.5 t/ha, respectively. However, these grain yields were not significantly affected by the intercrops. Siratro, also in the lowland, gave the highest average fodder dry matter yield of 2.2 t/ha. It gave the highest yield of 3.5 t/ha when intercropped with TVx 4677-08F, for a total of 4.2 t/ha.

Forage grass after rice. In the rainfed lowlands after WS rice is harvested, upland crops cannot be planted because of excess moisture. A second rice crop is also impossible because soil moisture would not suffice through crop maturity. Forages are being tried in such a situation to increase animal feed, especially during DS. Four species of forage grasses, evaluated after rice at IRRI, gave these dry matter yields per hectare from November 1985 to June 1986: para grass *Brachiaria mutica*, 13.3 t; Hoilo grass *E. pilata*, 9.3 t; setaria *S. anceps* cv Nandi, 4.3 t; and ruzi grass *B. ruziziensis*, 1.1 t. Combined herbage produced, including native grasses and weeds, 16.6 t para grass, 14.4 t Hoilo grass, 10.8 t setaria, and 9.4 t ruzi grass. The control (weeds) gave 9.8 t. The weed components were observed to be depressed by para and Hoilo grasses, but not by setaria and ruzi grasses.

The weed species in the subsequent rice crop were also monitored. Hoilo grass, setaria, and ruzi grass did not persist through the subsequent rice crop. Para grass was observed along the bunds, but not in the ricefield.

Fodder trees and shrubs. As an additional source of fodder in the integrated crop - livestock system, 5 leguminous and nonleguminous trees and shrubs were evaluated for herbage production, persistence despite constant defoliation (45- to 60-d cutting intervals), and other agronomic characters. Test species were planted in 5-m rows spaced at 3-m intervals between rows and 1 m between plants with 3 replications. The first cutting was done approximately 10 mo after planting. Herbage yields (dry matter cut per tree) were based on 1 yr's data: *Leucaena leucocephala*, 772 g; *Moringa oleifera*, 259 g; *Pithecellobium dulce*, 258 g; *Gliricidia sepium*, 196 g; and *Trema orientalis*, 143 g. *Leucaena* yielded higher in the first cut, but subsequent harvest was zero because of *Heteropsylla* infestation in October 1985. Leaf crude protein values were 24.6% for *Moringa*; 22.2%, *Gliricidia*; 21.1%, *Pithecellobium*; and 10.2%, *Trema*.

WOMEN IN RICE FARMING SYSTEMS

Rice Farming Systems Program, and Agricultural Economics and Communication and Publications Departments

Explicit attention to gender issues and to the roles of women as users and beneficiaries of technologies started in 1983 when IRRI convened a conference of biological scientists, social scientists, and policy makers. In 1985, IRRI participated in an Inter-Center Seminar on Women and Agricultural Technology at Bellagio, Italy, which produced an agreement that Consultative Group on International Agricultural Research centers and national agricultural research systems should develop long-term strategies to take the role of women into account, where possible, in all phases of research and technology development work.

With that agenda, a project design workshop was held at IRRI in April 1985, at which it was proposed that IRRI organize a collaborative effort with national programs and other agricultural

institutions to undertake action research concerning women in rice farming. The major objectives are to understand the needs of women in rural rice-growing areas and to identify and extend suitable technologies to improve the productivity and welfare of women. The ultimate goal is to institutionalize concern for women in agricultural research and extension programs covering rice-based farming systems. One strategy is to develop the Women and Technology Development Program under the overall umbrella of ARFSN using the farming systems methodology.

The Crop-Livestock Project in Santa Barbara, Pangasinan, is one of the ARFSN sites in which the Women in Rice Farming Systems (WIRFS) program is being integrated. This project, which started in 1984, is a collaborative venture among UPLB, IRRI's Rice Farming Systems Program, and IRRI's Agricultural Economics Department

Table 7. Labor participation in cropping activities by farming and landless households.[a] Carosucan, Santa Barbara, Pangasinan, Philippines, 1985.

Crop and activity	Participation (%)			
	Farming household		Landless household	
	Male	Female	Male	Female
Rice				
Land preparation	95	5	100	0
Pulling seedlings	6	94	9	91
Transplanting	98	2	100	0
Harvesting	76	24	69	31
Threshing	94	6	83	17
Buying inputs	82	18	66	34
Taking harvest to mills	56	44	100	0
Marketing	69	31	100	0
Glutinous rice				
Cooking	36	64	50	50
Pounding	71	29	59	41
Marketing	14	86		100
Mungbean				
Broadcasting	17	83	–	–
Harvesting	57	43	53	47
Threshing	42	58	53	47
Marketing	36	64	0	100
Buying inputs	79	21		
Vegetables				
Growing	79	21		
Selling	42	58	0	
Total households interviewed (no.)	69		26	

[a]Source: Census of total households, 1984.

The project seeks to improve existing farming systems through the integration of suitable crop and animal production technologies. On-farm crop and livestock experiments are being conducted in an irrigated and a rainfed area in Santa Barbara. In line with the objectives of this project, women's concerns were initially integrated in January 1986.

Using data from a total enumeration survey, gender specificity in major crop and livestock activities was described. There is sexual division of labor in rice production. Women pull seedlings while men do land preparation, transplanting, weeding, fertilization, spraying, harvesting, threshing, and hauling (Table 7). At the rainfed site, processing and marketing of glutinous rice are done mostly by women. For MB, CP, and vegetable production, women participate in planting, harvesting, and threshing; women also make most marketing decisions.

Men are generally responsible for large animals (carabao and cattle), women for swine and poultry. In the management of large animals, women and male children help or substitute for male adults in gathering of forage (straw, leucaena, grasses, etc.), feeding, providing water, bathing, and grazing the animals, and cleaning the pens (Tables 8, 9).

Table 8. Percentage of 19 households using adult and child labor sources for carabao and cattle care. Malanay, Santa Barbara, Pangasinan, Philippines, 1986.

Activity	Households (%)		
	Adult		Child[b]
	Male	Female[a]	Male
Gathering rice straw	74	63	26
Stacking rice straw	89	37	32
Gathering weeds	79	53	37
Gathering leucaena leaves	11	53	11
Gathering sugarcane tops	47	11	16
Giving rice bran	37	47	11
Feeding	79	84	37
Giving water	68	74	37
Grazing	79	68	32
Putting up animal shelters	84	26	16
Cleaning pens	79	74	32
Bathing	79	42	37
Detecting estrus	74	44	0
Taking animals for breeding	58	0	0
Buying and selling animals	47	21	0

[a]Two of the households were headed by widows. [b]Age 7-15 yr. No female child performed these tasks.

Table 9. Percentage of 18 households using adult and child labor sources for carabao and cattle care. Carosucan, Santa Barbara, Pangasinan, Philippines, 1986.

Activity	Households (%)			
	Adult		Child[b]	
	Male	Female[a]	Male	Female
Gathering rice straw	83	94	44	0
Stacking rice straw	83	28	44	0
Gathering weeds	83	89	39	0
Gathering leucaena leaves	33	56	17	0
Gathering mungbean fodder	28	33	17	0
Gathering acacia leaves	17	11	0	0
Gathering maize stover	11	6	0	0
Giving rice bran	56	72	11	6
Feeding	78	89	50	6
Giving water	83	78	39	6
Grazing	72	89	56	0
Putting up animal shelters	61	6	6	0
Cleaning pens	56	72	33	0
Bathing	83	94	33	11
Collecting dung	0	33	0	0
Detecting estrus	39	6	0	0
Taking animals for breeding	8	6	0	0
Buying and selling animals	78	17	0	0

[a]Two of the households were headed by widows. [b]Age 7-15 yr.

Decisions concerning buying and selling of large animals are handled by men. Collecting dry dung for fuel in the rainfed site is generally done by women (Table 9). Except for putting up the shelter, swine management and marketing are mainly women's responsibilities (Table 10).

Processing glutinous rice is an important traditional income-generating activity of women at the rainfed site. The major constraints identified by women involved in the production and processing of local glutinous rice varieties were low yields, long maturity, drudgery, and inefficiency in processing. In a production constraints study, 22 farmer cooperators tested IR65, a high-yielding and early-maturing glutinous rice, side by side with local varieties. IR65 has a potential yield of 5 t/ha and matures in 115 d; the local glutinous rice varieties range from 130 to 140 d with a grain yield of 3 t/ha. Under the farmers' level of management and inputs, the average yield of IR65 was 5.4 t/ha 16% higher than that of the local glutinous rice varieties (Table 11). The majority of the project cooperators were willing to test IR65 further because of its early maturity, better tillering

Table 10. Percentage of 37 households using adult and child labor sources for care of swine. Malanay and Carosucan, Santa Barbara, Pangasinan, Philippines, 1986.

Activity	Households (%)						
	Malanay (n = 18)			Carosucan (n = 19)			
	Adult		Child[a]	Adult		Child	
	Male	Female	Female	Male	Female	Male	Female
Gathering swamp cabbage	6	47	6	56	89	11	11
Gathering and giving leucaena	0	47	0	6	72	0	0
Feeding starter	0	53	0	0	61	0	0
Feeding rice bran	0	100	0	0	94	0	0
Buying rice bran	0	26	0	0	56	0	0
Cooking rice porridge and feeding	0	11	0	0	22	0	0
Gathering and grating banana stumps or stalks	11	26	0	6	33	0	0
Putting up shelters	79	0	0	89	0	0	0
Cleaning pens	16	100	0	22	94	6	11
Bathing, fetching, and giving water	11	100	0	17	100	6	0
Detecting illness	0	100	0	0	100	0	0
Buying and giving medicine	0	79	0	0	61	0	0
Applying traditional cures for illness	0	26	0	0	17	0	0
Detecting estrus	0	74	0	0	83	0	0
Taking sows for breeding	0	53	0	6	78	0	0
Castrating	0	0	0	0	17	0	0
Buying, selling, and pricing	0	100	0	0	100	0	0

[a]No male child performed those tasks.

capacity, higher yield, uniform plant height, better quality filled grains, and resistance to lodging, pests, and diseases. IR65 is sticky and tacky; however, it has to compete with the fancy variety Milagrosa, which has a pleasant aroma and commands a better price. The earlier maturity date of IR65 enabled the farmers to have cash before the main crop harvest.

To reduce the drudgery, time, and fuel in processing, engineers from the Agricultural Engineering Department developed two pieces of equipment: a cooking device with a wooden rotary paddle, and a wooden mechanical portable dehuller. These devices were tested at IRRI and will be further tested by women at the rainfed site.

To demonstrate income-generating opportunities for women, 20 women from each research site were given hands-on training in mushroom production using rice straw as the substrate. These trained women are now deriving supplementary women are now deriving supplementary income from mushroom production in their homesteads.

In cooperation with the Communication and Publications Department, *A farmer's primer on growing rice* was introduced to both men and women at the irrigated site. Pretests and posttests were given to gain insights into the level of farmers' technical knowledge. Farmers' classes on crop and animal production were conducted for men and women.

To sustain project activities, a farmers' association (including women members) at the rainfed site as well as an exclusively women's association at the irrigated site were organized. These associations aim to provide access to credit, technologies, markets, and other resources for farm workers, particularly women.

Table 11. Costs and returns of glutinous rice varieties,[a] Carosucan, Santa Barbara, Pangasinan, Philippines, rainfed site, 1986.

Item	Costs and returns ($/ha)	
	IR65	Local
Price ($/kg)	0.15	0.15
Gross returns (A)	791.30	683.30
Labor and power costs (B)	247.45	218.60
Land preparation	58.05	51.15
Crop establishment	28.75	28.45
Weed control	0.05	0.30
Fertilizer application	0.70	0.55
Insecticide application	0.10	0.10
Other care	1.55	1.40
Harvesting	158.25	136.65
Materials costs (C)	39.85	30.35
Seeds	17.15	5.95
Fertilizer[b]	21.25	20.95
Insecticides	1.45	3.15
Other costs	–	0.30
Total variable costs	287.30	248.95
Returns above variable costs (A/D)	504.00	434.35
Returns to labor and power costs [(A-C) ÷ B]	0.15	0.15
Returns to materials costs [(A-B) ÷ C]	0.68	0.77
Yield (kg fresh weight/ha)	5420	4680
Plots (no.)	22	22
Av plot size (m^2)	429.79	645.56

[a]Source: Ministry of Agriculture, Crop and Livestock Project, Santa Barbara, Pangasinan, Jul-Dec 1986. [b]58 kg N/ha (IR65) and 53 kg N/ha for local varieties.

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JAPAN-IRRI COLLABORATIVE PROJECT ON BACTERIAL BLIGHT

Plant Breeding and Plant Pathology Departments

We continued research on bacterial blight (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. In this fourth year of collaboration, three studies were conducted at IRRI and TARC.

Development of international differentials for bacterial blight (*Plant Breeding and Plant Pathology*). Using BB races from the Philippines and Japan, we developed near-isogenic lines for use as international differentials. These lines have single genes for BB resistance. We now have BC_4F_3 to BC_4F_6 with either *Xa-3*, *Xa-4*, *xa-5*, or *Xa-10*. Near-isogenic lines with either *Xa-1*, *Xa-2*, *Xa-7*, *xa-8*, or *Xa-11* are in the BC_4F_2 to BC_4F_4 stages.

Inheritance of resistance (*Plant Breeding*). The F_2's of two crosses Toyonishiki (susceptible)/Java 14 (*Xa-3*) and Toyonishiki/Zenith (*Xa-6*) were analyzed at TARC and the F_3's at IRRI. Identical results were obtained at IRRI and TARC, confirming the results of F_2 analysis at TARC and the finding that *Xa-3*, *Xa-6*, and *xa-9* are identical.

The reaction to four BB races of Semora Mangga, the original variety identified as having $Xa\text{-}4^b$, was similar to those of Java 14, Zenith, and Sateng. These varieties have *Xa-3* and are resistant to four Philippine races, whereas varieties having *Xa-4* such as IR20 are resistant to race 1, moderately resistant to race 4, but susceptible to races 2 and 3. An F_2 population from the cross Java 14/Semora Mangga, consisting of 331 plants, was inoculated with 4 races. All the plants were resistant. The results also confirmed that Semora Mangga has *Xa-3*.

The results of genetic analyses at IRRI and TARC during the last 4 yr are summarized in Table 1.

We located *Xa-3* of Java 14 on chromosome 11 through trisomic inheritance. Data on the segregation of the F_2 population are presented in Table 2.

Table 1. Identification of genes for resistance to bacterial blight (BB) in selected rice varieties, IRRI and the Tropical Agriculture Research Center (TARC), 1983-86.

Resistant variety	Genes identified	
	In earlier studies	In present study
IR8	Unknown	*Xa-11*
IR20	*Xa-4*	*Xa-1*, *Xa-4*
Semora Mangga	$Xa\text{-}4^b$	*Xa-3*
DV85	*xa-5*, *Xa-7*, + one dominant gene	*xa-5*, *Xa-7*
Zenith	*Xa-6*	*Xa-3*
Sateng	*xa-9*	*Xa-3*
Cempo Selak	Unknown	*Xa-3*

Table 2. Reaction to BB race 2 of F_2 populations from the crosses of Java 14 with 11 trisomics of IR36, IRRI, 1986.

Cross combination	Generation	F_2 population (no.) with indicated reaction		
		Resistant	Susceptible	χ^2 3:1 or 1:1
Triplo 1/Java 14	F_2	95	24	1.4927
Triplo 2/Java 14//IR24	BC_1	67	87	2.5974
Triplo 3/Java 14	F_2	154	51	0.0020
Triplo 3/Java 14//IR24	BC_1	92	102	0.5155
Triplo 5/Java 14	F_2	160	52	0.0251
Triplo 6/Java 14	F_2	176	45	2.5459
Triplo 7/Java 14	F_2	158	54	0.0251
Triplo 8/Java 14	F_2	71	20	0.4506
Triplo 9/Java 14	F_2	146	57	1.1017
Triplo 10/Java 14	F_2	144	41	0.8015
Triplo 11/Java 14	F_2	99	66	20.9846
		(101.5)	(63.5)	0.1600 (0.62:0.38)[a]
Triplo 11/Java 14 (2n)	F_2	168	40	3.6923
Triplo 12/Java 14	F_2	54	19	0.0385

[a]These expected values calculated the transmission rate to progeny of the extra chromosome as 40%.

We also examined the linkage relations of *Xa-3* with gene markers from chromosome 11. As seen in Table 3, *Xa-3* is linked with *d-27* with a recombination value of 22.3%. We also crossed IR1545-339 (*xa-5*) with some gene markers from chromosome 5. The F_2 data showed that *xa-5* is very closely linked with gl_1 (Table 4).

Rice varietal groups based on reaction to four races of bacterial blight (*Plant Breeding*). We continued to evaluate resistant varieties against four Philippine BB races and reconfirmed that there are three major varietal groups: Java 14 (*Xa-3*), TKM6 (*Xa-4*), and DZ192 (*xa-5*).

Furthermore, we identified several varieties from Burma, Bangladesh, and India whose reaction pattern is similar to that of CAS209 (*Xa-10*). Varieties having *Xa-10* might be put into the fourth main group. From genetic analysis, we also found two smaller groups of varieties: varieties that have two genes — either *Xa-4* and *Xa-10*, or *xa-5* and *Xa-7*.

A COOPERATIVE FOR RESEARCH ON ADVERSE SOILS

Plant Breeding Department

The complexity and location specificity of adverse soils compel research to be carried out in target environments. To develop a collaborative research program for the improvement of rice yields in adverse soils, we convened a workshop in November, participated in by Bangladesh, India, Indonesia, Pakistan, Philippines, Sri Lanka, Thailand, and Vietnam. We reviewed the present status of research and future needs in varietal improvement. It was evident from the discussions that the lack of prebreeding research and the inability of national programs to conduct such research are the biggest constraints.

We formed a research cooperative wherein IRRI, in collaboration with national programs selected for each adverse soil type, will conduct prebreeding research. IRRI will also assist national programs by organizing shuttle breeding, rapid generation advance methods, exchange of germplasm, etc., to develop commercial varieties from prebreeding materials. The cooperators identified were India for coastal and inland salinity, Pakistan for alkalinity, Thailand and Vietnam for acid sulfate conditions, Indonesia for peats, and Sri Lanka for Fe toxicity.

HIGH ALTITUDE RICES IN THE PHILIPPINES

Plant Breeding Department

Our collaboration with the Philippine Bureau of Plant Industry in improving high altitude rices continued, with strong emphasis on shorter growth

Table 3. F_2 data from crosses of Java 14 with gene markers *d-27*, *1a*, and *sp*. TARC, 1986.

Cross	F_2[a] (no.)				χ^2 (9:3:3:1)	Estimated recombination value (%)
	+R	+S	mR	mS		
d-27/Java 14 (*Xa-3*)	235	30	43	55	82.286	22.3
1a/Java 14 (*Xa-3*)	208	46	74	27	8.577	43.1
sp/Java 14 (*Xa-3*)	207	65	68	26	0.620	47.2

[a]R = resistant, S = susceptible, + = normal type, m = marker type.

Table 4. F_2 data from crosses of IR1545-339 (*xa-5*) with gene markers gl_1, d_1, *eui*, and nl_1. IRRI, 1986.

Cross	F_2[a] (no.)				χ^2 (3:9:1:3)	Estimated recombination value (%)
	+R	+S	mR	mS		
gl_1/IR1545-339 (*xa-5*)	48	137	0	74	30.002	0
d_1/IR1545-339 (*xa-5*)	37	130	7	53	6.967	>50
eui/IR1545-339 (*xa-5*)	49	163	14	41	3.202	48.2
nl_1/IR1545-339 (*xa-5*)	49	153	18	37	3.328	44.2

[a]R = resistant, S = susceptible, + = normal type, m = marker type.

duration. Field evaluation and selection were done in Banaue (about 1,000 m elevation).

In the dry season (DS), 24 F_3 and 37 F_2 bulk populations were established, and plants that expressed cold tolerance comparable to that of commonly cultivated local varieties but with shorter growth duration were mass selected. A pedigree nursery with 367 advanced lines from 49 crosses was evaluated; only 11 lines were found suitable. The 1986 International Rice Cold Tolerance Nursery and 257 elite lines were tested for adaptability; 30 lines were better than the local variety and were selected for further testing.

We conducted an observational yield trial (OYT) with three advanced breeding lines and nine hybrids. The checks were Pinidua (the popular local cultivar) and Barakat (a short-duration, cold-tolerant variety). All test lines were earlier than Pinidua. The duration of four of the nine hybrids was comparable to that of Barakat (Table 5). In terms of yield, all advanced lines and six of the hybrids were superior to the local check: one elite line and three hybrids produced almost double the yield of Pinidua. One hybrid with short growth duration (V20A/Milyang 46) was among the very high yielders, and its productivity was more than double that of Barakat. Three hybrids were fully sterile. The results of this yield trial suggest that crop duration can be reduced by about 3 wk while significantly increasing yield. Some hybrid combinations seem to offer more promise in that a reduction of about 6 wk in duration is possible without any effect on yield.

A replicated yield trial was also conducted with five elite lines and one hybrid. The checks were Pinidua and Barakat as in the OYT. The duration of one elite line and the hybrid were similar to that of the short-duration check. The others were late but were at least 3 wk earlier than Pinidua. All test entries except one outyielded both checks (Table 5). As in the OYT, the hybrid produced high yields in spite of its short duration, and it outyielded the elite line with comparable maturity.

Although we isolated several breeding lines and hybrids with shorter duration and high yield, their high grain shedding was a major disadvantage. Any new variety for the ricelands in Banaue must have low or no grain shedding, like Pinidua. Therefore, further improvements in this trait are essential. The new lines, however, may be suitable for other high-altitude areas where low grain shedding is not essential.

Table 5. Plant height, duration and yield of entries listed in yield trials, Banaue, Philippines, 1986 WS.

Variety or line	Height (cm)	Duration (d)	Yield (t/ha)
Observational yield trial			
IR40094-4-5-2	101	160	5.51
IR40094-4-5-5	100	160	7.21
IR40094-5-3-1	92	160	5.14
IR21845-90-3A/IR54R	86	161	4.72
IR21845-90-3A/IR14753-120-3	104	168	7.45
IR21845-90-3A/IR19392 211-1	89	160	7.39
IR21845-90-3A/IR20933-68-21-1-2	96	167	6.72
IR21845-90-3A/IR29512-81-2-1	92	168	4.88
IR46830A/IR50	64	140	4.66
IR46830A/IR9761-19-1	67	140	5.96
IR46830A/IR13292-5-2	62	145	5.97
V20A/Milyang 46	71	145	7.27
Barakat (short-duration check)	83	140	3.12
Pinidua (local check)	140	180	4.42
Replicated yield trial			
IR206152269	92	155	6.15
IR9202-5-2-2-2	88	148	4.51
IR40094-1-5-2	103	159	7.29
IR40096-2-2-2	86	160	6.20
IR40097-1-3-1	85	159	6.15
Wei You 64	66	140	6.56
Barakat (short-duration check)	83	140	4.03
Pinidua (local check)	131	180	4.13
		LSD (.05) =	0.91
		(.01) =	1.26
		CV (%) =	9.27

In Banaue, rice is not grown during the wet season (WS). After the DS harvest, fields lie fallow for about 5 mo. Although the temperature conditions are not damaging and there is no shortage of water, cloudy weather, heavy rains, and gusty winds discourage farmers from growing a second crop. We followed farmer practices during DS, and in the following WS established a nursery consisting of 90 varieties (some with cold tolerance) and 30 F_2 and F_3 bulk populations. Our objective was to determine whether there can be varieties or genotypes that have tolerance for the adverse conditions. We observed plant growth to be extremely slow. Flowering was unusually delayed, and grain sterility was high except in three varieties and some plants of the bulk populations.

Table 6. Some promising F_1 rice hybrids identified in the Korea-IRRI collaborative trials. Suweon and Iri, Korea, 1986.

Hybrid	Suweon			Iri		
	Yield (t/ha)	Difference from check (t/ha)	% of check	Yield (t/ha)	Difference from check (t/ha)	% of check
V20A/Milyang 46	9.2	1.1**	114	8.2	0.2	102
IR54756A/IR9761-19-1	8.7	0.6**	107	8.0	0	100
V20A/IR9761-19-1	8.3	0.2ns	102	8.8	0.8*	110
LSD (0.05)		0.37			0.64	

We found varieties or genotypes that can tolerate the adverse weather conditions, but the major limitation is the effect of the decomposition of the DS crop residue. The DS crop is harvested by removing only the panicles; the straw is left behind. Therefore, it may not be possible to introduce a second crop unless the duration of the DS crop is reduced by 2 mo or longer, or unless its residues are removed from the field.

IDENTIFICATION OF PROMISING F_1 RICE HYBRIDS IN KOREA, MALAYSIA, AND INDONESIA

Plant Breeding Department

In the advanced yield trials conducted at Suweon and Iri, Korea, we identified three F_1 combinations – V20A/Milyang 46, IR54756A/IR9761-19-1, and V20A/IR9761-19-1 – as promising (Table 6). However, they are not acceptable in Korea because of their poor grain quality. In another trial, we evaluated a number of F_1 hybrids derived from new cytoplasmic male sterile (CMS) and restorer lines developed at IRRI and in Korea. Some of these combinations yielded higher than the check varieties at Suweon but not at Iri (Table 7). The grain quality of all these hybrids except V20A/Iri 371 should be acceptable in Korea because both of their parents were derived from locally developed elite lines and varieties that were acceptable.

Six experimental F_1 hybrids were compared with local check varieties in Bumbong Lima, Malaysia, in the 1986 off-season. IR54752A/IR14753-120-3 yielded 1.1 t/ha higher than the best local check (Muda), but the difference was statistically nonsignificant (Table 8).

None of the F_1 hybrids developed at IRRI and evaluated during the year in Indonesia were found

Table 7. Performance of some experimental F_1 rice hybrids and check varieties in a preliminary yield trial. Suweon and Iri, Korea, 1986.

Hybrid or variety	Yield (t/ha)	
	Suweon	Iri
HR1619A/Iri 362	9.7	8.9
IR54756A/Iri 361	9.3	8.6
HR1619A/Suweon 318	9.3	8.0
HR1619A/Iri 371	9.3	7.9
V20A/Iri 371	9.2	8.9
HR1619A/Suweon 294	9.1	8.6
IR54756A/IR28143-56	8.8	7.7
Suweon 287 (check)	8.2	–
Suweon 294 (check)	8.1	–
Suweon 332 (check)	8.0	–
IR64 (check)	6.4	6.1
Iri 346 (check)	–	7.4
Iri 362 (check)	–	8.8
LSD (0.05)	0.54	0.98

Table 8. Performance of some IRRI experimental rice hybrids compared with local check varieties. Bumbong Lima, Malaysia, 1986 off-season.

Hybrid or variety	Yield (t/ha)	% of yield of best check	Growth duration (d)
IR54752A/IR14753-120-3	5.0 a	127	128
IR54752A/IR20933-68-21	4.7 a	122	129
IR54752A/IR4422-480-2-3-3	4.6 a	118	122
IR54752A/IR19392-211-1	4.4 a	112	126
IR54752A/IR54R	4.0 ab	102	126
IR54752A/IR29512-81-2-1	3.8 ab	97	123
IR54R (check)	3.8 ab	97	121
IR64 (check)	3.0 b	77	114
Muda (local check)	3.9 ab	100	135
MR84 (local check)	3.8 ab	99	138

significantly superior to the best local checks. We sent additional newly developed hybrids derived from CMS line IR54752A and elite restorer lines.

EFFECT OF FEMALE-TO-MALE ROW RATIO ON OUTCROSSING RATE AND HYBRID SEED YIELD OF CMS LINES

Plant Breeding Department

A cooperative trial at Suweon, Korea, studied the effect of four female-to-male row ratios (8:2, 6:2, 4:1, and 3:1) on the outcrossing rate and seed yield of two CMS lines (V20A and Zhen Shan 97A). Zhen Shan 97A synchronized in flowering with the restorer lines (Milyang 46R, Milyang 54R, and IR9761-19-1R) used in the study. Flowering synchronization between V20A and restorer lines Milyang 46R and Milyang 54R was not as good. Results (Table 9) indicate that 4:1 and 3:1 ratios give higher outcrossing rates and seed yields than 8:2 and 6:2. The outcrossing rate on CMS line Zhen Shan 97A ranged from 6.3 to 18.5%, resulting in hybrid seed yields of 29.1-76.1 g/m^2. V20A showed an outcrossing rate ranging from 6.6 to 38.6%, yielding 29.7-90.8 g/m^2. The highest seed yield (90.8 g/m^2) was obtained with a 4:1 row ratio in V20A/IR9761-19-1R.

TISSUE CULTURE COLLABORATION WITH KOREA AND PERU

Tissue Culture Facility

In the project with the Rural Development Administration (RDA) of Korea for the development of cold-tolerant lines through anther culture, 64 lines were sent to RDA for evaluation, bringing the total to 1,248. An experiment to compare the anther culturability of 10 SRT crosses under 2 conditions was begun concurrently by IRRI and RDA, using the same media and *in vitro* culture techniques and conditions.

The research into the production of lines adapted to Latin America through anther culture is in collaboration with the Peruvian National Rice Program and the National University Pedro Ruiz Gallo. A total of 726 green plants from 6 of 8 crosses tested were regenerated in the first batch of F_1 hybrids (indica/indica). Seeds of 224 anther culture lines from 6 crosses were planted in Peru in October 1986. A second set of 19 crosses with parentage different from that of the first set was inoculated in callus induction medium in 1986 WS.

GREEN LEAFHOPPER "BIOTYPE" AND TUNGRO TRANSMISSION IN INDONESIA

Plant Pathology Department

The IRRI-Agency for Agricultural Research and Development (AARD) Collaborative Research on Rice Tungro Virus Disease was conducted at the Maros Research Institute for Food Crops (MORIF), South Sulawesi, Indonesia, from August to October 1986. The studies aimed to clarify the relations between green leafhopper (GLH) "biotypes" and tungro (RTV) transmission using four GLH colonies that had been maintained on IR20, IR42, IR54, and TN1 at MORIF since 1982. IR26 and IR30 were selected as possible differentials for IR20 colonies; IR36 and IR42 were selected for IR42 colonies; and IR50 and

Table 9. Effect of female-to-male[a] row ratios on outcrossing rate and seed yield of CMS lines V20A and Zhen Shan 97A, Suweon, Korea, 1986.

Genotype	Outcrossing rate (%)					Seed yield (g/m^2)				
	8:2	6:2	4:1	3:1	Av	8:2	6:2	4:1	3:1	Av
V20A/Milyang 46R	6.6	8.7	14.5	17.3	11.8	37.2	43.0	52.9	49.6	45.7
Zhen Shan 97A/Milyang 46R	8.2	6.6	6.7	11.1	8.2	33.0	29.2	40.7	38.5	35.4
V20A/Milyang 54R	6.6	9.7	19.9	16.3	13.1	29.7	34.0	40.7	39.9	36.1
Zhen Shan 97A/Milyang 54R	14.6	16.2	13.5	18.5	15.7	51.8	52.3	76.6	71.8	63.1
V20A/IR9761R	17.6	20.3	28.3	38.6	26.2	69.9	73.6	90.8	82.0	76.6
Zhen Shan 97A/IR9761-19-1R	6.3	10.1	11.8	15.2	10.9	44.3	61.7	70.6	76.1	63.2
Av	9.9	11.9	15.8	19.5	14.3	42.7	49.0	62.1	59.7	53.4

[a] In the ratio, the first number refers to female rows and the second to male.

IR54 were selected for IR54 colonies. IR60 was selected as the resistant check and TN1 as the susceptible check.

Green leafhopper preference. Pregerminated seeds of the selected varieties were planted in a plastic tray, in rows of 10 seeds per row per variety. Ten days after planting, 40-60 GLH that had fed on RTV-infected plants were introduced in the center of the tray in a cage. The GLH alighting on the test varieties were counted at 24 h after infestation. Two weeks after infestation, the seedlings infected with RTV were counted.

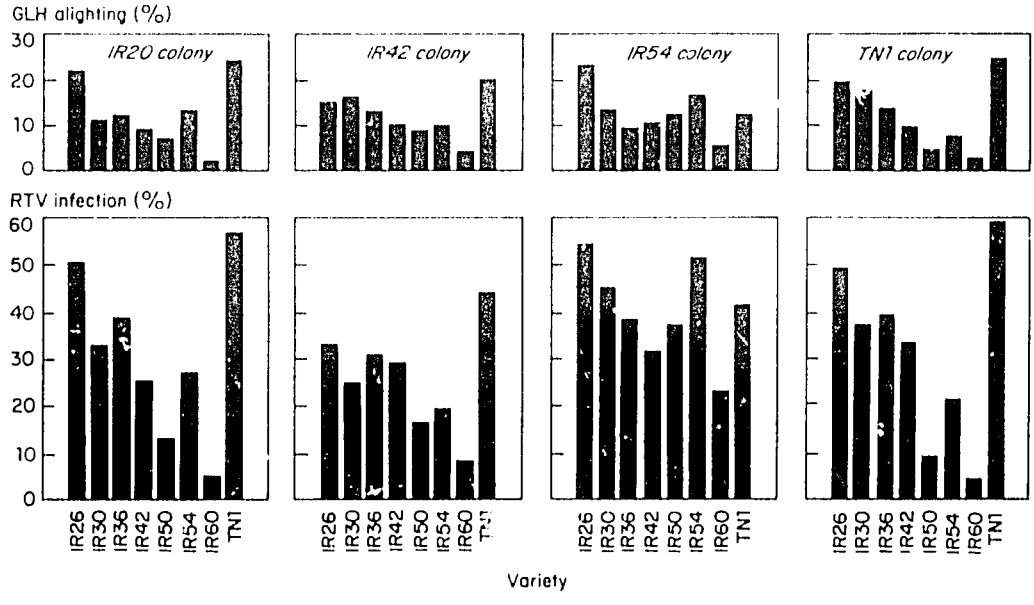
Depending on the colonies used, GLH showed preferential choice of varieties (Fig. 1). Those that alighted on IR26, IR30, IR36, and IR42 were comparable regardless of origin. The percentage of GLH on IR50, IR54, and IR60 was higher with IR54 colonies than with the other colonies. On TN1, the percentage of GLH from IR54 colonies was less than that from the other colonies.

The RTV infection rate varied depending on the variety and the GLH colony used (Fig. 1). Generally, the varieties on which a higher percentage of GLH alighted had higher RTV infection rates. IR54 colonies gave higher RTV infection rates in IR50, IR54, and IR60 than the other colonies did. The percentage infection by IR54 colonies in TN1 was lower than that by the other colonies.

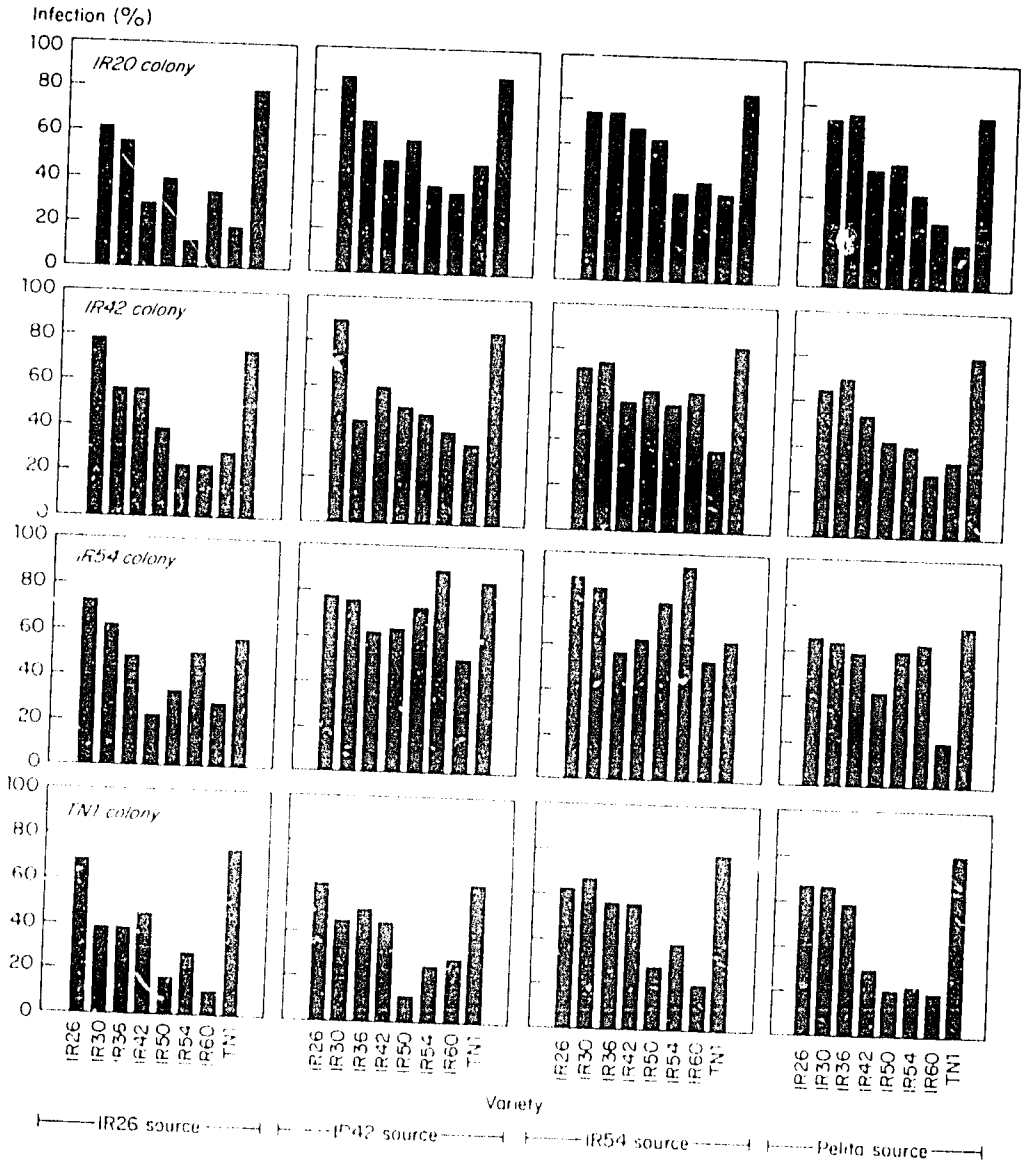
RTV transmission by GLH thus varies, depending on preference for the variety when GLH has a choice of varieties on which to feed. IR54 colonies preferred IR50, IR54, and IR60, which probably have common resistance genes derived from Giam Pai 30-12-15, but other colonies showed no characteristic preference for any test variety.

Tungro transmission. Another study aimed to determine the effects of RTV source and GLH colony on RTV transmission to selected varieties. GLH adults of the 4 colonies that had fed on RTV-infected plants of different varieties were confined in a test tube with test seedlings at 1 or 3 GLH per seedling for 1 d. Aside from visual scoring of infection based on RTV symptoms taken 14 d after inoculation (DAI), test plants were also indexed for the presence of tungro bacilliform virus (RTBV) and tungro spherical virus (RTSV) by the latex test at 30 DAI.

Disease source did not affect RTV infection rate much (Fig. 2). Regardless of source used, a distinct differential reaction of the varieties was observed when IR54 colonies were used. RTV transmission by IR54 colonies on varieties IR50 and IR54 was higher than that by the other colonies. IR54



1. Green leafhopper (GLH) alighting on test varieties at 24 h after infestation and the resulting tungro (RTV) infection. Maros Research Institute for Food Crops (MORIF), Sulawesi, Indonesia, 1986.

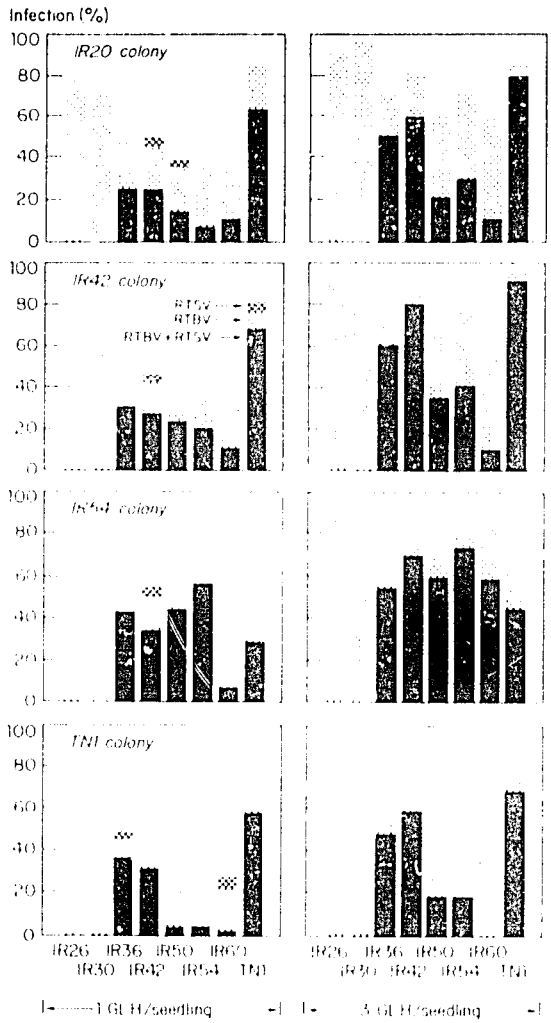


2. Visual score of RTV infection of rice varieties inoculated at 1 GLH seedling in test tubes by different GLH colonies that had fed on RTV-infected plants of varieties IR26, IR42, IR54, and Pelita. MORIF, Sulawesi, Indonesia, 1986.

colonies preferentially transmitted RTBV and RTSV together to IR50 and IR54, whereas the other colonies preferentially transmitted RTBV alone (Fig. 3). On susceptible TN1, IR54 colonies produced relatively low RTV infection, and the infected plants showed relatively high infection with RTBV alone.

IR20 and IR42 colonies did not show a distinct differential reaction, although the RTV transmission rate of these colonies in the differential varieties was higher than the rate of TN1 colonies (Fig. 2). This may indicate partial adaptation of IR20 and IR42 colonies to their respective varieties.

Regardless of colony used, IR26 and IR30 were infected with RTBV only. Generally, varieties other than IR20 and IR30 had increased infection rates with both RTBV and RTSV when GLH number was increased from 1 to 3.



3. Average infection with tungro bacilliform virus (RTBV) and tungro spherical virus (RTSV) on rice varieties inoculated at 1 and 3 GLH per seedling by 4 selected GLH colonies that had fed on RTV-infected source plants of IR26, IR42, IR54, or Pelita. MORIF, Sulawesi, Indonesia, 1986

PESTICIDE SUSCEPTIBILITY MONITORING

Entomology Department

A project was initiated to monitor the susceptibility of rice insect pests to insecticides in India, Sri Lanka, Bangladesh, Thailand, Vietnam, Malaysia, Indonesia, Philippines, China, Korea, and Japan. The 14 national program scientists involved hope to standardize methods of determining susceptibility and to monitor the baseline susceptibility of stem borers, planthoppers, and leaffolders to eight insecticides.

INCREASING IRRIGATION EFFECTIVENESS, CROP PRODUCTION, AND FARMER INCOME IN BANGLADESH

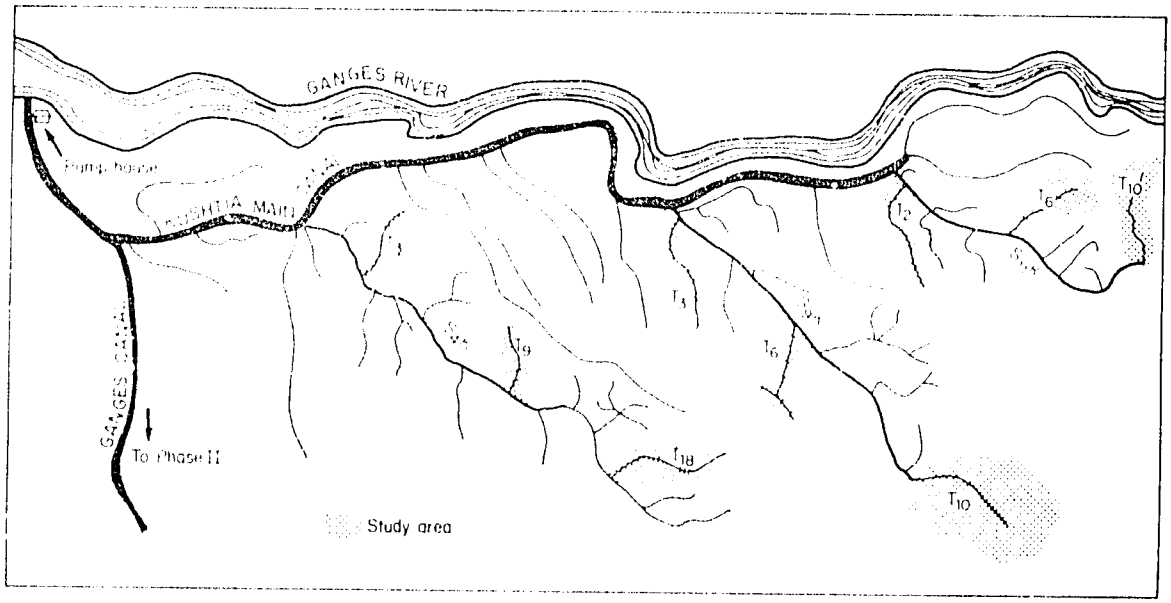
Water Management Department

An applied research project was initiated in 1981 in collaboration with the Bangladesh Rice Research Institute (BRRI) and the Bangladesh Water Development Board (BWDB). A multidisciplinary group of professionals from BRRI and BWDB studied two irrigation systems — the Ganges-Kabodak (G-K) irrigation system (Phase I), which is a lift-cum-gravity type facility for irrigating over 40,000 ha of riceland, and the North Bangladesh tubewell irrigation system, which manages 378 deep tubewells. IRRI provided technical support in planning, data collection, data analysis, reporting, and training.

In the G-K irrigation system, the research assessed the system's tertiary level water allocation-distribution method and its effectiveness, introduced improved crop production technologies compatible with the water status, and evaluated the prospects of crop production increases to boost farmer income. The field research was conducted in the service areas of nine selected tertiary canals of three secondary canals representing the head, middle, and tail sections of the system main canal. Likewise, the head, middle, and tail areas of each secondary canal were represented by a set of three tertiaries, one from each sectional area (Fig. 4). From each tertiary area, 50 sample farm plots were monitored to create a farm-level database covering water status, cultural practices, variety use, crop establishment date, inputs use, and yields. Irrigation water flow through each tertiary canal was measured each season. Rainfall and pan evaporation rates were measured in an agrometeorological station established for each tertiary canal area.

Impact of irrigation water on crops. Some selected findings on water allocation methods and plans, as they relate to improvements in irrigation effectiveness and crop production, are summarized.

Pump operation schedule. Farmers wait for the start of pump operation and water delivery before starting field operations for aus, the beginning of which is usually very dry. Knowledge of the water delivery schedule is needed for farmers to be prepared for farm level operations such as land

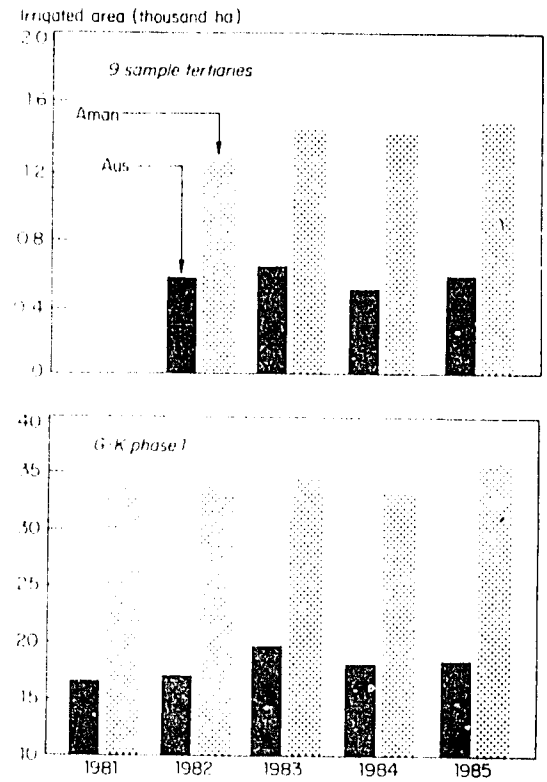


4. Diagram of the Ganges-Kabodak (G-K) irrigation system showing 9 selected tertiary canal areas, 1986.

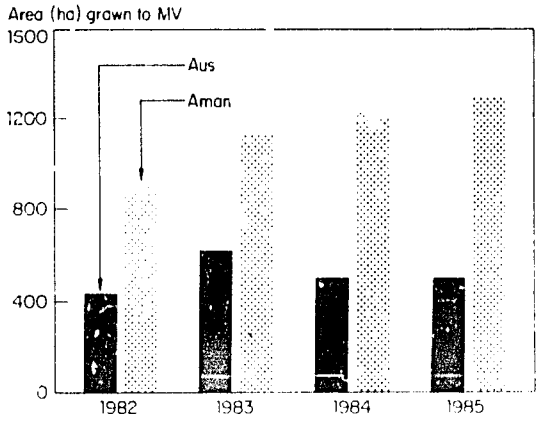
soaking, land preparation, and seedling care. If there is no fixed pump operation and water delivery schedule, water use in the system cannot be efficient. During the past 12 yr, pump operation started at various times between the first week of January and the first week of March.

An early start of water delivery is desirable because it allows early harvest of aus rice, say by July, and aman rice transplanting at the optimum time, i.e., by the middle of August, for high yields. Considering the two seasons together and the water supply fluctuations at the source, the annual pump operation schedule for two rice crops should be 1 Feb-31 Oct. This schedule would allow the use of modern rice varieties (MVs) in both seasons, better use of peak rainfall in July for aman rice land preparation, and 5 mo every year for repair and maintenance work. The schedule should be strictly implemented, and all farmers should be informed of its intents and benefits.

Irrigation coverage, modern variety and inputs use, and yields. Irrigation coverage during the study period increased in the system as a whole and in the nine tertiary areas, especially in aman (Fig. 5). Similarly, modern variety (MV) use increased steadily in aman in the nine tertiary areas



5. Total irrigated area in 9 research tertiaries and the whole G-K (Phase I) irrigation system, Bangladesh, 1981-85.



6. Area grown to modern varieties (MVs) in aus and aman, 9 research tertiary areas, G-K irrigation system, Bangladesh, 1982-85.

(Fig. 6), consistent with improvements in their water management status. Suitable varieties for aus are limited, and uncertainties in the river water supply during early aus are major limiting factors in improving the benefited area and MV adoption in that season.

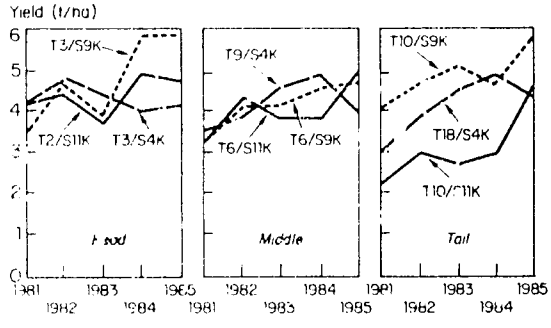
In 1983-85 aus, scarcity of water was more severe in the sample areas farthest from the water source. Farmers' use of inputs and yields were affected in the service areas of the last secondary canal (S11K) and the tail tertiary of each secondary canal. The average NPK use and yield were significantly lower in S11K than in the two upper secondary areas. Similarly, the average inputs use and yields of the three tail end tertiary areas in aus were significantly lower than those of the three head or three middle tertiary areas (Table 10). In aman, when sufficient rainfall occurred, by and large all tertiary areas were well supplied with water to meet their local requirements, and inputs use and yields of tail tertiary areas were similar to the other areas. Among the secondary areas, farmers in S11K, which is the last secondary of the three, used slightly lower inputs and had lower yields.

Improved irrigation service in the nine tertiaries during 1982-85, coupled with use of better varieties and higher inputs, increased rice yields in the service areas. The greatest beneficiaries of this improvement were the tail and middle end farmers, who achieved an average aman yield increase of

Table 10. Average yields and inputs use of farms in 3 selected secondary areas and in the head, middle, and tail reaches of the secondary canals, Ganges-Kobodak irrigation system, Bangladesh, 1983-85.

Location	Yield[a] (t/ha)	Input use (kg/ha)		
		N	P	K
	Aus			
S4K	4.0 a	97	43	26
S9K	4.2 a	90	48	30
S11K	2.0 b	62	36	21
Head[b]	4.2 a	90	50	31
Middle	3.5 b	91	43	27
Tail	3.3 b	65	27	14
	Aman			
S4K	4.8 a	94	36	21
S9K	4.9 a	103	49	29
S11K	4.1 b	78	41	25
Head[b]	4.6 a	92	46	27
Middle	4.5 a	91	43	26
Tail	4.6 a	90	38	21

[a]Within a group of 3, figures followed by a common letter are not significantly different at the 5% level by DMRT.
[b]Implies the 3 head-reach tertiaries -- 1 each from secondary S4K, S9K, and S11K. Middle and tail have similar meaning.



7. Average aman rice yields of farmers at head, middle, and tail end tertiary service areas of 3 secondary canals, G-K irrigation system, Bangladesh, 1981-85.

about 1.0 t/ha in 1982-85 compared with the 1981 benchmark yield (Fig. 7). The farmers in the head tertiaries also had an average yield increase of about 0.5 t/ha. Rice production in aus and aman increased by over 20% in the 9 tertiaries and by about 50% in the 3 tail end tertiaries in 1985 compared with that in 1982.

Irrigation service and cropping patterns. In the areas where irrigation water is delivered in both aus and aman, the most profitable as well as preferred pattern was rice - rice. A three-grain crop system such as rice - rice - wheat is not recommended. The third crop, grown on residual soil moisture, should be a leguminous crop to maintain soil fertility and production sustainability. The irrigation system had previously tried to deliver water to limited areas for irrigated wheat in rabi after aman rice, but this practice was not sustainable and precluded proper repair and maintenance. Furthermore, wheat grown in rabi delays aus rice establishment, which in turn delays aman rice, resulting in lower rice production and less income.

Rice production is more risky and less profitable in areas where irrigation water delivery in aus is late or inadequate. The service area of T10 S11K is such an area. Attempts to grow two rice crops usually delay plantings in both seasons, resulting in low yields. The average yields of T10 S11K in 1982-85 were 2.0 t/ha for aus and 3.1 for aman, which were 1.7 t/ha less in aus and 1.2 t/ha less in aman than the respective average yields in the other tertiary areas receiving more timely and adequate irrigation water in aus.

We attempted to grow only aman rice in the T10 S11K area — thus replacing two delayed rice crops — with timely irrigation water, timely establishment of MVs, and incorporating the biomass of a green manure crop (sesbania) of the preceding aus using rainwater to improve the soil N status. From replicated experiments in farmers' plots, yields of BR11 were 6.3 t/ha in 1984 and 6.5 t/ha in 1985 aman, with about 50% of recommended chemical N. These yields were about 2.6 and 1.9 t/ha higher than farmers' yields in the same season for the same variety in the area — highly encouraging results. After a timely aman rice, farmers can grow pulse (leguminous) crops in rabi using residual soil moisture.

A SIMULATED TANK IRRIGATION SYSTEM TO IDENTIFY RICE YIELD REDUCTIONS IN TAMIL NADU, INDIA

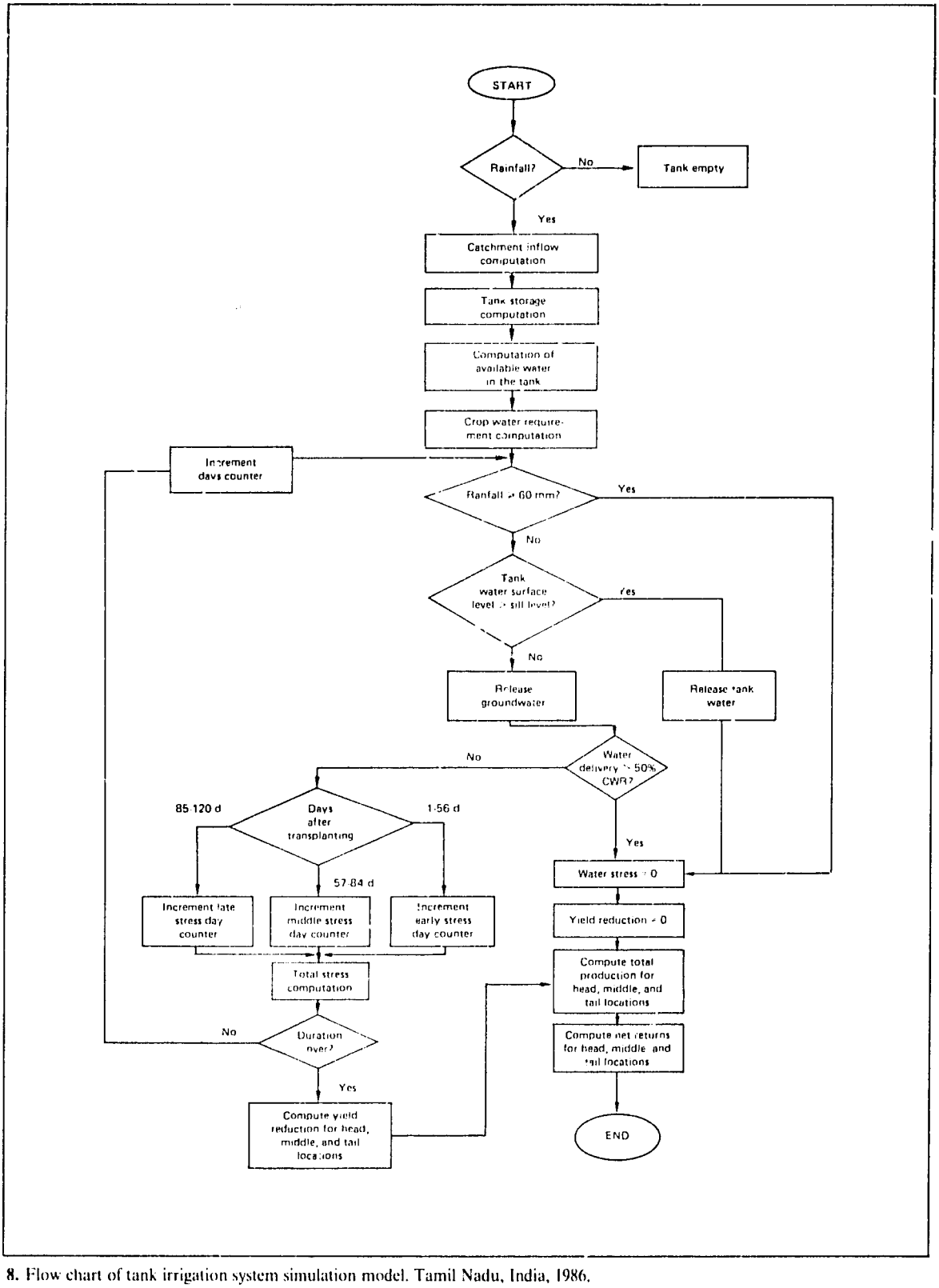
Agricultural Economics Department

An irrigation tank is a small earthen reservoir constructed across the gentle slope of a minor valley to catch and store rainfall runoff. Tank irrigation systems are more than a century old and cover over 30% of the total irrigated area in Tamil Nadu, Karnataka, and Andhra Pradesh States in South India. The tanks irrigate mainly WS rice from September to December.

Currently, the tanks have several performance constraints. Tank siltation, foreshore encroachment, and weak tank structures (such as tank bunds, sluices, surplus weirs, etc.) are the major problems above the outlet; badly maintained canals, absence of water users' organizations, improper tank operation, and inadequate groundwater supplies to supplement tank water are the major constraints below the outlet. The above-outlet problems reduce the water available in the tank. The below-outlet problems introduce inequity in water distribution among the farmers. Both above- and below-outlet problems result in water stress and rice yield reductions. Hence it is important to identify appropriate investment strategies to improve water availability at the tank and farm levels. This study was an attempt in this direction in Ramanathapuram District, Tamil Nadu, using 1984 field and tank level data. The major objective of the study was to evaluate tank irrigation system management strategies by developing a simulation model. More specifically, the study estimated the rice stress days and yield reduction under existing as well as improved physical and management strategies, and evaluated tank improvement strategies. It was done in collaboration with the Water Technology Center of Tamil Nadu Agricultural University.

Tank irrigation system simulation model. A simulation model is an appropriate and advanced tool to study the performance of an irrigation system as it embodies the variables and relationships that characterize an operating irrigation system. The model simulates decision making at several levels of activity, including water releases for crops and crop yield reductions because of water stress at different crop stages as well as at different locations in the system.

The flow chart of the tank irrigation system simulation model is given in Figure 8. The model works on a daily basis and has these inputs: inflows from the catchment and supply channel, seepage and evaporation losses, sill level of the surplus weir,



8. Flow chart of tank irrigation system simulation model. Tamil Nadu, India, 1986.

full tank capacity, number of sluices, sill level of the sluices, values on elevation of tank water surface vs tank storage and elevation of tank water surface vs tank water surface area, area and percentage of crops in each sluice, delivery efficiency of the canals, field water requirement of crops, and number of wells.

The model computes daily water balance at the tank by subtracting the daily crop water requirements and seepage and evaporation losses from the tank storage. Thus, storage at the beginning of the day is calculated by adding the previous day's balance (storage) to the inflows on that particular day. From the tank storage, corresponding elevation and surface area are calculated using a subroutine from which tank evaporation and seepage losses for the water surface are calculated. The model automatically calculates the emptying as well as surplusing of the tank using the sill level of the sluices and surplus weir. It also allows farm level pumping of groundwater when the tank water level is below the sill level of the sluices. The stress days at different periods of crop growth — early, middle, and late — are calculated when the groundwater available for rice is less than half of its field requirement. Rice yield reductions are estimated using the calculated stress days with the yield-stress days equation for head, middle, and tail farm groups of the irrigation system. Then the total stress days and yield reductions are computed for the season for each sluice.

The model was field tested for its reliability and then rerun for 1) different investment strategies such as restructuring the sluices, lining the main canal, and introducing more groundwater wells for supplementary irrigations; and 2) improved management strategies such as sluice and rotation management. With sluice management, the sluices are closed if the daily rainfall exceeds 60 mm; with rotation management, the 4 sluices are rotated alternatively (2 each week) for irrigation. Srivilliputhur Big Tank in Ramanathapuram District was selected as a representative tank for field testing the model. The catchment area is 1,536 ha, storage capacity is 14,160 ha-cm, water spread is 53.39 ha, and the irrigated area is 401.87 ha. The model was applied using 1984 data.

Equations used in the model

1. Inflow from catchment:
   $INFLOCAT_k = RF_k \times RUNPER \times AREACAT$
2. Evaporation losses
   $EVATK_k = DAEVA_k \times TSURARE_k$
3. Seepage losses
   $SEETK_k = DASEP_k \times TSURARE_k$
4. Field water requirement of rice
   $CROPREQ_k = (CROPREQ_l / NDFOR_l) + SPREQ_k$
   $TCRREQ_{ki} = (CROPREQ_k \times ARESLU_i) / DELEFI_i$
5. Groundwater supply
   $GWAT_{ik} = f(TSTO_k) \times NW_i$
6. Stress days
   $TDS_i = (SD_{1i} \times W_1) + (SD_{2i} \times W_2) + SD_{3i}$
7. Yield reduction
   $YRD_{ij} = (SDCO_j \times TSD_i) \times ARE_{ij}$

where

$INFLOCAT_k$ = inflow from catchment on k^{th} day in 100 m^3 (k=1-243 d),
RF_k = rainfall on k^{th} day in cm,
$AREACAT$ = tank catchment area in ha,
$RUNPER$ = runoff percentage,
$EVATK_k$ = evaporation losses from the tank on k^{th} day in cm,
$DAEVA_k$ = evaporation rate on k^{th} day in cm,
$TSURARE_k$ = tank surface area on k^{th} day in 100 m^2,
$SEETK_k$ = seepage losses from the tank on k^{th} day in cm,
$DASEP_k$ = seepage rate on k^{th} day in cm,
$CROPREQ_l$ = water requirement of rice at l^{th} fortnight in cm
$NDFOR_l$ = number of days at l^{th} fortnight
$SPREQ_k$ = seepage and percolation requirement on k^{th} day in cm
$TCRREQ_{ki}$ = total field water requirement on k^{th} day i^{th} sluice
$TSTO_k$ = initial tank storage on k^{th} day in 100 m^3
$CROPREQ_k$ = field water requirement of rice on k^{th} day in cm,
$ARESLU_i$ = rice area in i^{th} sluice in ha (i=1-4 sluices),
$DELEFI_i$ = delivery efficiency of the canal in i^{th} sluice in percent,
$GWAT_{ik}$ = groundwater available for pumping on k^{th} day in i^{th} sluice in 100 m^3,
NW_i = number of wells in i^{th} sluice,

TSD_i = total stress days in i^{th} sluice,
SD_{1i} = number of early stress days in i^{th} sluice,
SD_{2i} = number of middle stress days in i^{th} sluice,
SD_{3i} = number of late stress days in i^{th} sluice,
W_1 and W_2 = weight for early and middle stress days,
YRD_{ij} = rice yield reduction in farm group j, in sluice i in t (j=1-3 groups)
$SDCO_j$ = stress days coefficient in the yield stress day equation for farm group j, and
ARE_{ij} = rice area in farm group j in sluice i in ha.

Stress days and rice yield reduction. The model estimated the stress days and rice yield reduction for each sluice. With existing conditions, the stress days range from 17.7 d in sluice 1 to 37.3 d in sluice 4. The yield reductions are also correspondingly varied, from 79.5 t in sluice 1 to 150.5 t in sluice 3. The total yield reduction is about 446 t. The differences in stress days and yield reductions among the sluices stem from the differences in the areas they command. When different tank improvement strategies are introduced, the stress days and yield reductions are minimized. The magnitude of the minimization of stress days and yield reductions is directly related to the types of strategies. Combinations of physical strategies – such as canal lining or provision of additional groundwater wells – and management strategies prove better than either physical or management strategies alone (Table 11).

The effectiveness of each strategy was further studied using three criteria, viz., productivity ratio, equity ratio, and financial benefit-cost ratio (B:C) (Table 12). Productivity ratio as the criterion is

Table 11. Stress days and rice yield reductions under different tank improvement strategies, Ramanathapuram, Tamil Nadu, India, 1984.

Investment strategies	Stress days (no.)				Yield reduction (t)				
	Sluice 1	Sluice 2	Sluice 3	Sluice 4	Sluice 1	Sluice 2	Sluice 3	Sluice 4	Total
Existing conditions	17.67	37.76	21.77	37.31	79.50	91.48	150.55	124.61	446.14
Sluice modification	16.60	38.38	22.65	35.79	74.68	92.98	156.78	119.53	443.97
Canal lining	0	34.62	0	33.55	0	83.87	0	112.05	195.92
Additional wells	0	37.76	0	27.86	0	91.48	0	93.05	184.53
Canal lining and additional wells	0	34.62	0	0	0	83.87	0	0	83.87
Sluice management	13.30	29.0	16.48	27.48	59.97	70.26	114.07	91.78	336.08
Sluice management and canal lining	0	25.41	0	23.10	0	61.56	0	77.15	138.71
Sluice management and additional wells	0	29.00	0	20.28	0	70.26	0	67.73	137.99
Sluice management, additional wells, and canal lining	0	24.96	0	0	0	60.47	0	0	60.47
Rotation management	1.35	20.93	6.75	14.40	6.07	50.71	46.72	48.09	151.59
Rotation management and canal lining	0	13.95	0	13.50	0	33.79	0	45.09	78.88
Rotation management and additional wells	0	15.30	0	9.00	0	37.07	0	30.06	67.13
Rotation management, canal lining, and additional wells	0	13.50	0	0	0	32.71	0	0	32.71

Table 12. Productivity and equity ratios for tank improvemant strategies, Ramanathapuram, Tamil Nadu, India, 1984.

Investment strategies	Productivity ratio[a]	Equity ratio[b]	B:C analysis[c]	
			Life period (yr)	B:C
Existing levels	–	Very high		
Sluice modification	1.00	Very high	6	0.47
			11	0.66
Canal lining	1.30	1.62	6	1.79
			11	2.91
Additional wells	1.32	1.51	8	1.70
			16	2.09
Canal lining and additional wells	1.44	1.27	8	1.54
			16	1.90
Sluice management	1.13	2.66	10	10.04
			15	10.57
Sluice management and canal lining	1.37	1.40	6	2.30
			11	3.68
Sluice management and additional wells	1.38	1.37	8	2.02
			16	2.46
Sluice management, additional wells, and canal lining	1.47	1.23	8	1.74
			16	2.13
Rotation management	1.36	1.55	10	10.81
			15	10.91
Rotation management and canal lining	1.45	1.33	6	1.89
			11	2.89
Rotation management and additional wells	1.46	1.26	8	1.94
			16	2.37
Rotation management, canal lining, and additional wells	1.50	1.21	8	1.40
			16	1.81

[a]Ratio of average rice productivity with modernization strategies to average rice productivity with existing conditions in the system. [b]Ratio of per hectare net returns of head farms to per hectare net returns of tail farms in the system. [c]Discount rate = 12.5%.

useful if the objective of tank improvement is to increase rice yield. The equity ratio criterion is useful if the objective is to minimize the income inequalities between farmers in different locations within the system. According to these two criteria, sluice management in combination with canal lining and additional wells ranks first, followed by sluice management, additional wells, and canal lining. However, both criteria may be useful if the investment fund is generated from the beneficiaries (tank farmers); if the investment is from outside borrowing, then financial B:C may be a useful criterion. Accordingly, both strategies are financially more attractive with their comparatively higher B:C's. This may be because of the lower cost of management investment, as the cost may be only a variable cost toward the additional labor for supervision and operation of the system.

Analysis. Tamil Nadu has a rice area of more than 0.9 million ha under tanks. It is important to select relevant modernization strategies to exploit the tank irrigation potential fully. The results of the simulation indicate that several modernization strategies such as canal lining, providing additional groundwater wells, and proper sluice management — when used individually and in combinations — will improve the overall performance of the tank system. However, the priority strategies were identified using different evaluation measures.

The productivity and equity criteria are very useful in defining system performance in a consistent way so that modernization strategies can be compared when the government aims to maximize crop productivity and minimize income inequities. They are particularly relevant when the responsibility for the operation and management of the tank system is fully vested in the local community, with minimal or no intervention by the government. Under such situations, farmers will participate in tank improvement strategies provided

that they know the benefits of participation. Productivity increases coupled with reduction in income inequities will help achieve improved tank performance. Then location-neutral modernization options such as combination of rotation management, canal lining, and additional wells; combination of sluice management, canal lining, and additional wells; and combination of rotation management and additional wells will be useful to achieve increased system performance. In cases where improved management is difficult to introduce because of farmer conflicts and differences, a combination of physical improvements will be more appropriate.

The tanks can possibly be modernized through heavy national and international funding. Under such conditions, where the accumulated interest rates will be high, the government may be interested in investing in modernization strategies with higher rates of return. Hence, evaluating modernization investments using B:C's is important. The simulation results indicate that rotation or sluice management is the single most cost-effective strategy, and if it is achieved with farmer cooperation, the returns from tank irrigation will be high, because currently most tanks are run without any operator, resulting in wastage of water. Wherever rotation or sluice management is difficult because of farmer heterogeneity, canal lining is the next best alternative, followed by provision of additional wells.

YIELD GAP IN TANK-IRRIGATED AREAS OF TAMIL NADU, INDIA

Agricultural Economics Department

Siltation, foreshore encroachment, weak tank structures, poor management, and uncertain rainfall reduce the total water availability to rice from tank irrigation in South India. The growing inadequacy of tank water supplies has encouraged farmers to seek groundwater supplementation, particularly at the later stages of the rice crop. However, the availability of supplementary groundwater irrigation is constrained by the limited number and capacity of wells in the command area. This helps develop a monopoly market for well owners, who have a noticeable influence upon price and who receive a considerable portion of the tank irrigation benefits of the nonowners.

Inadequate tank and well water supplies have both direct and indirect effects on rice yield. They affect yield directly by influencing crop growth through water stress, and they affect growth indirectly by influencing the use of other inputs such as fertilizer, labor, and management. Both water and crop management affect yield considerably. Farmers with higher levels of water management have necessarily higher levels of crop management and higher yields. In years of adequate tank supplies, farmers concentrate on crop management for higher output. However, the effect of water supply in deficit and surplus rainfall years on input use and rice output has rarely been quantified. Such quantification would help in developing strategies for tank modernization. The objectives of this study were 1) to determine the effect of water supply on other inputs used and on rice yield, 2) to determine the return to supplementary groundwater irrigation, and 3) to analyze the behavior of the groundwater market. The study was done in collaboration with the Water Technology Center, Tamil Nadu Agricultural University.

Selection and basic characteristics of the tanks. Ramanathapuram District in Tamil Nadu was selected because of its many and varied tanks for irrigation. Eight tanks with varying dimensions were identified for the field research. One hundred sixty farmers, selected randomly with the help of the revenue inspectors, were interviewed. In-depth discussions were held with Public Works Department engineers, agricultural officers, and Forestry Department officials regarding system operation and maintenance, crop cultivation, and tree planting in the catchment and watershed areas. Data for 4 yr (1981-84) were collected for the September-December crop season because tank irrigation is common only then. On the basis of rainfall distribution and as confirmed by F-test, 1981 was considered a surplus rainfall year, 1982 was a failure year, and 1983 and 1984 were deficit years. In the present study, only surplus and deficit years were used.

Simultaneous equations system. A simple model of rice yield as a function of water use, fertilizer management, etc. cannot adequately capture the effect of these independent variables on rice yield, as each independent variable can again be ex-

pressed as a function of several other variables. Hence, a system of simultaneous equations was considered appropriate to a study of such relationship.

Because of their joint dependence on the dependent and independent variables, the following set of (structural) equations constitutes the simultaneous equations system for the present study. The model consists of six equations. As the equations were overidentified, the model was estimated using the 3SLS method.

Tank water use equation: $Y_1 = f(Y_5, X_1, X_2, X_3, X_4, X_5, X_6, X_7, \mu_1)$

Well water use equation: $Y_2 = f(Y_1, Y_5, X_3, X_8, X_9, X_{10}, X_{11}, \mu_2)$

N use equation: $Y_3 = f(Y_1, Y_2, Y_4, X_{12}, X_{13}, X_{14}, \mu_3)$

Labor use equation: $Y_4 = f(Y_1, Y_2, Y_3, X_{14}, X_{15}, \mu_4)$

Management equation: $Y_5 = f(Y_1, Y_2, X_{14}, X_{16}, \mu_5)$

Rice yield equation: $Y_6 = f(Y_1, Y_2, Y_3, Y_4, Y_5, X_{17}, \mu_6)$

where,

Y_1 = tank water availability at farm level in ha-cm/ha,

Y_2 = well water availability at farm level in ha-cm/ha,

Y_3 = N use at farm level in kg/ha,

Y_4 = labor use at farm level in d/ha,

Y_5 = crop management index, arrived at by giving different scores to different crop operations and adding all the scores for each farmer,

Y_6 = rice yield at farm level in t/ha,

X_1 = water management expenditure for main and secondary canal cleaning, and diversion labor expenditure in $/ha,

X_2 = number of sluices in the tank,

X_3 = number of wells in the command area,

X_4 = dummy variable for water users organization (WUO) (0 if WUO is absent, 1 if WUO is present),

X_5 = dummy variable for tank type (0 if nonsystem tank, 1 if system tank),

X_6 = dummy variable for tank size (0 if minor tank, 1 if major tank),

X_7 = current season's rainfall over mean rainfall, in percent,

X_8 = ownership of well (0 if not owned, 1 if owned),

X_9 = well water-to-rice price ratio,

X_{10} = service charges for well water supplies in $/ha,

X_{11} = cost of tertiary canal cleaning in $/ha,

X_{12} = N-to-rice price ratio,

X_{13} = value of farm assets in $,

X_{14} = credit availability in $,

X_{15} = labor-to-rice price ratio,

X_{16} = expected water management expenditure by farmers in $/ha,

X_{17} = expenditure on plant protection chemicals in $/ha, and

μ_1 to μ_6 = random variables.

Results and discussion. The input levels and rice yields were significantly different between surplus and deficit years. Considering the seasonal field water requirement of 100 ha-cm/ha, in a deficit year tank water availability accounted for about

Table 13. Input use and rice yield in Ramanathapuram, Tamil Nadu, India, 1981-84.

Input	Unit	Deficit year		Surplus year		t-value[a]
		Quantity	Coefficient of variation (%)	Quantity	Coefficient of variation (%)	
Tank water	ha-cm/ha	74.97	37.05	118.41	21.78	16.94*
Well water	ha-cm/ha	22.03	95.85	5.91	127.46	12.18*
Nitrogen	kg/ha	102.56	28.81	91.41	24.28	4.62*
Labor	d/ha	147.35	31.89	134.20	40.25	2.62*
Water management expenditure	$/ha	3.20	33.27	0.54	73.51	39.54*
Crop management	index	32.79	48.85	40.83	36.51	5.15*
Crop management expenditure	$/ha	1.87	75.14	2.22	62.55	2.51*
Plant protection	$/ha	17.36	42.10	22.97	32.69	7.79*
Rice yield	t/ha	2.68	38.15	3.22	21.17	6.90*

[a]For testing the differences between means.

68% and groundwater 20%; in a surplus year availability was in excess (Table 13). The results of the simultaneous equation model indicate that the major determinants of rice yield in a deficit year are tank water, well water, fertilizer, labor, crop management, and plant protection; in a surplus year, the determinants are fertilizer and crop management. Most of the inputs act as rice yield constraints in a deficit year because of water scarcity, and flooding of ricefields due to overuse of water in a surplus year results in a fertilizer and management gap (Table 14, 15).

The model results were also used to derive the rice yield gap caused by input constraints. Compared with potential yield and input use levels in the study area, the yield gap caused by current level of input use is 1.52 t/ha in a deficit year, accounted for mainly by crop management (~25%), tank water (~18%), and well water (~12%). In a surplus year, the yield gap is 1.23 t/ha, accounted for mainly by crop management (~50%) and N (~35%) (Table 15).

The study further analyzed the importance of supplementary irrigation in a deficit year. When tank water is exhausted before the rice season is over, farmers have to purchase well water. The average number of supplementary irrigations varied from as low as 1 to as high as 16. The average return per supplementary irrigation also varied considerably, from $1.39 to $18.54 (Table 16). The optimum number of irrigations was determined from the equation:

$$Y = .5131^{**} + 0.0909I^{**} - .0036I^{2**}$$
$$(0.0651) \quad (0.0142) \quad (.0007)$$
$$(n = 135,\ R^2 = 0.24)$$

where Y = rice yield in t/ha, and
I = number of irrigations.

The optimum number of irrigations to maximize yield was 12.5; to maximize net return, the optimum number was 9.0. However, the farmers applied only about six irrigations because of the inadequate number of wells serving their area. The well owners hence acted as monopolists in their area, charging a high price for their water. About 26-37% of the net return to farmers who did not own wells was captured by the well owners because

Table 14. Results of the simultaneous equations system, Ramanathapuram, Tamil Nadu, India, 1981-84.[a]

Variable[b]	Deficit year		Surplus year	
	Coefficient	t-value	Coefficient	t-value
Intercept	−5.922	−4.85**	−3.422	−4.49**
ln Y_1	1.147	5.08**	0.039	0.2[illegible]
ln Y_2	0.125	6.46**	0.012	1.10
ln Y_3	−1.369	−3.71**	0.524	3.01**
ln Y_4	1.107	7.37**	−0.037	−0.47
ln Y_5	0.201	1.77+	0.569	9.56**
ln X_{17}	0.198	1.79+	0.012	0.23
N	320		160	
R^2	0.47		0.44	

[a]** = significant at the 1% level, + = significant at the 10% level. [b]The variables are explained in the text. Dependent variable: ln Y_6

Table 15. Allocative inefficiencies and rice yield gap, Ramanathapuram, Tamil Nadu, India, 1981-84.

	Deficit year				Surplus year			
	$\partial Y_6{}^a / \partial Y_i$	$dY_i{}^b$	Contribution to yield gap		$\partial Y_6{}^a / \partial Y_i$	$dY_i{}^b$	Contribution to yield gap	
			t/ha	%			t/ha	%
Tank water	0.085	3.28	0.27	17.97	–	–	–	–
Well water	0.025	7.61	0.19	12.46	–	–	–	–
N	−0.094[c]	1.48[c]	0.14[c]	9.11	0.036	12.09	.44	35.51
Labor	0.070	1.77	0.12	8.13	–	–	–	–
Management	0.019	20.50	0.39	25.51	0.054	11.40	.62	50.29
Plant protection	0.032	4.33	0.14	9.05	–	–	–	–
Residual			0.27	17.77			.17	14.20
Yield gap			1.52	100.00			1.23	100.00

[a]Refers to the Marginal Physical Product (MPP) of input i (i=1-5, and X_{17}). The notations are the same as those in the simultaneous equations system. [b]Refers to the difference in input level Y_i and X_{17} between farmers with deficit and those with adequate water supply. [c]N was overused and MPP is negative. The dY_i refers here to the reduction in N use compared with current use. By reducing N use from the existing level, the yield is increased.

Table 16. Returns to supplementary irrigations in a deficit year, Ramanathapuram, Tamil Nadu, India, 1981-84.

Range of supplementary irrigations per ha[a]	Farmers (no.)	Actual supplementary irrigations (no./ha)	Rice yield (t/ha)	Gross return ($/ha)	Net return[b] ($/ha)	Net return/ supplementary irrigation ($/ha)
< 2	21	0.42[c]	1.14	135.05	-58.90	–
2 - 4	10	3.24	2.29	240.07	60.07	18.54
4 - 6	20	4.98	2.18	232.04	79.33	15.53
6 - 8	34	7.04	2.44	253.28	79.15	11.24
8 - 10	24	8.88	2.70	280.09	97.68	11.00
>10	26	14.74	2.25	241.23	20.50	1.39

[a]Only those farmers whose tank water supplies are more or less equal (i.e., between 60 and 80% of the total requirement) are considered here. This helps minimize the upward- or downward-biased yield estimates stemming from higher or lower tank water supplies. [b]Excluding the cost of supplementary irrigations. The cost per supplementary irrigation is $2.73. [c]This is as good as no supplementary irrigation.

Table 17. Well owners' share in tank irrigation benefits in a deficit year in Ramanathapuram, Tamil Nadu, India, 1981-84.

Item	Share ($/ha) based on	
	AC[a]	P_1[b]
Gross return	282.57	282.57
Gross cost[c]	203.38	203.38
Cost of well water[d]	5.04	24.48
Net return	74.15	54.71 (26.22)
Cost of well water[e]	7.00	34.00
Net return	72.19	45.19 (37.40)

[a]Value of water at actual cost to the well owners ($0.28/ha-cm). [b]Value of water at well owners' current selling price ($1.36/ha-cm). Figures in parentheses are percentage decrease in net returns from actual cost. [c]Excluding cost of groundwater. [d]Cost of water at farmers' optimum number of irrigations (9) to maximize profit. Net return = gross return – gross cost – cost of well water. [e]Cost of water at number of irrigations (12.5) to maximize yield. Net return = gross return – gross cost – cost of well water.

they priced well water over the actual pumping costs (Table 17).

The following conclusions may be made:

- It is important to increase tank water supplies in a deficit year through tank management activities such as canal cleaning and efficient diversion of rainfall runoff. Also, it is important to improve water allocation practices; because tank water is currently allocated through continuous sluice opening, rotation of sluices at 1-wk intervals would help allocate the tank water for a longer period, thus minimizing dependence on well water. Tank improvement strategies such as canal lining and sluice as well as rotation management have already proved financially feasible.
- When tank water is exhausted, increased groundwater supply for supplementary irrigations at a cheaper price is necessary to exploit the full benefits of tank irrigation. Currently, about 15% of the tank farmers own their wells, and the price of their water is 4 times higher than the actual cost. It is important to increase the number of wells in the tank command area either by farmer investment with adequate support from financial institutions or by government investment, i.e., community wells at selected locations in the command area.
- Poor management is the major contributing factor to the rice yield gap. Once water supplies are made adequate, improved crop management must be emphasized to minimize the yield gap.

ESTABLISHMENT OF SYMBIOSIS IN *ANABAENA*-FREE AZOLLA

Soil Microbiology Department

Separation of the azolla - *Anabaena* complex into its host and the endophytic *Anabaena* has been reported. The establishment of symbiosis in *Anabaena*-free azolla has not yet been reported. *Anabaena* cells live in the backside of the indusium, are transferred to the embryo germinating from the megasporocarps, and enter into the leaf cavities of the young azolla seedling. Before the germination of megasporocarps, the indusium was removed

from the megaspore apparatus so the young azolla became free from *Anabaena*. After indusium removal, the indusium of the same species or another species was grafted onto the original site. Azolla plants with symbiotic *Anabaena* developed from these grafted megasporocarps.

When the indusium from *A. filiculoides* was grafted onto *A. microphylla* megasporocarps, the identity of the *Anabaena* on the newly developed azolla was confirmed by a monoclonal antibody, which reacts with *Anabaena* from *A. filiculoides*. The monoclonal antibody test and megasporocarp collection were conducted at the National Azolla Research Center in Fuzhou, China.

Free-living *Anabaena* cells isolated by Newton or Bai were inoculated into megasporocarps after removing their indusium. The inoculated *Anabaena* entered into the leaf cavities of newly developed azolla. Unlike symbiotic *Anabaena*, the inoculated *Anabaena* had filaments outside the leaf cavities. The azolla inoculated with free-living *Anabaena* could not grow in a N-free medium.

EVALUATION OF ON-FARM MANAGEMENT OF RICE IN SIND, PAKISTAN

Agricultural Economics Department

The Dokri Rice Research Institute (DRRI), Sind, Pakistan, in cooperation with the Pakistan Agricultural Research Council (PARC) and IRRI economists, examined factors limiting the on-farm yields of IRR16 in Upper Sind.

Considering previous research, four factors were examined: tillage (a combination of seedling age plus density), fertilizer rate, seedling management, and Zn. DRRI and PARC economists and agronomists conducted 42 on-farm experiments from 1983 to 1985. The year-to-year results were highly consistent; thus overall results are summarized.

Agronomic analysis. The mean yield for the simulated farmers' practice over the 42 experiments was 6.2 t/ha, with a minimum 4.9 t/ha and a maximum 7.7 t/ha. These are simulated farmers' yields in the sense that researchers sought to duplicate the levels and manner in which farmers managed the four factors being studied. The mean yield from recommended practices was 8.7 t/ha, with a low of 7.0 t/ha and a high of 11.1 t/ha.

The yield gap between recommended and simulated farmers' practices averaged 2.5 t/ha across the 42 experiments. The smallest gap was 1.8 t/ha, and the largest, 3.7 t/ha.

Tillage resulted in significantly higher yields at 41 of 42 sites. A significant yield gain resulted from the recommended fertilizer rate and seedling management at all 42 sites and from Zn at 33 sites.

The analysis of variance of the pooled data shows that the direct effects of the four factors were highly significant (in each case at the 0.01% level). Several higher-order interactions were also highly significant: tillage × fertilizer rate, tillage × seedling management, fertilizer rate × seedling management, fertilizer rate × seedling management × Zn, and tillage × fertilizer rate × seedling management.

The prevalence of many significant higher-order interactions makes it impossible to apportion the direct effects to each factor and to their interactions. Therefore, in Table 18, the mean yields of each factor at the recommended and farmers' levels are compared when pooled over levels of the three other factors.

Simulating farmers' practices. Simulated farmers' yields were higher than the 4-5 t/ha reported by farmers as the mean yield of IRR16 in Upper

Table 18. Mean yields of each management factor over combined levels of remaining management factors in on-farm experiments, Dokri Rice Research Institute (DRRI), Sind, Pakistan, 1983-85.

Management factor	Mean yield (t/ha)		
	Recommended practice	Simulated farmers' practice	Difference[a]
Land preparation	7.6	7.0	0.6**
Fertilizer	7.7	6.8	0.9**
Seedling management	7.5	7.1	0.4**
Zn	7.4	7.1	0.3**

[a]Significant at the 1% level, based on paired *t*-tests (n = 42).

Sind. Farmers' yield estimates may be biased downward, particularly if respondents fear that the data they provide may be used for tax assessment. The simulated farmers' yields are representative of those achieved by progressive growers in the District, and the rice tract in which the experiments were located is recognized as among the most productive in Upper Sind.

Even allowing for these possibilities, simulated farmers' yields were high. Farmers interviewed at the research sites attributed these high yields, in part, to the experiments' location on better quality land with better irrigation than is usual in the District (Table 19).

Researchers may also have unintentionally maintained high levels of management when simulating farmers' practices, as was also the impression of farmers. For example, the simulated farmer plant density may have been higher than is actually practiced over large areas; weeding of small plots was completed more quickly and more effectively than farmers' weeding practice. Therefore, yield gaps estimated from small plots may overestimate that which occurs in practice at the farm level.

Economic analysis. The partial budget analyses are summarized in Table 20. The analysis is partial in the sense that only factors included as experimental variables are incorporated; it is assumed that all other practices (i.e., nonexperimental variables) are held constant at the farmers' level. The net benefit of the recommended technology (T16) as a package exceeded $570/ha, while the net benefit of the simulated farmers' technology (T1) was about $450/ha. Thus, the recommended technology resulted in added net benefits of $120/ha at an added cost of $82/ha above the simulated farmers' technology. The marginal benefit-cost ratio (MBCR) of 2.5 means that, for the additional dollar invested in T16, the average net return is $1.5.

While the net benefit of the simulated farmers' practice (T1) was lower than the other treatments', the MBCRs in treatment T9 through T14 were less than 2. These treatments included the recommended level of land preparation and imply that the added benefit of high tillage for these treatments yielded a net return over added costs of less than 100%, often regarded as the breakeven point for the adoption of more costly technology. High tillage is profitable however when other management factors are also at recommended levels.

Table 19. Farmers' impressions of experimental sites and crop management vs conditions common in Upper Sind, Pakistan, 1983-85.[a]

Subject of questions	Farmer response (%)		
	Agree	Disagree	Don't know
Land quality			
Trials are located on better land than is usual.	99	1	1
Researchers have better irrigation than farmers.	100	0	0
Farmers' land is better leveled than research sites.	21	79	0
Resources			
Researchers apply inputs at a more appropriate time.	95	5	0
Farmers spend more time on crop care than researchers do.	6	93	1
Farmers prepare land better than researchers.	5	95	0
Harvest and postharvest operations			
Researchers have higher transporting and stacking losses.	13	56	31
Researchers have less threshing and winnowing losses.	50	29	21
Farmers have lower grain weight than researchers because their paddy is drier when weighed.	96	3	1

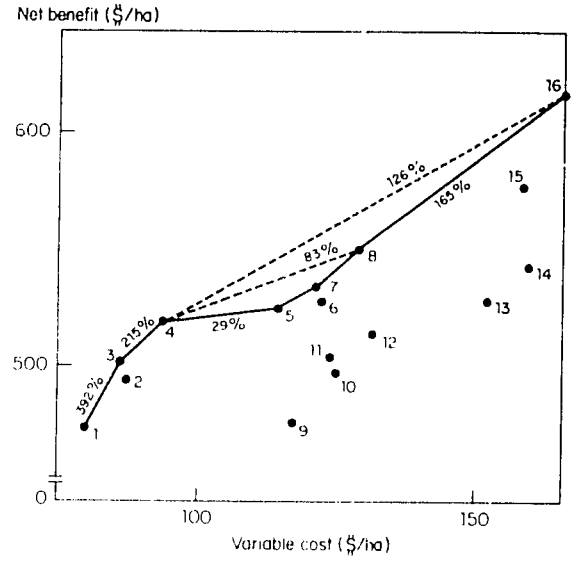
[a]Source: survey of 144 farmers, after harvest of 1984 rice crop.

One way to directly compare and interpret the partial budget reported in Table 20 is to plot the net benefit of each treatment against its variable cost (Fig. 9). The set of treatments to the upper left-hand side of the graph, joined by the solid line, are those that provide either the highest net benefit for a given variable cost or the lowest variable cost for a given level of net benefits. Treatments incor-

Table 20. Partial budget analyses of on-farm constraints experiments for the owner-operator, DRRI, Upper Sind, 1983-85.[a]

Treatment	Factor[b] level				Output value	Input cost	Net benefit	MBCR[c]
	T	F	S	Zn	($/ha)	($/ha)	($/ha)	
T1	Si	Si	Si	Si	559	79	480	n.a.
T2	Si	Si	Si	R	586	87	499	3.43
T3	Si	Si	R	Si	592	85	507	4.92
T4	Si	Si	R	R	617	93	523	3.96
T5	Si	R	Si	Si	643	114	529	2.39
T6	Si	R	Si	R	654	122	532	2.19
T7	Si	R	R	Si	659	121	538	2.37
T8	Si	R	R	R	681	129	553	2.46
T9	R	Si	Si	Si	600	117	483	1.07
T10	R	Si	Si	R	627	125	502	1.48
T11	R	Si	R	Si	632	123	509	1.64
T12	R	Si	R	R	650	131	519	1.73
T13	R	R	Si	Si	684	152	532	1.71
T14	R	R	Si	R	706	160	546	1.81
T15	R	R	R	Si	737	159	578	2.22
T16	R	R	R	R	782	167	616	2.54

[a]All sites combined. [b]T = tillage, F = fertilizer level, S = seedling management, Si = simulated farmers' practice, R = recommended practice. [c]MBCR = marginal benefit-cost ratio = added total returns ÷ added costs of treatment with respect to farmers' practice. n.a. = not applicable.



9. Net benefit surface for treatments included in on-farm experiments, Upper Sind, Pakistan, 1983-85. Combined data. See Table 20 for description of treatments, and their variable costs.

porating the simulated farmers' tillage practices (T1-T8) lie on or near the solid line that forms the net benefit surface, while the recommended tillage practices, other than for T16, form a cluster lower and to the right of the net benefit surface.

If a farmer increases cash inputs beyond his current practices (T1), considering all possible combinations of farmers' and recommended practices, it is most profitable to first adopt the recommended method of crop establishment (T3). The marginal rate of return (MRR) from shifting from T1 to T3 exceeds 390%. The next most profitable shift in management is to combine the recommended levels of Zn and crop establishment (T4), retaining fertilizer and land preparation at the farmers' levels, for which the MRR exceeds 210%. The addition of the recommended fertilizer technology to T4, i.e., T8, with fertilizer, seedling management, and Zn at recommended levels, but tillage at the simulated farmers' level, is the next choice.

The next most profitable shift (from T8) is to adopt the recommended tillage practice (T16), provided that Zn, fertilizer and seedling management are at recommended levels. The MRR measured with respect to T8 is 165% while the MRR of both fertilizer and tillage adoption (given Zn and seedling management at recommended practices, i.e., T4) is 126%. Thus, the complementarity of higher fertilizer rates and tillage combined is evident; that is, for either practice to be clearly profitable it is necessary first to have the cheaper inputs (Zn and seedling management) at recommended levels, and second to combine both tillage and fertilizer at recommended levels.

Stepwise adoption of technology. The economic analysis of the on-farm trials demonstrated that it is profitable to adopt components of a recommended technology in a sequential manner, depending on cash availability, as opposed to adopting the recommendations as a package. Therefore, the current emphasis in rice extension on the "package of practices" approach needs closer examination.

It appears advantageous for farmers to adopt the recommended technology, but in a stepwise manner. First, the application of Zn may be made an important extension message, and ensuring its availability at standard quality an important objective of the government and the private sector.

Second, increasing stand density is economically attractive, but the constraints due to labor availability at transplanting time are also recognized. Therefore, alternative methods to cheaply increase plant density (direct seeding or the adoption of mechanical transplanters) may be important items for the research agenda in Upper Sind. Third, increasing fertilizer and tillage to recommended levels may become an extension priority after the lower-cost recommendations have been thoroughly extended to farmers. Evaluating intermediate levels of fertilizer and tillage practices is also warranted. The complementarity between the recommended tillage and fertilizer practices results in the benefits of one factor being conditional on the other factor also being used at the recommended level. In this case, it may be advantageous to recommend tillage and fertilizer as a package of technology.

INDUSTRIAL EXTENSION PROJECTS

Agricultural Engineering Department

Philippines. IRRI completed 5 yr of a collaborative program with the Philippine Ministry of Agriculture and Food (MAF) designed to enhance MAF capabilities to develop and promote agricultural equipment suitable for small farmers and fabricated by local manufacturers. The program was evaluated in September 1986 by a team of representatives from the United States Agency for International Development (USAID), MAF, and the private sector. The review team concluded that the program had successfully developed a range of small-farm implements and machinery that had been well accepted by the farmers who used them. At the request of MAF, the USAID Philippine mission agreed to provide funds to IRRI for continuing the program for an additional 10 mo.

The program has placed emphasis, in its final stages, on strengthening the institutional structure for the development, extension, and marketing of low-cost equipment suitable for rainfed areas, with highest priority given to upland areas.

India. The Central Institute of Agricultural Engineering-IRRI collaboration program came to an end in September 1986. The major accomplishments included the introduction of IRRI-designed reapers, threshers, and transplanters. Some manufacturers in the southern states of India now fabricate these machines.

The program assisted a manufacturer in adapting the IRRI PT5 power tiller with a 1.0-m reaper to be powered by a locally made 6 HP air-cooled diesel engine (Fig. 10). Field tests indicated satisfactory and economical performance. The machine is now commercially produced, and other manufacturers have adopted the design.

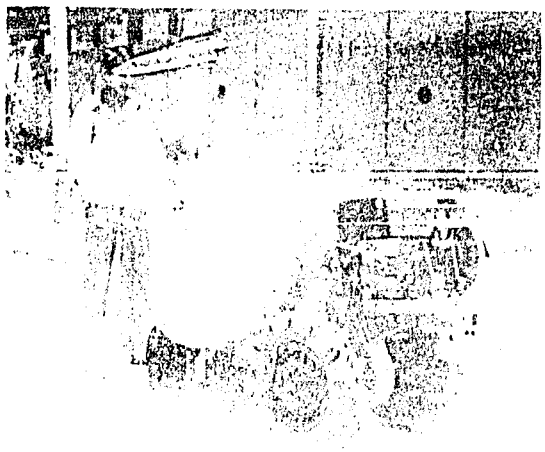
The program also assisted manufacturers in designing jigs and fixtures to reduce fabrication time and costs in the production of this reaper.

Bangladesh. IRRI provided assistance to the Bangladesh Rice Research Institute (BRRI) in modifying the IRRI PT3 power tiller to suit local farming conditions. A detachable rotary tiller was designed, and two prototype units fabricated at the Bangladesh Machine Tool Factory were field tested by BRRI for performance and durability. Another prototype (Fig. 11) was subsequently built at the BRRI workshop for training and demonstration purposes.

On BRRI's recommendation, the Bangladesh Ministry of Agriculture has approved the promotion and manufacture of the IRRI PT3 power tiller in the country. The plan is to use the diesel engines of over 200,000 shallow well irrigation pump sets during the slack pumping periods for powering locally made power tillers.

IRRI assisted BRRI in conducting a training course on the use and maintenance of the IRRI

10. PT5 power tiller-reaper powered by 6 hp air-cooled diesel engine. India, 1986.



11. Modified PT rotary tiller, Bangladesh, 1986.

power tiller for 15 engineers from the Bangladesh Agricultural Development Corporation (BADC). BADC service centers, originally organized for repair and maintenance of tubewells, are expected to handle sales, distribution, and servicing of power tillers in the country.

Madagascar. Near Lac Alaotra and Marovoay, major rice-producing areas of Madagascar, large tractors have serious problems in the soft soil of flooded ricefields. Lack of spare parts and high maintenance costs also are problems. But labor shortages during planting and harvesting delay crop establishment and cause excessive losses when harvesting and threshing are not timely. Appropriate small-farm machines would help increase cropping intensity and production.

An IRRI engineer was assigned to the IRRI-Madagascar collaborative project on two separate occasions to assist in the assembly, test, and demonstration of IRRI machines. His visits were also used to assess farmers' needs for equipment and machinery and to assist the government in determining research objectives, strategies, and priorities for an agricultural mechanization program. Many Madagascar farmers expressed interest in the IRRI machines because of their simple design, low cost, and suitability to their scale of farming operations.

The first phase of development of the Rice Research Station at Mahitsy was completed. The station will eventually include offices, laboratories, a medium-term germplasm storage facility, a documentation center, and dining facilities.

COLLABORATION WITH NATIONAL PROGRAMS

Various departments

Our memoranda of agreement with many countries of the world not only help us identify the research that IRRI can provide as the building blocks for national agricultural research planning and implementation; they also enable national programs to cooperate regionally and globally. IRRI's cooperative agreements cover more than 85% of the world's ricelands and rice production.

IRRI's relationships with national programs pass through different phases, with technical assistance shifting to cooperative programs and collaborative research as national resources grow. A common model of cooperation with a national agricultural research system begins with IRRI being invited to participate in a country program. Early priorities usually involve human resource development and participation in research networks.

As national capability increases, participation in networks becomes more specialized and contributory. Scientific collaboration on specific research problems may grow to become the major ingredient of a country's program. At the most advanced stage, a national agricultural research system may assume regional or global responsibilities based on its comparative agro-ecological and scientific advantages.

Our cooperative agreements with some countries are long-standing—almost since IRRI's inception. Other agreements are quite recent. All memoranda of agreement are reviewed periodically and refined to reflect achievements and to incorporate newly identified needs, capabilities, and priorities. The following pages describe only a few of the IRRI-country collaborations that illustrate the range of relationships.

Bangladesh. The current 6-yr memorandum of understanding with BRRI was ratified December 1985, with the goals of increased productivity, expanded attention to rice-based farming systems, and increased local manufacture of small-scale agricultural machinery. Two IRRI outreach

scientists are an integral part of BRRI's program.

Water management research with BRRI and BWDB was reported earlier in this section.

Three IRRI scientists worked 30 mo at BRRI, and headquarters scientists provided 116 d of technical support. Twenty-two Bangladeshi scientists participated in workshops and short-term training programs at IRRI. One postdoctoral, one Ph D, and two MS scholarship programs were initiated. One of 10 Ph D and 2 of 13 MS scholars completed their training programs and returned to BRRI. The IRRI Dhaka office provided support to enable BRRI scientists to conduct periodic surveys of rice crop conditions and to conduct on-farm trials in different regions of the nation.

Bhutan. We have been collaborating with the Royal Government of Bhutan since 1983 in developing and introducing appropriate technologies that can increase productivity in the country's rice-growing areas. The major thrust has been institution building, primarily through human resource development. Since 1983, 14 Bhutanese have been trained at IRRI. The superintendent of the main crop research station has begun a MS degree program under the collaborative arrangement between IRRI and UPLB.

We are also working closely with the Bhutan Department of Agriculture to improve rice-based farming systems. Initially, the collaboration has focused on the medium (1000-1500 m) and lower altitude (<300 m) rice-growing areas that represent about 80% of Bhutan's 31,000 ha of riceland.

In on-farm demonstrations and varietal trials at Wangdiphodrang and Punakha, IR36 and IR64 showed excellent adaptation at 1300-1500 m. In 13 farmers' field demonstrations with farmyard manure as the only fertilizer, IR36 yielded 5.0 t/ha; local varieties yielded 4.2 t/ha. With 30 kg N/ha as topdressing, IR36 yielded 5.7 t/ha. Local variety yields were unusually high because of favorable climatic conditions, but lodging was widespread.

In a set of replicated varietal trials, the local variety yielded 4.5 t/ha, IR36 yielded 5.0 t/ha, and IR64 yielded 5.2 t/ha.

One constraint to the adoption of modern high-yielding varieties in Bhutan may be their straw production. Rice straw is an important source of livestock feed and bedding. Low-input demonstration trials indicated that IR36 produced an estimated 40% less straw than the local variety. There are indications that Bhutanese farmers prefer IR64 because it is taller.

In the lower altitudes of southern Bhutan, rice yields are restricted by poor soil fertility and disease and pest problems. Several promising varieties have been identified, and green manure crops have been introduced. At Bhur Research Station, Gaylegphug, incorporating sesbania increased IR36 yields from 1.3 t/ha to 1.9 t/ha.

China. Chinese scientists from the Chinese Academy of Agricultural Sciences (CAAS), China National Rice Research Institute (CNRRI), and provincial agricultural academies have participated for more than 6 yr in the International Rice Testing Program, International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER), and the Asian Rice Farming Systems Network. Nearly 600 Chinese scientists and administrators have been trained at IRRI, as scholars and in training courses. Scientists from many countries have participated in jointly sponsored training courses, symposiums, conferences, and workshops in China. Germplasm exchange has been on a large scale.

The development of hybrid rice was a great breakthrough in rice breeding and a technical innovation in rice production. IRRI and China actively collaborate on developing elite restorer lines and CMS lines with early maturity, high yield, good eating quality, and multiple resistance to diseases and insects. We jointly conduct training courses and have published a training manual on hybrid rice technology. The cosponsored International Symposium on Hybrid Rice was held at the Hunan Hybrid Rice Research Center, 6-10 Oct 1986.

When the Chinese Government decided to set up a national rice research institute, IRRI participated from the beginning in its conceptualization and development. Five IRRI scientists were consulted on designing CNRRI buildings and on rice breeding, cereal chemistry, grain quality analysis, and farming systems research. At the same time, 17 CNRRI scientists came to IRRI to study recent

advances in science and research management. IRRI scientists also have advised on the purchase of research equipment.

A shuttle breeding project with CNRRI started in 1983 to collaboratively develop cold-tolerant varieties with superior grain quality and multiple disease and insect resistance. Seeds of nine short-duration Chinese varieties were crossed with four elite IRRI breeding lines. The F_1 seeds of 36 cross combinations were planted at IRRI in Dec 1983.

The F_2 seeds were planted at CNRRI in late April 1984, and 1,653 short-duration plants with blast resistance and good grain appearance were selected in August. The F_3 was planted at IRRI in November and field-inoculated with bacterial blight and evaluated for resistance to brown planthopper.

From this F_3, 2,592 selections were made in February-March 1985. The F_4 was planted in April, half at Hangzhou and half at IRRI. That screening yielded 1,915 selections, with the F_5 planted in November 1985 at both Hangzhou and IRRI. Uniform rows were bulk harvested in February 1986, and an additional 2,128 individual plant selections were made. The F_6 was planted in China in early April, and observational yield trials were planted at both IRRI and CNRRI.

Several promising lines were selected for replicated yield trials in 1987.

The National Azolla Research Center at Fuzhou is gradually developing the capacity for international research and training in the use of azolla as a N source for rice. Azolla has been cultivated in China for generations.

The collaborative program of IRRI and CAAS is guided by the Memorandum of Understanding agreed upon during the joint annual planning session, when administrators and scientists of both institutions review progress and formulate the program of work for the next year.

Egypt. With the scarcity of its arable land, Egypt's agricultural research program focuses on improving productivity and cropping intensity.

Breeding to combine high resistance, high yield potential, resistance to lodging, blast (Bl) resistance, and short duration in new varieties is a major part of the program. Several lines combining desired agronomic and quality ventures with diverse sources of disease resistance were identified.

The most encouraging aspect of these breeding efforts is that a continuous chain of Bl-resistant lines is being developed. These lines are primarily japonicas, but because IR indicas have short duration and good resistance to Bl, they are becoming more common.

Research in pathology also intensified, with emphasis on identifying strong and diverse sources of resistance, screening breeding lines, identifying Bl races, and measuring the weather parameters that favor disease development.

The Rice Research Center at Sakha is unique in the Middle East North Africa area. Rice is being researched as both a food crop and a problem soils reclamation crop.

IRRI also has agreements with the University of Cairo and the Academy of Scientific Research for collaborative graduate study programs.

India. Scientific and technical cooperation with the Indian Council of Agricultural Research (ICAR) focused initially on collecting and exchanging rice germplasm, exchanging and evaluating breeding materials, studying diseases and insect biotypes, and conducting crop production research

By 1986, collaborative efforts also covered rainfed rice, hybrid rice, botanicals for managing insect pests in rice-based cropping systems, the economics of water management, rice production constraints, and manufacture of IRRI-designed small-farm machinery. IRRI scientists worked with Indian scientists in 22 agricultural universities, 50 central research institutes, and 90 All-India Coordinated Research projects in the country's different agroclimatic zones.

During 1986, 64 scientists from agricultural universities and national research organizations participated in training, professional advancement programs, and workshops at IRRI. We also entered into a formal agreement with the Indian Agricultural Research Institute and Andhra Pradesh Agricultural University for graduate training of agricultural scientists. A special rice production program was designed for senior extension officers of several states.

Special collaborative research and training programs were organized in integrated pest management (IPM) for deepwater rice farming systems and in developing improved varieties for ecologically handicapped areas. The International Fund for Agricultural Development approved funding for an IRRI-ICAR collaborative research program for the development of rainfed rice production in eastern India. Major components of the project are rice environmental analysis, varietal improvement, rainfed rice crop management, development of more productive rainfed cropping patterns, and postharvest technology.

Indochina. IRRI signed a memorandum of understanding with the Government of Australia early in 1986 to address the problems of rice production in the Indochina region—Kampuchea, Laos, and Vietnam. This region has considerable potential for greater rice production.

In January 1986, an IRRI team visiting Kampuchea identified several areas where IRRI might contribute significantly to the acceleration of rice production.

IRRI's goal is to assist Kampuchea, Laos, and Vietnam in developing and introducing appropriate technologies that can increase productivity in the rice-growing areas while increasing the income and nutrition of small-farm households and communities.

Indonesia. IRRI-Indonesia cooperative research has evolved into true collaboration. Under a memorandum of understanding, priority is given to genetic evaluation and utilization and resource exchange, upland rice cultivation, rice-based farming systems, water management, farm machinery development, increasing the technology base through training, graduate studies, nondegree training at IRRI, conferences and workshops, and exchange of technical information and publications.

Indonesia hosted the 1985 Upland Rice Research Conference, which led to further collaboration in work on Bl and management of acid upland soils. All elite IRRI breeding lines are being evaluated as irrigated rice in Indonesia. Three very short-duration breeding lines from IRRI performed well as rainfed lowland rice on Lumbok Island.

AARD in collaboration with IRRI intensified research on IPM for more effective control of BPH and RTV. The President of Indonesia announced a far-reaching IPM policy that recognizes the adverse effects of nonselective use of chemicals.

A technical cooperation with the Directorate General of Food Crop Agriculture provided special training and technical advisers on constructing the IRRI warehouse dryer, including installing vortex wind machines on traditional storage structures in the villages.

In 1986, IRRI staff members spent 372 d in Indonesia working with the AARD-IRRI program. In addition to the network programs, attention was focused on food demand and supply prospects, RTV, and training in editing and publication. Short-term training continued, with the largest number of participants since 1981: 33 persons received training at IRRI during the year, bringing the total to 453 since 1972. A large number of AARD senior and junior staff participated in 21 conferences, workshops, and seminars during the year.

At the Seventh Annual AARD-IRRI Collaborative Research Planning Meeting in Bogor, 24-25 Jun, the following priority areas were identified for collaborative research during 1986-87:

- Genetic evaluation and utilization
  - Germplasm collection and conservation
  - Exchange of improved germplasm
  - Hybrid rice
  - Grain quality
  - Brown planthopper
  - RTV
  - Blast
  - IRTP
- Soil and crop management
- Farming systems research
- Machinery development
- Water management
- Training
- Database management

In September, two joint AARD-IRRI publications were released: *Indonesian farming systems research and development: the food crop subsystem*, and *A case study: the impact of cropping systems research in Indonesia*. IRRI staff assisted the Central Research Institute for Food Crops in conducting a concentrated 3-wk training course in Editing and Publication for 15 participants from various institutes of AARD, with IDRC funding.

Madagascar. During the 2-1/2 yr of the Madagascar-IRRI collaboration, a Malagasy rice research team composed of scientists, agricultural technicians, and administrators from several departments of the National Center for Applied Research on Rural Development (FOFIFA) was formed.

In addition to IRRI's resident team leader/agronomist and plant breeder, a number of IRRI consultants worked with Malagasy scientists in 1986 on research station development and management, soil fertility and adverse soil problems, agricultural machinery, agroeconomic research, and rice environment mapping.

Training is an important component of the project, with 11 Malagasy scientists having so far graduated from IRRI training courses. In addition, an in-country training course was conducted for FOFIFA research assistants and field technicians.

In the rice research program, 870 varieties passed quarantine and 456 cultivars were tested on research stations or in farmers' fields at 10 locations representing major rice environments. On the tropical west coast, under moderately low inputs, new materials yielded 50% more than the local check. On the high plateau, on-farm cropping systems research was begun in three different environments. INSFFER trials were conducted both on-station and on-farm.

Philippines. Our cooperation and collaboration with the Philippines recognizes the role of the Philippine Government in the establishment of IRRI and its continuing support, along with the contributions of our Filipino staff and our long history of partnership with Philippine agricultural institutions, notably MAF and the University of the Philippines at Los Baños (UPLB).

Further strengthening of the collaboration between IRRI and Philippine scientists is anticipated with the establishment of the Philippine Rice Research Institute (PhilRice) in 1986. PhilRice is mandated to develop a strong national rice research program to sustain and further improve the gains already made in rice production. The Board of Trustees of PhilRice expressed the need for close collaboration with IRRI in achieving its goals of national rice self-sufficiency and increased income and employment opportunities for Filipino rice farmers and their families.

An important mechanism for exchanging information and developing collaborative work plans with Philippine rice workers is the biannual Technology Transfer Workshop. The 8th MAF-IRRI Technology Transfer Workshop at IPRI, 13-14 Jun 1986, focused on technologies that can reduce production costs without lowering yields. Collaborative projects in integrated nutrient management and integrated pest control were initiated.

The 9th MAF-IRRI Technology Transfer Workshop was held in November in Bohol, an upland farming province in the Central Visayas. At this workshop, 117 participants from IRRI and Philippine agencies reviewed the development of upland rice farming systems. Upland rice farmers become commercially oriented when inputs, credit, and produce markets are available. In the more remote slash-and-burn areas, opportunities for selling extra produce are few. Workshop participants agreed that such local variations in upland rice farming systems should be considered in developing programs for their improvement.

Early in 1986, we counted more than 75 projects underway in collaboration with Filipino scientists and institutions.

Cooperative programs

Communication and publications

Communication and Publications Department

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PUBLICATIONS

At least 173,000 copies of major IRRI publications were distributed during 1986. Of these, 43,000 were in the English language; 130,000 were translated editions of IRRI publications.

Of the English publications distributed, about 48% were free, mostly to key Third World libraries.

Distribution of 95% of the translated editions was funded by donor agencies.

Twelve books in English were released in 1986. An additional seven translations of IRRI publications were copublished by cooperators in national programs. The section on Publications and Seminars has a full listing.

Four issues of the *IRRI reporter* were published and distributed to 16,500 rice workers. Six issues of the *International rice research newsletter* and its *Subject index for 1985* were distributed to 14,000 rice workers. The second issue of the *International azolla newsletter*, the third issue of the *Rice genetics newsletter*, and two issues of the *Deepwater rice newsletter* were published. Six issues of the *IRRI research paper series* came out.

Thirty-eight news releases were written and distributed.

The IRRI information brochure was published in Tagalog and Japanese.

A leaflet on Philippine traditional rice varieties in the IRRI germplasm bank was published in English and Tagalog.

SUPPLEMENT TO INTERNATIONAL AGRICULTURAL RESEARCH CENTERS PUBLICATIONS CATALOG

IRRI published the *1986 Supplement* to *Publications of the international agricultural research and development centers* and handled its world distribution on behalf of all centers. The catalogs, which include scientific and educational materials published by all centers under the Consultative Group on International Agricultural Research (CGIAR), as well as those of non-CGIAR centers, are probably collectively the world's largest compilation of titles on Third World agricultural science.

BOOK FAIRS

For the fourth year, IRRI, the German Agency for Technical Cooperation (GTZ), and the CGIAR sponsored an exhibition of center publications at the Frankfurt Book Fair. IRRI books were also exhibited at international exhibitions in China, India, and the USA.

EDITING AND PUBLICATION TRAINING COURSE

EdPub is a 4-mo course, jointly sponsored by IRRI and the International Development Research Centre of Canada, to train Third World information specialists. The third EdPub course was completed with information specialists from Barbados, China, Ethiopia, India, Nigeria, Papua New Guinea, Philippines, Vietnam, and Tanzania.

RESEARCH ON EFFECTIVENESS AMONG FARMERS OF *A FARMER'S PRIMER* IN TWO PHILIPPINE DIALECTS

The Tagalog and Hiligaynon editions of *A farmer's primer on growing rice*, which is published in 30 languages, were evaluated for their effectiveness in transferring rice technology information to 84 farmers in Cavite and Negros Occidental, Philippines.

A 73-item test was used to measure initial knowledge level. The farmers were then given copies of the primer in Tagalog or Hiligaynon. A post-test was given 45 d later.

Only 4% of the farmers had high knowledge in the pretest, but 46% had high scores after reading the book. The *t*-test also showed that, although farmers who finished the book and those who did not were not significantly different in initial rice knowledge, the difference in post-test scores was highly significant. The farmers' knowledge gain concerning fertilizers was highest. In the pretest, only 15% knew the meaning of "24-12-12" on a fertilizer sack, but after the treatment, half knew it. The Cavite and Negros farmers generally matched well in socioeconomic variables.

Farmers evaluated the primer's design, packaging, and message content favorably, but suggested improvements to increase its effectiveness, such as the deletion or replacement of abstractions and symbols that they found confusing or hard to understand.

IRRI is using the findings of this study to make forthcoming publications, designed on the primer concept, more effective.

Cooperative programs

Technology generation and sharing

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COOPERATIVES AND NETWORKS

Rice Genetic Engineering Network. In 1984, IRRI organized a Conference on Biotechnology Applications in Agricultural Research, with financial support from the Rockefeller Foundation. Following this conference, the Rockefeller Foundation decided to sponsor an international network on rice genetic engineering in collaboration with IRRI to generate the knowledge and technology needed to apply advances in molecular and cellular biology to the genetic improvement of rice. Research is being done by 27 collaborating institutions in Australia, Belgium, China, Colombia, France, the Federal Republic of Germany, Japan, the Republic of Korea, the Netherlands, the Philippines, the United Kingdom, and the United States.

Fundamental investigations are being made into gene characterization, regulation, and expression in conjunction with attempts to increase the efficiency of protoplast regeneration. These studies will form the basis for transformation in rice once a suitable method has been identified. Various modes of transformation are being investigated, namely *Agrobacterium*-mediated DNA transfer, microinjection, and electroporation. The wide hybridization program initiated by IRRI several years ago is being further strengthened to transfer agronomically desirable genes from wild *Oryza* species using both conventional cytogenetical and embryo rescue procedures. The development of a more complete genetic linkage map is under way in association with the Rice Genetics Cooperative. This work will be combined with the development of improved cytogenetical maps and the preparation of a restriction fragment length polymorphism map by Cornell University. Finally, studies of the genetics of pathogenicity and the establishment of suitable techniques for race identification in selected rice pathogens have begun in collaboration with IRRI. The scientists participating in this research cooperative met at IRRI in October 1986. The next meeting of the group will take place at IRRI in January 1988.

Rice Genetics Cooperative. The Rice Genetics Cooperative established during the International Rice Genetics Symposium held at IRRI in May 1985 has as its major aim fostering cooperative research on all aspects of rice genetics. Its secretariat is at IRRI, its 15-member coordinating committee is supported by 4 standing committees.

The committee on gene symbolization prepared a set of rules for symbolizing marker genes and for numbering chromosomes. The committee on genetic stocks established two centers: IRRI and Kyushu University, Japan. The committee on genetic engineering compiled a list of possible DNA vectors. Volume 3 of the Rice Genetics Newsletter was published in December 1986. The second International Rice Genetics Symposium will be held at IRRI in 1990.

Integrated Pest Management Project. IRRI is working with the Food and Agriculture Organization-sponsored Integrated Pest Management in Rice Project for Asia to establish pest population thresholds and to train extension field staff in the integrated pest management (IPM) concepts of pest control methods. Each region will need a localized set of IPM practices. With verified IPM technology for each environment and region, farmers can be trained to apply the technology to maximize profits and stabilize yields.

COLLABORATION WITH ADVANCED INSTITUTIONS

Our collaborations with advanced research institutions involve numerous complex interactions. Some include the assignment of scientists to IRRI to conduct research of interest to IRRI and to the organizations seconding the scientists. In other partnerships, advanced scientific institutions apply sophisticated analytical techniques in their own laboratories to help resolve problems identified at IRRI. In 1986, we collaborated in more than 70 projects with advanced research centers in different parts of the world.

Many of the research areas related to rice are also concerns of other international institutions: insect pest physiology and ecology (International Centre of Insect Physiology and Ecology), fertilizer technology development (International Fertilizer Development Center, IFDC), soil (International Board for Soil Research and Management) and water (International Irrigation Management Institute) management, and agricultural policy analysis (International Food Policy Research Institute). Sister institutions funded by the Consultative Group on International Agricultural Research that

include rice research in their agendas are the International Institute of Tropical Agriculture (IITA) in Nigeria, the West Africa Rice Development Association, and the International Center for Tropical Agriculture in Colombia.

The International Service for National Agricultural Research is concerned with strengthening national research systems and contributes to the increased effectiveness of rice research and development more generally. The International Crops Research Institute for the Semi-Arid Tropics and the International Maize and Wheat Improvement Center have mandates for crops that are of interest in rice-based farming systems.

In addition, nationally funded organizations, such as the Centre International de Recherche Agronomique pour le Developpement (CIRAD) in France, pursue activities closely related to global interests in rice research and development.

Through collaboration with these — and many other institutions — IRRI seeks to identify and capitalize on all the complementarities that exist. In establishing collaborative basic and strategic research relationships, IRRI applies these principles:

- The research is identified by IRRI as necessary to solve specific problems.
- The collaborating institution has a clear comparative advantage and competence in the type of work involved.
- The reasonable expectation is that the research will yield significant results within a given time.
- Necessary funding is available.

Such collaboration helps us capture the power of upstream research for solving complex downstream problems. In addition, it helps to advance the frontiers of knowledge, a basic requisite for the continuous flow of new technologies. A few reports of progress on several research fronts follow.

Genetic engineering. The understanding of rice genetics lags far behind that of other important food crops. To accelerate our application of emerging techniques in genetic engineering to improve rice, we have intensified our research on basic genetics and our collaborations with basic research institutes.

Genetic markers and trisomic stocks have been assembled or produced; linkage maps have been associated with respective chromosomes through the primary trisomic technique, and additional marker genes are being mapped. Such research on linkage mapping is expanding through the Rockefeller Foundation-supported wide hybridization project.

We have already begun wide hybridization. Wild species of rice possess genes of potential value for improving cultivated varieties, but until recently these genes could not be reached by rice breeders because of crossing and recombination barriers. Through embryo rescue techniques, we have been able to produce hybrids between *O. sativa* and *O. officinalis*, a wild species with high resistance to brown planthopper (BPH) and whitebacked planthopper (WBPH). We selected lines from a second backcross that look like *O. sativa* but are resistant to BPH and WBPH. The next step is to combine these new sources of resistance with other breeding lines.

Useful traits are present in other wild species; we are expanding our research in utilizing these traits for rice improvement.

Protoplast culture and fusion between wild rices and cultivated species could solve prefertilization incompatibilities. Regeneration of plants through *in vitro* culture is a prerequisite to successful protoplast fusion. In addition to *O. perennis*, which has shown regeneration in somatic cultures, we have produced callus from *O. nivara* and *O. rufipogon*/*O. sativa* and are studying regeneration from the induced calli. In addition, we have successfully germinated immature seeds of *Porteresia* (=*Sclerophyllum*) *coarctatum*, a wild species that is an important source of genes for salinity and submergence tolerance. Plants have been raised from protoplasts of a japonica variety at the University of Nottingham, UK.

Cooperative experiments with the Tissue Culture for Crops Project, Colorado State University, USA, are exploring the use of biotechnology in improving rices for adverse environments. Some somaclonal variants isolated already have produced superior breeding materials for salt tolerance.

We studied the physiological and genetic aspects of tolerance for problem soils in cooperation with the University of Sussex, England. The research has been directed mainly toward explaining the basic mechanisms of salt tolerance in rice. The importance of growth rate, tissue tolerance, leaf

compartmentation, and root selectivity of Na uptake for salinity tolerance in rice has been established, and screening methods have been developed.

Serodiagnosis of rice viruses. Serology is essential in virus research. We have isolated pure forms of rice tungro bacilliform and spherical viruses from rice plants infected with tungro and have purified rice grassy stunt (GSV) and ragged stunt viruses.

For immunization, we separately injected purified viruses into rabbits and obtained antisera specific to each virus. The serological tests we have developed (enzyme-linked immunosorbent assay and latex) are efficient in detecting the viruses in rice plants and vector insects. The latex test is particularly simple and does not require sophisticated laboratory equipment to run.

We also obtained a monoclonal antibody to GSV in collaboration with the American Type Culture Collection, Maryland, USA.

Using the antisera, we can make major progress on understanding virus resistance and epidemiology. Because the antisera available had been very limited, serology was not widely adopted in most countries of South and Southeast Asia. Now, antisera from IRRI have been applied in national research programs on virus resistance, diagnosis, and epidemiology at 12 institutes in 7 countries. A special training course for serological techniques and their application in the study of virus resistance and virus ecology has been started.

Resistance to brown planthopper. We are collaborating with the Tropical Development and Research Institute (TDRI), London, to determine the mechanisms of rice resistance to BPH. The acceptability of a variety to BPH can be quantified by the time from the start of insect probing to the time of sustained feeding. Using a high-resolution video system, we detected a resistance mechanism associated with the plant surface. Data suggest antibiosis, a nonpreference mechanism, that is stronger in resistant variety IR62 than in IR46.

When we electronically monitored BPH feeding on other varieties, we found no difference in the insect's ability to locate its primary feeding site (the phloem) regardless of the resistance of the variety.

Biological control of fungal diseases. We collaborated with the Department of Microbiology and Microbial Genetics at the University of Ghent, Belgium, to isolate and test the taxonomy of 23 bacteria strains from Korean ricefields. On the basis of phenotypic and biochemical tests, the bacteria were identified as *Bacillus pumilus, B. laterosporus, Pseudomonas aeroginosa, P. fluorescens,* and *P. rubrisubalbicans. Serratia marcescens* and a species of *Erwinia* also were identified.

As part of the application of biotechnology to rice improvement, scientists from diverse disciplines discussed the problems and research strategies related to blast, bacterial blight, and virus diseases at a Rockefeller Foundation-sponsored workshop.

Botanicals for insect control. We expanded our studies on neem *Azadirachta indica* seed derivatives for pest management. National programs in Bangladesh, China, India, and the Philippines are collaborating with IRRI and the East-West Center, Hawaii, USA, in adaptive experiments in farmers' fields.

A simple procedure was developed to extract neem seed bitters (limonoids) as a crystalline brownish powder. The powder is water soluble, relatively photostable, and nonphytotoxic. A 500-ppm solution sprayed on rice plants checked BPH, WBPH, and green leafhopper populations. With both 100 and 500 ppm sprays, the first generation BPH males to emerge had significantly low frequencies of meiotic cells, reducing their insemination potential.

Natural enemies of rice-damaging insects were not harmed by the neem spray. The mirid predator continued to consume about 50% of the eggs and about 25% of the BPH nymphs. The extract, which also has systemic action, is being evaluated in field trials.

Soluble Zn^{2+} in Zn-deficient soils. After N deficiency, Zn deficiency may be the most widespread nutrient deficiency in flooded rice. A scientist from the University of Minnesota, St. Paul, USA, investigated at IRRI the factors controlling soluble Zn^{2+} in flooded soils.

Results so far suggest that the formation of ZnS, possibly in a mixed phase with Fe^{2+}, is an important factor in the control of soluble Zn^{2+}. But soil solutions remain highly oversaturated (3-4 orders of magnitude) in respect to the precipitation of crystallized ZnS (wurtzite). This suggests severe

kinetic constraints on the formation of separate phase ZnS.

Sulfide ion concentrations appear to be controlled by the formation of amorphous FeS, but the S^{2-} concentrations are 3 to 10 times greater than that predicted by the solubility of pure amorphous FeS. Iron and Mn^{2+} are also oversaturated in respect to the formation of separate phase phosphates and carbonates.

Simplified technique to estimate NH_3 volatilization. In our collaboration with the Commonwealth Scientific and Industrial Research Organization (CSIRO) Division of Plant Industry, Australia, we used a simplified horizontal transport method to estimate NH_3 loss under different fertilizer management treatments. A ^{15}N balance technique was used to estimate total N loss from irrigated ricefields at 3 Philippine sites over 2 yr.

The simplified technique indicated that NH_3 volatilization loss from the 3 sites was 30-54% when N fertilizer was surface-applied into floodwater at 10 d after transplanting, the common practice used by many Asian farmers. Basal incorporation of N fertilizer without standing water but with soil saturation maintained for 4 d greatly minimized NH_3 loss and increased crop recovery of applied N and yield. The estimated nitrification-denitrification loss was generally unaffected by fertilizer application rate and method.

Aggregation in puddled soils. The cloddy, poorly aggregated soil left after rice hinders the establishment of second crops. We studied the formation of soil aggregates and their stability in puddled soils after rice in collaboration with the Soil Science Institute, University of Hamburg, Federal Republic of Germany.

Special discriminating analyses established a system by which the water stability of aggregates can be derived from the analytical data commonly gathered in soil surveys. The system, now being tested on 200 soils in the Philippines, could be a simple tool for soil surveying and for mapping soil aggregation in puddled soils where data of routine chemical analyses are already available.

Evaluation of water retention curves in long-term experiments with different organic amendments indicates that organic matter is effective in increasing the water-holding capacity as well as the porosity of the Tropaquepts and Haplaquolls tested.

Rice straw decomposition. We labeled rice straw with ^{14}C to measure its decomposition pattern in aerobic and submerged soils in collaboration with the Soil Science Institute, University of Hamburg.

In laboratory studies, mineralization rates were highly retarded under submergence. But in the field, mineralization was very rapid, regardless of water regime, and followed a logarithmic function in all soils. The decomposition of remaining, more resistant metabolites and residues is similar for all soils, with a half-life of about 2 yr.

These results are in line with long-term studies at IRRI on the effect of water management in straw-amended plots.

Effect of tillage on soil physical properties. Tillage studies at Sukamandi, Indonesia, of soybean following irrigated rice are paralleled by studies at Los Baños of mungbean following irrigated rice. Both soybean and mungbean following deepwater rice will be studied in An Giang, Vietnam. The studies have similar experimental designs and use similar procedures to measure soil-water and soil-strength variables.

For the Los Baños experiments, the ITA Program in Grain Legume Improvement is providing intensive evaluation of crop-water relations for promising cultivars, and IFDC is helping with studies of soil-nitrate conservation by weeds in legume - fallow - rice sequences. These studies are part of a large collaboration with the University of Reading, England, that is examining water and N relationships in rice - legume cropping systems. Growth-chamber studies are being done in England.

Special facilities at the Consiglio Nazionale delle Ricerche, Pisa, Italy, used different implements and varying levels of puddling water and energy to measure Los Baños soil samples for the soil-micromorphological effects of puddling.

New techniques of pneumatic fracture for measuring soil strength were applied to soil samples from Los Baños tillage experiments at the University of Minnesota.

The suitability of soil for dry tillage or puddling is influenced by the mechanical strength and stability of aggregates. The appropriateness of various rice soils for alternative forms of land preparation is being evaluated, using tests of aggregate stability developed for temperate-latitude soils from CSIRO, Australia (Fig. 1).

The studies show that effective puddling can be achieved with lower inputs of puddling water and energy than farmers generally use, and that rice yields do not suffer with lower inputs. We determined that the minimum energy needed to decrease water infiltration to an acceptably low 1 mm/d was 3 kJ/m^2 ground area with plowing and 5 kJ/m^2 with rototilling.

A new floating rototiller was able to puddle a unit area of ricefield more quickly and conveniently than either a skid-supported rototiller or a plow and harrow. However, it was less effective in controlling weeds and it weakened a shallower zone of soil — a feature that could impair root and crop growth during periods when field submergence cannot be maintained.

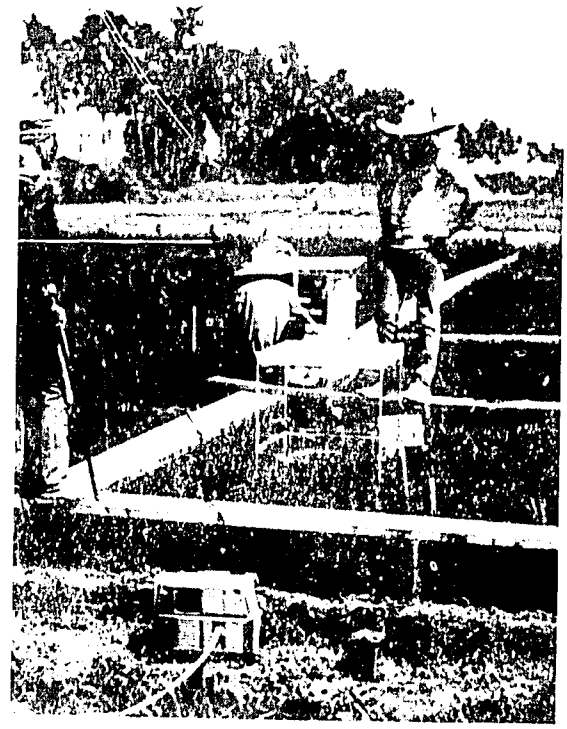
Monitoring canopy photosynthesis. We monitored canopy photosynthesis and night respiration in irrigated rice and used computer-modeling to detect constraints to light utilization and yield formation at different developmental stages of the crop in collaboration with the Botany Institute, University of Hamburg (Fig. 2).

In both wet and dry season studies, traditional transplanting caused severe physiological shock, strongly reducing tillering and delaying crop development by 2 wk. Dibble-seeded rice formed a closed canopy in a shorter time and produced more dry matter than transplanted rice.

Blue-green algae. A better understanding of the ecology of blue-green algae (BGA) in wetland ricefields would permit developing cultural practices that consistently maximize the contribution of photodependent N_2 fixation to the N_2 nutrition of rice. A senior scientist from the French Scientific Research Institute for Development has been researching free-living BGA at IRRI since 1981.

Studies of the composition, productivity, and N available to rice have shown that N_2-fixing BGA have a potential of about 30 kg N/ha per rice crop.

1. Soil suitability for flooded and for dry tillage is influenced by the mechanical strength and stability of aggregates. Rice soils and soils used for dry tillage of mungbean following rice were studied using newly developed techniques at IRRI in 1986.



2. Field measurement of rice canopy photosynthesis, IRRI, 1986. A transparent chamber is placed over the crop for less than a minute to monitor CO_2 uptake and vapor release of the plants. A portable generator makes the system mobile.

Depending on the nature of the algal material and the application method, 15-36% of the N from BGA is available to the 2 crops following application. Limiting factors are P deficiency and invertebrate pests.

We have found that N_2-fixing BGA are ubiquitous in rice soils. Their abundance correlates with soil pH and available P. In most rice soils, indigenous N_2-fixing BGA occur at densities much higher than can be brought about by inoculation with strains selected in the laboratory. Applying P, controlling grazer populations with organic pesticides, using deep-placed N, and inoculating with an inoculum produced from the indigenous soil had positive effects on N_2-fixing activity, surface accumulation of N, total plant weight, and grain weight.

Green manure crops. Research on the stem-nodulating legume *Sesbania rostrata* has intensified in collaboration with the University of Giessen, Germany, GTZ, and CIRAD.

Increasing yields of short-duration varieties. Short-duration varieties usually have lower yields than medium-duration varieties. In collaboration with the Tropical Agriculture Research Center, Japan, we studied N level and spacing with six short-duration varieties and breeding lines. Low yields could be explained by less sink, which is attributed to less N in the plant at flowering.

This can be offset by closer plant spacing, resulting in maximum tiller numbers before panicle initiation. Panicle number type varieties are less responsive to cultural practices than are panicle weight or intermediate-type varieties.

Optimum growth duration and maximum yield may vary with cultural practices and soil fertility. When growth duration is shorter than optimum, yields decrease because of the amount of differentiated sink caused by low N in the plant at the spikelet initiation stage. When growth duration is longer than optimum, yields decrease because of an increase in degenerated sink.

Maximum N efficiency in sink formation was observed in 125-d varieties at 20- × 20-cm spacing.

Grain quality. The major aroma principle in cooked milled rice of eight aromatic varieties from five countries was identified as 2-acetyl-1-pyrroline through gas chromatography-mass spectrometry studies by flavor chemists at the United States Department of Agriculture Western Regional Research Center, Albany, California. IRRI cereal chemists identified the rices. Pandan leaves commonly added during cooking to impart aroma contain the same chemical.

IRRI cereal chemists earlier found that hard gel consistency rices have harder cooked rices than those with soft to medium gel consistency. A cooperative study with starch chemists at Kagoshima University, Japan, demonstrated that the amyloses of hard gel consistency rices have properties similar to those of low-amylose Japanese rice starches.

High-amylose content (AC) rices have lower plasma glucose and insulin response than waxy, low-AC and intermediate-AC rices. Estimates by nutritionists at the University of Toronto of the glycemic index of three high-AC rices differing in gel and Amylograph consistency at the gelatinization temperatures used in processed rice products, parboiled rice, and rice noodles suggest that low gelatinization temperature rices have higher glycemic index than intermediate ones. The major factor seems to be shorter cooking time. Processed rice products also tend to have lower glycemic indexes than milled rice.

Feed quality of straw. The ruminant feed quality of the straw of IRRI varieties was studied in cooperation with animal scientists at the Institute of Animal Science, University of the Philippines at Los Baños and the University of Melbourne and La Trobe University, Australia. Varietal screening of both high-yielding and traditional varieties was also done with the animal feeds section, TDRI, London. Dry matter and organic matter digestibilities differed between wet and dry season crops, suggesting a significant effect of environment on the feed value of rice straw.

TRAINING

A previous section gives an overview of IRRI's extensive activities in training. We highlight here two new courses with special international connections.

Genetic Resources Conservation and Management Training Course. The first Genetic Resources Conservation and Management Training Course officially started on 1 Oct 1985 and ended on

30 Sep 1986. It was designed to provide a systems approach to an intense study of plant genetic resources conservation, evaluation, documentation, management, and dissemination.

The course had four components:

- field collection of traditional cultivars and wild species in the participants' home countries
- a 2-wk Rice Production Training Course
- a 3 1/2-mo training course in Genetic Evaluation and Utilization
- genebank operations and management

There were 12 participants from 8 countries in Asia and 2 in Africa. An additional participant attended the fourth component.

The overall training program emphasized the process of learning by doing. Participants were required to practice all the skills and procedures taught.

The lecturers and laboratory instructors came from the staff of IRRI, especially from the International Rice Germplasm Center (IRGC); the Institute of Plant Breeding (IPB), Department of Agronomy, Department of Horticulture, and Institute of Biological Sciences of UPLB; the International Board for Plant Genetic Resources (IBPGR); the Land Institute of Salina, Kansas; the Rural Advancement Fund International; the Bari and Nordic Genebanks; and the University of Tuscia in Italy. Thus, the course drew on the combined expertise and experience of the world's largest crop-specific genebank (IRGC), a national plant genetic resources laboratory (IPB-UPLB), two regional genebanks (Bari and Nordic), an international coordinating body (IBPGR), and other relevant organizations.

The participants went through a series of technical lectures, classroom discussions, oral reports, and various field and laboratory exercises. Evaluation was based partly on written and partly on practical examinations.

The lectures included basic topics in biology such as the morphology and physiology of the rice plant, biosystematics, phytogeography, taxonomy, evolution, biostatistics, population and quantitative genetics, and seed physiology. The lectures on the basic principles of genetic conservation and management of genebanks included topics on preservation of seed viability, refrigeration and dehumidification, seed viability and monitoring, seed health testing, documentation, *in vitro* and *in situ* conservation, evaluation of germplasm, and genebank design. There were also lectures and laboratory exercises on the genetic resources and conservation of crops other than rice.

Discussions on the availability of crop germplasm and on related politico-socio-economic issues were held with several internationally known experts on plant genetic resources.

Field trips included a climb halfway up Mt. Makiling; a tour of the medicinal plant genebank and the tree species collection of UPLB; a visit to wild rice sites in Pangil, Laguna; and a trip to the rice terraces of Ifugao Province.

The Statistics Department held intensive sessions on the use of microcomputers, database management software, a micro-based statistical package specially designed for genebanks, and a micro-based seed inventory system. A few participants learned enough about word processing to be able to prepare written reports by themselves on the computer.

A unique feature of the course — the special project — was on seed increase and the characterization of rice cultivars originating from the participant's home country. The participants each planted 100 entries, mostly materials they had collected themselves. They then carried out on these entries all the operations involved in seed increase, systematic description, harvesting, and seed preservation that are normally followed by IRGC. In the process, the participants became familiar not only with cultivars from their own countries but with those from their fellow participants' countries as well. Documentation was done with the help of personal computers. The participants analyzed their own data statistically and submitted written reports on their special projects.

The participants also joined IRGC staff in several activities: pulling of seedlings and arranging the harvested material. All activities were closely supervised in a spirit of cooperation and teamwork.

All the activities were designed to provide academic training and first-hand experience in field collection, genebank management, and documentation, along with the evaluation and utilization facets of crop germplasm. In addition, the course aimed to develop an attitude of service as

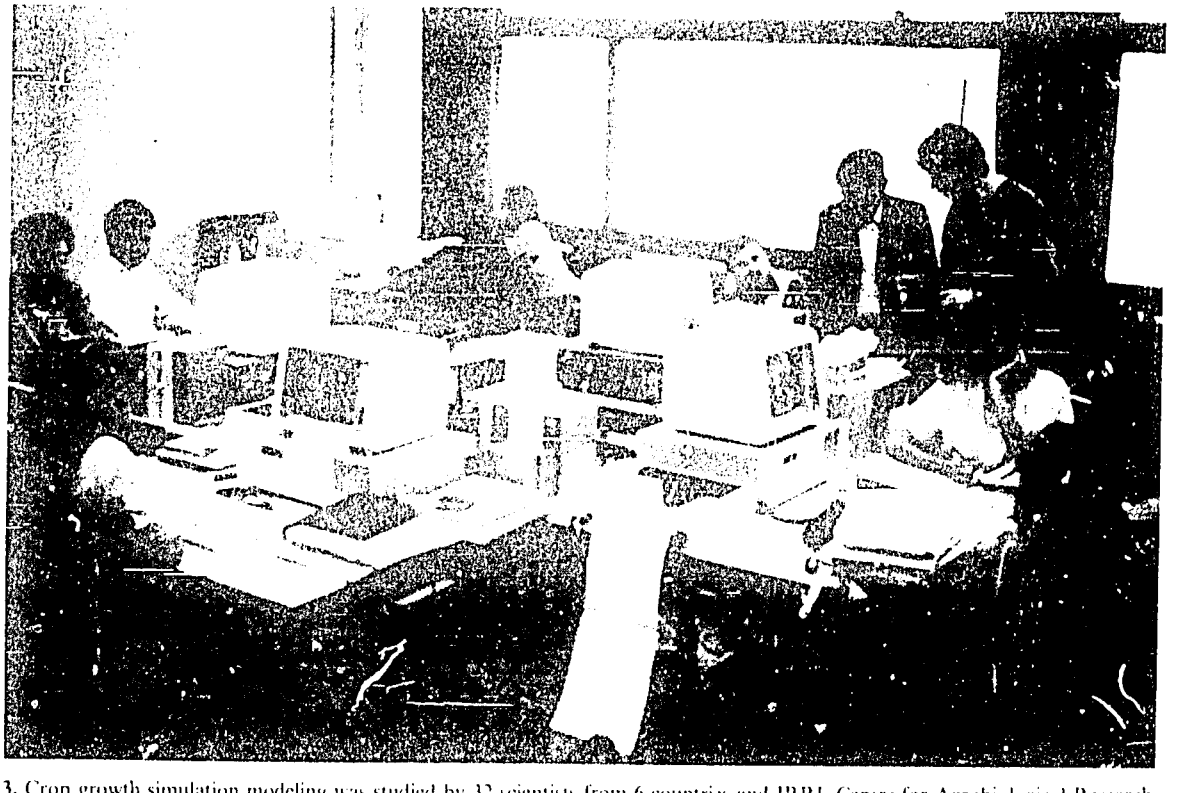
well as expertise in integrating technical operations to fulfill the ultimate goals of crop improvement.

At the end of the course, the participants were awarded the Diploma of Associateship of the International Rice Research Institute in Genetic Resources Conservation and Management. This was the first IRRI training course to confer such a diploma.

Systems analysis and simulation for rice production. The ultimate objective of this project is to promote agricultural growth in developing countries on a sustainable basis, and in particular to improve rice-based cropping systems under rainfed upland and lowland conditions. This is to be accomplished through adaptive research and active cooperation with national research institutes in rice-growing countries. The medium- and short-term aims of this project were the development and the presentation of a training course on modeling and simulation of rice production.

Simulation models — simplified, mathematical representations of reality — are now much more accessible because of the availability of personal computers. Models of crop production with no soil or biological constraints now help predict potential yields for new sites. Water status and the effect of water stress on crop growth can be simulated fairly well, particularly for a field with a deep soil water table. New models are being developed as knowledge of crop processes grows.

We have been collaborating with the Centre for Agrobiological Research (CABO), Wageningen, The Netherlands, in this training course. Basic materials were crop simulation models developed at Wageningen and rice crop data from IRRI. A course of 2 mo was presented to 7 multidisciplinary teams of 4 scientists from different national institutes (India [two times], Indonesia, Malaysia, Philippines, Sri Lanka, and Thailand) and to 1 team of IRRI research assistants. Each team subsequently completed a research study involving both a crop growth simulation model and crop growth validation research (Fig. 5). Some participants computed potential rice production in their



3. Crop growth simulation modeling was studied by 32 scientists from 6 countries and IRRI. Centre for Agrobiological Research (CABO), Wageningen, the Netherlands, 1986.

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LIBRARY AND DOCUMENTATION CENTER

The following publications were issued by the library in 1986:

- International bibliography of rice research, 1985 supplement
- International bibliography of rice research, cumulative indexes, 1981-85
- Theses and dissertations on rice available in the library of the International Rice Research Institute, 1986 supplement
- 12 issues of Library list of recent accessions (January to December)

As in previous years, all the publications were distributed, without charge, to more than 600 libraries and documentation centers in the rice-producing world. A large number were also sold to subscribers.

At the end of 1986, the Rice Literature Search System, which became operational in 1985, had 88,956 rice literature entries covering the years 1967 through 1986. There are now 17 registered IRRI Literature Search System users, all trained by the staff of the Statistics Department. In addition to two terminals and a printer in the library, there are three public terminals at the Computer Center for literature searching.

Numerous requests for information and photocopying services were received in 1986. The library also furnished assistance in library organization and management, selection and acquisition of agricultural materials, and the processing of special materials such as microfilm, maps, pamphlets, and ephemera.

The library gave in-service training to the catalog librarian of the Bangladesh Rice Research Institute.

As in previous years, lectures on literature searching and using the library, plus library tours, were given to IRRI scholars, trainees, and visitors. Computer literature searches, purchase of textbooks, binding of theses and dissertations, and provision of certificate folders were also handled by the library.

The number of books and journals borrowed within the Institute reached an all-time high. Researchers and students from the Los Baños community, Metro Manila, and as far as Central Luzon used the library facilities. The demands were not for rice literature alone, but for works in other disciplines as well.

The addition of 4,139 monographs (books, pamphlets, and reprints) increased the total monographic collection to 78,034. An additional 173 serial titles were acquired during the year. Maps, translations, and microfilms were also added.

In 1986 the library acquired a significant number of publications on women in agriculture. Rice publications from the Asian Institute of Technology and Thammasat University, both in Thailand, were also accessioned.

To keep scientists informed of the latest publications on rice, circulation of the tables of contents of newly received journals was continued within IRRI and to several stations in Indonesia, Bangladesh, and Africa. Citations of Japanese and Chinese publications were also forwarded to the Commonwealth Agricultural Bureaux, resulting in numerous requests for photocopies.

EXPERIMENTAL FARM

A deep well with a capacity of 4,000 liters/min was installed in block UK to supply water to blocks UK, UC, UG, UE, and UJ. Blocks UZ, UR, UQ, UL, and UX will thus be adequately supplied with water from the reservoir in UX. Water in the upland area will no longer be a problem in the dry season.

Ten hectares adjacent to the upland farm were loaned to the Institute by the University of the Philippines at Los Baños (UPLB) on the condition that IRRI will vacate the land upon a 1-yr notice if it is needed by UPLB. This is a rainfed area, and no puddling of soil will be done as per agreement. The soil is a Typic Tropudalf with an ochric epipedon and an argillic subsurface horizon. The thickness of the A-horizon varies from 19 to 36 cm. The soil has a loamy to clay texture. The B_t horizon is clearly indicated by increased clay content (Table 1). The substratum (BC) consists of highly fragmented, yellowish brown, weathered tuff and can be found at a depth of 50-90 cm. The variation in soil characteristics is small (Table 1). The very high K content in the topsoil is a relic of previous sugarcane cropping. Though direct K toxicity has never been reported, the high K content might aggravate nutrient imbalances in rice caused by the low

Table 1. Soil characteristics of the new rainfed area, IRRI, 1986.

Horizon	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	pH (H_2O)	Organic matter (%)	N_t	Cation exchange capacity	Exchangeable cations (meq/100 g)				Base saturation (%)	Olsen P (mg/kg)
									Na	K	Mg	Ca		
							Profile 1							
Ap	0-21	35	41	24	6.0	1.4	0.12	25.1	0.11	0.76	5.59	12.8	76	10
B_{2t}	21-50	52	37	11	5.7	0.9	0.09	30.7	0.48	0.20	7.75	16.3	80	3
BC	50-	51	32	17	5.8	0.5	0.05	34.6	1.20	0.18	8.74	18.3	82	9
							Profile 2							
A_{11}	0-07	25	43	32	5.7	1.6	0.15	22.9	0.09	1.44	5.03	10.8	75	19
A_{12}	07-36	27	41	32	5.7	1.4	0.12	22.6	0.09	0.88	4.81	10.9	73	16
B_{21t}	36-53	49	31	20	5.6	0.9	0.10	28.8	0.31	0.33	7.37	15.7	82	2
B_{22t}	53-87	56	26	18	5.7	0.6	0.06	31.0	0.44	0.23	8.69	16.4	83	2
BC	87-	59	30	11	5.7	0.5	0.05	32.8	0.63	0.22	8.86	16.6	80	9
							Profile 3							
Ap	0-19	42	39	19	5.5	1.0	0.12	25.1	0.08	0.73	5.79	12.7	77	6
B_{21t}	19-43	58	31	11	5.6	0.5	0.07	30.4	0.34	0.24	7.88	16.6	82	2
B_{22t}	43-65	61	31	8	5.6	0.4	0.05	31.6	0.42	0.19	8.72	16.9	83	4
BC	65-	60	32	8	5.6	0.3	0.04	32.7	0.59	0.21	8.93	17.0	82	11
							Profile 4							
Ap	0-19	41	42	17	5.7	1.3	0.13	26.6	0.13	0.51	6.47	13.1	76	4
B_2	19-51	56	31	13	5.7	0.6	0.06	33.2	0.58	0.23	9.05	17.3	82	2
BC	51-	44	29	27	5.8	0.4	0.05	35.4	0.84	0.18	10.00	18.1	82	6

Ca:Mg of about 2. P fertilization is essential because of the soil's low available P.

The Experimental Farm continued to repair and construct peripheral fences to prevent pilferage and to keep stray animals from entering the station. Repair and construction of roads likewise continued. Construction of small roads was pursued to provide access to all experimental plots.

The supply of topsoil from the farm for greenhouse use was becoming a problem, so recycling of soil was begun.

Bird and rat control continued to be major activities. Improved spraying with better protective equipment was established.

Monthly meetings were held with research assistants, research aides, and assistant scientists to solicit their comments, suggestions, and problems so that the operations of the farm could be optimized.

The department prepared and planted more than 256 ha for other departments during the year – an increase of 27.5 ha over 1985. Major users were Plant Breeding (97 ha), Experimental Farm (42 ha), Agronomy (30 ha), Entomology (19 ha), and the International Rice Germplasm Center (IRGC) (15 ha).

We planted over 42 ha for seed multiplication and for rice for IRRI employees during the Christmas season. The following varieties and selections were planted: IR29, IR36, IR48, IR54, IR60, IR62, IR64, IR65, IR841-85-[illegible]-2, IR841-67-1, IR2071-137-5-5-1, and IR32307-107-3-3-2. In addition we also multiplied sesbania, crotalaria, and azolla.

We spent $226,481 for contract labor for land preparation, planting, weeding, and bird watching, the last activity requiring considerably more expenditure than the other three combined.

In 1986, we made $63,265 from sales of farm products (Table 2). At year's end we had in our seed room 19,053 kg of seed valued at $4,521 and 17,142 kg of rough rice valued at $2,571.

A total of 18,417 rats were killed during the year by electric fence, digging, mowing, trapping, and flame throwing operations.

ANALYTICAL SERVICE LABORATORIES

Output. The Chemical Analysis Laboratory ran 141,221 analyses on 58,905 samples for 63 parameters in 1986. About half of the work was devoted to analyses of plant samples, and the remaining

Table 2. Farm income, IRRI, 1986.

Item	Value ($)
Seed	
IR29	3
IR36	65
IR42	55
IR43	25
IR44	2
IR45	2
IR48	13
IR50	67
IR52	10
IR56	2
IR58	50
IR60	358
IR62	127
IR64	10,955
IR65	539
IR32307-107-32-2	64
IR841	5
Rice for milling	39,846
Milled rice	3,816
Soybean	70
Glutinous rice	3,925
Glutinous maize	167
Rejected supersweet maize seeds	81
Yellow flint maize	116
Sorghum	13
Rice bran	37
Sweet potato	4
String bean	277
Potato	489
Cowpea	16
Pechay	23
Supersweet maize (green)	1,749
Wheat	2
Tomato	121
Vegetable maize (baby maize)	89
Sesbania seed	85
Total	63,265

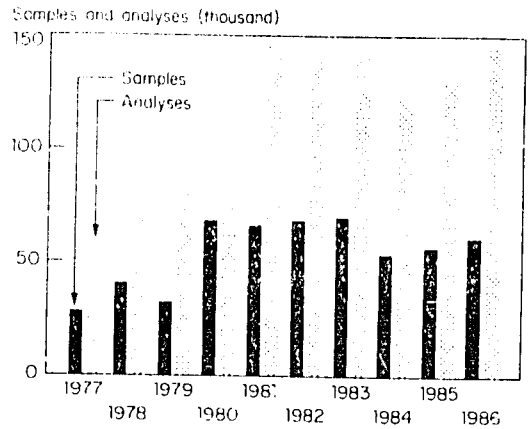
half was almost equally distributed between soils and solutions. Fertilizer analysis accounted for less than 1% of the total work load. The distribution according to program area is shown in Table 3.

The year's output was consistent with the mean annual output of the preceding 5 yr (Fig. 1) and is an indicator of the maximum capability of the laboratory.

The Mass Spectrometry Laboratory ran 8,611 ^{15}N analyses on $(^{15}NH_4)_2SO_4$ derived from soil, plant, and floodwater samples. Malfunction of the MM622 resulted in a downtime of more than 7 mo. The capability of the laboratory was later enhanced by an additional unit, a VG Isogas MM 903ES, made operational in August.

Table 3. Analyses done by program area, Chemical Analysis Laboratory, IRRI, 1986.

Program area	Percent
Soil and crop management	71.1
Genetic evaluation and utilization program	9.7
Cropping systems program	5.4
Irrigation water management	4.2
Control and management of rice pests	3.9
Constraints on rice yields	3.5
Cooperative programs	1.2
Others	1.0



1. Output of the Chemical Analysis Laboratory, IRRI, 1977-86.

The Radioisotope Laboratory ran activity counts on 2,445 samples of soil, plant, and aqueous solutions, generated mainly by research on organic matter in tropical rice soils. Annual maintenance operations performed were decontamination of the plant growth chamber, cleaning and degreasing of the two high-vacuum sample preparation lines, and running of diagnostic tests and calibration of the liquid scintillation counter.

Research. Rapid technological advances and changing research needs necessitate updating of existing analytical methods and adoption of new ones. Research to improve the methods of analysis was continued.

Extraction of plant samples. Ten methods of extraction of plant samples for the analysis of the macroelements and microelements by atomic absorption spectrophotometry were compared. Dry ashing was deemed a suitable preparative method for determination of P, K, Ca, Mg, Zn, and Mn, but not for Na, Si, and the trace elements

Fe, Al, and Cu. Wet ashing is preferred to dry ashing when determining the microelements Fe, Al, Mn, and Cu and is the only choice for the analysis of crude silica. Extraction with normal HCl is a simple and convenient preparative procedure for the analysis of Na, K, Ca, Mg, Zn, Cu, and Mn, but not for P, Fe, and Al.

Simultaneous carbon and nitrogen analysis. Simultaneous analysis of the C and N contents of organic samples with the Perkin Elmer Elemental Analyzer Model 240C was evaluated and found to give an accuracy of ±2%. This analyzer makes possible the analysis of C and N in very small samples (3-5 mg).

Computerized data acquisition. The large numbers of samples requiring analysis and the demand for fast delivery of results necessitate the use of computer-aided analytical techniques. An early-generation 64-kilobyte North Star microcomputer system was upgraded with a 15 Mbyte hard disk. This expanded storage gives the computer the capability to acquire data from as many as 32 analog signal sources. Four channels were interfaced to the Technicon II autoanalyzers. Programs to handle data acquisition and manipulation procedures were written in Microsoft BASIC and compiled for speed. They include algorithms that handle peak detection, signal to noise discrimination, and correction for drift, blanks, and other factors. Complications arising from the simultaneous access of several channels include event timing, which is normally not a concern in single-channel acquisition. Simulation delays were incorporated in the program to maintain even-signal spacing during access. The peak-detection subroutine, however, breaks down when a relatively flat peak is being accessed. Several peak-screening algorithms were tested for handling a wide range of peak shapes.

Service fees. A new schedule of service fees was implemented in May. The new rates reflect actual costs of the services.

PESTICIDE RESIDUE LABORATORY

The Pesticide Residue Laboratory received 2,332 samples for complete analysis in 1986. Of these, 1,560 were water samples tested for residues of regularly applied organophosphates and carbamates for the special Experimental Farm Waterways Monitoring Project for pesticide runoff. The Entomology Department submitted 395 formulations of various pesticides, 22 water samples for molluscicide residue analysis, and 6 azolla samples for diazinon residue analysis. The IRRI Central Safety Committee submitted 196 gauze patches from its pesticide applicator exposure studies for determination of BPMC and monocrotophos levels. The Agronomy Department turned in 134 soil and water samples for butachlor analysis. The remainder were samples from the Cereal Chemistry and Agricultural Engineering Departments and the Experimental Farm. A total of 14,812 analyses were done on these 2,332 samples (Table 4).

Table 4. Analyses performed by the Pesticide Residue Laboratory, IRRI, 1986.

Test	Complete analyses	GLC[a] injections only
Monocrotophos	1,742	
Carbofuran	1,709	
Diazinon	1,698	
Butachlor	1,694	
BPMC	1,638	
Isoprocarb	1,626	
Acephate	1,560	
Carbaryl	1,560	
Chlorpyrifos	1,560	
Niclosamide	16	
Triphenyltin acetate	6	
Paraquat	2	
Carbosulfan	1	
Others		352
Total	14,812	352

[a] Gas liquid chromatography.

The Plant Physiology Department sent in 258 and the Plant Breeding Department 60 rice leaf extracts for epicuticular wax determination. Cereal Chemistry submitted 34 aldononitrile acetate derivatives of cell wall sugars for injection and quantitation.

PHYTOTRON

The entire 40 environment rooms were used for 57 research projects of 11 departments from January to October 1986. Of these projects, 32 were new studies and the remainder were experiments con-

tinuing from 1985. The main users were 20 senior staff, 3 visiting scientists, and 19 research fellows and scholars.

The glasshouse rooms had the highest occupancy rate (92%), followed by the artificially lighted cabinets Conviron, HNL, KG (89-90%). In the other rooms, occupancy levels ranged from 30 to 82%. The experiments lasted from 6 d to 10 mo, with a downtime of 2-5 d between experiments.

As in the past, the drying oven and cold room were used heavily by phytotron users; in addition, 36 requests from other departments were accommodated, 16 for the oven and 20 for the cold room. Six departments (38 requests) used the automatic leaf area meter.

The phytotron spent $120,005 for electricity and $6,069 for diesel fuel in 1986. These energy costs included electricity supplied to the Mass Spectrometry Laboratory, Personnel Scientific Supply Store Building, Soils Laboratory, and Tissue Culture Facility. Sixteen scheduled and 45 unscheduled power interruptions were recorded with an elapsed time of over 228 h. During interruptions, the two phytotron generators were used.

Thirty-nine main and four support facilities were serviced in November and December. Twenty-eight artificially and naturally lighted cabinets were thoroughly checked and tested by phytotron staff; in the past, calibration and testing had been conducted by an engineer from Japan.

Four cooling coils for service areas (corridor, KG room, mezzanine, preparation room) and five blowers for glasshouse and preparation rooms were replaced. Two main power circuit breakers for automatic transfer switches and generators were also replaced. The power metering device was repaired and calibrated, and a new KWH meter was installed.

An artificially lighted cabinet (Koitotron HNL-15-A Special), donated by the Soil Microbiology Department, was installed in the KG room for growing azolla.

SEED HEALTH UNIT

The Seed Health Unit field-inspected 9,869 entries from the seed increase plots of the International Rice Testing Program (IRTP), IRGC, the Plant Breeding Department, and the Korean seed increase program in 1986. There were 518 requests for phytosanitary certification of 54,513 outgoing seed lots coming from IRTP, IRGC, Plant Breeding, and other research departments. Routine seed health tests were run on 2,444 seed lots from which samples could be drawn. Phytosanitation treatments were hot water (52-57 °C, 15 min) or fungicide slurry with mancozeb and benomyl applied at 0.3% by seed weight. All materials were fumigated with Al phosphide.

Seventy-two seed parcels representing 4,892 seed lots were received and tested for postentry quarantine clearing. Samples were drawn from 644 seed lots for routine testing; the remaining lots were of limited quantities. All incoming seed lots were given phytosanitation treatments of hot water (52-57 °C, 15 min), followed by mancozeb and benomyl seed dressing. Postentry field inspection was done on all plantings of incoming seeds.

Two Vietnamese trainees attending the GEU Seed Production Program spent 2 wk in the Seed Health Unit, familiarizing themselves with seed health testing and quarantine for rice.

Publications and seminars

PUBLICATIONS

Under Institute publications are listed the 14 major books produced by the Communication and Publications Department, 2 of which were copublished in 6 multilanguage editions; 6 monographs in the IRRI Research Paper Series on a variety of topics, and several 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

Rice improvement in Eastern, Central, and Southern Africa. 159 p.

IRRI highlights for 1985. 101 p.

Rice grain quality and marketing. 76 p.

Progress in upland rice. 567 p.

The flowering response of the rice plant to photoperiod: a review of the literature, 4th ed., by B. S. Vergara and T. T. Chang. 61 p.

Appendix to the rice economy of Asia, by B. Rose. 404 p.

Annual report for 1985. 558 p.

Small farm equipment for developing countries. 637 p.

Rice genetics: proceedings of the international rice genetics symposium. 956 p.

Progress in rainfed lowland rice. 446 p.

A farmer's primer on growing rice (Creole, Pangasinan, Northern Waray, and Magundanao editions), by B. S. Vergara. 221 p.

Field problems of tropical rice (Lao, Hindi and Nepali editions). 172 p.

International bibliography of rice research: 1985 supplement. 736 p.

Publications of the international agricultural research and development centers: 1986 supplement. 167 p.

Research Paper Series

117. Morphological changes in rice panicle development: a review of literature, by Xu-hun Xu and B. S. Vergara. 12 p.

118. IRRI-Korea collaborative project for the development of cold-tolerant lines through anther culture, by E. J. Zapata, R. R. Aldemita, A. U. Novero, L. B. Torrizo, L. B. Magaling, A. M. Mazaredo, R. M. Visperas, M. S. Lim, and H. P. Moon. 7 p.

119. Problem soils as potential areas for adverse soils-tolerant rice varieties in South and Southeast Asia, by G. Boje-Klein. 43 p.

120. Changes in small-farm rice threshing technology in Thailand and the Philippines, by B. Duff. 24 p.

121. Landforms and modern rice varieties, by R. A. Morris, J. H. Kim, and J. B. Valera. 15 p.

122. Yield stability and modern rice technology, by J. C. Flinn and D. P. Garrity. 18 p.

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International rice research newsletter, Vol. 10, nos. 1-6, plus subject index

Azolla newsletter, Vol. 2, no. 1

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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

1986: A look ahead. Dr. M. S. Swaminathan.

Sheath blight management in future rice farming — the role of rice varieties. Dr. S. W. Ahn, visiting associate plant pathologist, Plant Pathology Department.

Scientific photography. Mr. M. Scott, Eastman Kodak Co., New York, USA.

Balancing productivity, stability, and sustainability of rice farming systems. Dr. G. L. Denning.

Seeding equipment for upland crop establishment. Dr. M. A. Chaudhary, visiting scientist, Agricultural Engineering Department.

Ecology and control of needle nematode *Paralongidorus australis* on rice in North Queensland. Dr. G. R. Sterling, Agricultural Research Laboratories, Queensland, Australia.

Some factors affecting yield potential of cereals. Dr. L. T. Evans, Division of Plant Industry, CSIRO, Australia.

Ethylene as a biochemical marker for tolerance in rice. Dr. A. A. Khan, visiting scientist, International Rice Testing Program.

The electoral process in the Philippines. Dr. R. P. de Guzman, chancellor, University of the Philippines at Los Baños (UPLB), College, Laguna.

Biotechnology research in the US: its implication for developing countries. Dr. R. Barker, professor, Department of Agricultural Economics, Cornell University, Ithaca, New York.

Philippine rice research. Dr. R. Villareal, dean, College of Agriculture, UPLB.

Policies and institutional issues in the Philippine agricultural sector: a donor's view. Mr. D. J. Clark, chief, Rural and Agricultural Development Office, USAID, Manila.

Upland rice breeding for difficult environments. Mr. M. Arraudeau, visiting scientist, Plant Breeding Department.

Distribution of justice in the Philippines: a historical perspective. Dr. M. Mangahas, consultant, Philippine Social Science Center, Diliman, Quezon City.

Possible biochemical role of photorespiration in plants. Dr. M. S. Naik, head, Biochemistry Department, Indian Research Institute, New Delhi, India.

Environmental perspectives in upland development. Dr. P. E. Sajise, director, Program on Environmental Science and Management, UPLB.

Poverty and plenty — IRRI's role and responsibility and national program perspective. Dr. C. Lightfoot (Cornell University), Farming Systems Development Project — Eastern Visayas Ministry of Agriculture and Food, Tacloban, Leyte.

Management of rice research in the Philippines. Dr. D. P. Gapasin, deputy executive director for research, Philippine Council for Agriculture and Resources Research and Development, Los Baños, Laguna.

Education in a third world country: the need for reorientation. Dr. F. Bantilan, Jr., director, Institute of Applied Mathematics and Physics, UPLB.

Constraints on turnaround time in Bangladesh: a regional study. Dr. A. Orr, agricultural economist, IRRI-ODA postdoctoral fellow, IRRI-BRRI project.

Carbon metabolism in soybean nodules. Dr. S. Tajima, associate professor, Department of Agricultural Chemistry, Kagawa University, Kagawa, Japan.

Cabbage looper resistance in soybeans. Dr. Z. R. Khan, collaborative research scientist, ICIPE-IRRI Collaborative Program.

The CGIAR: vision for the future. Dr. M. S. Swaminathan.

Competition and control over land resources in a Cavite municipality: implications for capital accumulations and class conflict. Mr. J. McAndrew, research specialist-anthropologist, and Ms. T. Cantada, research assistant, International Institute for Rural Reconstruction, Silang, Cavite, Philippines.

Comparative lexicography of the vocabulary of the rice plant. Ms. N. Revel-MacDonald, researcher on Philippine culture, environment and language, Ce DRASTMI CNRS, Paris.

The availability of crop germplasm. Dr. T. T. Chang.

Prospects for structural adjustment in Japanese agriculture. Dr. Y. Hayami, professor of economics, School of International Politics, Economics and Business, Aoyama Gakuin University, Tokyo, Japan.

Beta-linked dynamical modes in DNA as the basis for sequence-dependent promoter interaction. Dr. A. D. Nazarea, professor of biophysics, National Institute of Physics, College of Science, University of the Philippines, Diliman, Quezon City.

Analysis of crosses between strains of the rice blast pathogen. Dr. J. L. Notteghem, plant pathologist, Institut de Recherches Agronomiques Tropicales

(IRAT) et des Cultures Vivrieres, Montpellier Cedex, France.

Agricultural mechanization and the evolution of farming systems in Sub-Saharan Africa. Dr. P. L. Pingali, economist (consultant), Agricultural and Rural Development Department, The World Bank, Washington, D.C.

Goals and consequences of rice policy in Japan. Dr. K. Otsuka, visiting scientist, Agricultural Economics Department.

Sensory and chemical examination of aromatic and nonaromatic rices. Dr. C. M. Paule, Department of Food Science, University of Georgia, Athens, Georgia, USA.

A physicist at IRRI. Dr. L. Woodhead.

Prospects of using some nonconventional breeding methods in rice varietal improvement. Dr. S. S. Virmani.

Comparative economics of innovations with respect to systems, sectors, and size in farming. Dr. A. M. Lang, Winrock associate and visiting professor, College of Development Economics and Management, UPLB.

Pilipino values. Dr. L. Quisumbing, minister of Education, Culture, and Sports, Republic of the Philippines.

Utilization of VA mycorrhizae in crop production. Dr. L. L. Ilag, visiting scientist, Plant Pathology Department.

Improving rural nutrition and quality of life. Dr. M. P. de Tavera, minister of Social Services and Development, Republic of the Philippines.

Saturday seminars

Water allocation distribution strategies in droughty season, lessons from the Upper Pampanga Irrigation System. Mr. W. C. de la Viña, Mr. M. M. Alagcan, and Dr. S. I. Bhuiyan.

Equity implications of technology changes in the Indonesian rice economy. Dr. I. Jatileksono, research fellow, Agricultural Economics Department.

Reapers in small farm rice production: a review of evidence from Bataan. Ms. F. Juarez.

Technical and allocative efficiency in fine-grained rice production in the Pakistan Punjab. Dr. M. Ali, research fellow, Agricultural Economics Department.

Performance evaluation of selected types of mechanical dryers. Ms. J. A. Demegillo, graduate student, UPLB.

Performance analysis of an IRRI natural convection dryer. Mr. L. Halos.

Inheritance of resistance to green leafhopper. Dr. B. Ruangsook, research fellow; and Dr. G. S. Khush, plant breeder and head, Plant Breeding Department.

Wide hybridization in rice improvement. Dr. K. K. Jena, collaborative research scientist; and Dr. G. S. Khush, plant breeder and head, Plant Breeding Department.

Selectivity of several insecticides to the brown planthopper and its predator, wolf spider. Mr. M. T. Hoang, research fellow; Dr. O. Mochida, entomologist, Entomology Department; and Dr. B. M. Rejesus, chairman, Entomology Department, UPLB.

Inheritance of amylose content in rice. Dr. I. Kumar, postdoctoral fellow; and Dr. G. S. Khush, plant breeder and head, Plant Breeding Department.

Screening rice and wild rice for resistance to the green leafhopper, whitebacked planthopper, and yellow stem borer. Ms. L. Sunio, senior research assistant; Ms. A. Romena, senior research assistant; Dr. E. Tryon, visiting scientist; and Dr. F. A. Heinrichs, entomologist and former head, Entomology Department.

Flight periodicity and interisland movement of the brown planthopper in the Philippines. Mr. H. Justo and Dr. R. C. Saxena.

Developing a chemical insecticide recommendation based on economic threshold for irrigated rice in Nueva Ecija. Mr. J. Bandong and Dr. J. A. Litsinger.

Study of algal inoculation in microplot and field experiments. Dr. P. M. Reddy, postdoctoral fellow, Soil Microbiology Department.

Effect of physiological and morphological characteristics on *in vitro* cellulose solubility of different varieties of rice straw. S. J. Bainton, senior research officer, Tropical Development and Research Institute, London, U.K.

Nutritional value of nonrice crops in rice-farming systems. Dr. B. O. Juliano, chemist, Cereal Chemistry Department; Dr. V. R. Carangal, agronomist, Rice Farming Systems Program; and Dr. B. O. Eggum, Department of Animal Physiology and Biochemistry, National Institute of Animal Science, Copenhagen, Denmark.

A plant sampling procedure for acetylene reduction assay to detect rice varietal differences in N_2 fixation stimulation ability. Ms. A. T. Padre.

Varietal differences in quality of processed rice products "puffed rice" and "rice cakes." Ms. C. M. Perez and Ms. C. P. Villareal.

The effect of climate on rice development and yield. Dr. A. B. Dua, postdoctoral fellow, Multiple Cropping Department.

A new nitrogen-fixing species of *Pseudomonas: P. diazotrophicus* sp. nov. isolated from the roots of wetland rice. Mr. R. So.

Temperature response of azolla species. Ms. T. Ventura

Effective use of water and energy in rice-soil and puddling. Dr. D. K. Painuli, postdoctoral fellow, Physics Unit, Soils Department.

Rice response to waterlog-tolerant green manures. Mr. R. E. Furoc, Sr.

Zero flux plane penetration, water use, and water use efficiency under postrice monocropped and intercropped cowpea and sorghum. Dr. R. A. Morris, agronomist and head; Ms. A. N. Villegas, research assistant; Mr. A. Polthanee, research fellow; and Ms. H. Centeno, research aide, Multiple Cropping Department.

Effect of shading sequences simulating relay cropping and intercropping on soybeans. Dr. R. A. Morris, agronomist and head; Mr. W. T. Herrera, assistant scientist; Dr. P. K. Aggarwal, visiting research scientist; and Ms. H. Centeno, research aide, Multiple Cropping Department.

Effect of gypsum addition and of Na/Ca and Na/K ratios on the growth and mineral nutrition of K-efficient rices in coastal saline-sodic soils. Dr. S. Muhammed, visiting scientist, Soils Department.

Effect of incorporation of sesbania, azolla, and rice straw on nitrogen release pattern in flooded rice soils. Dr. S. Nagarajah, visiting scientist; Ms. M. C. G. Robielos, research assistant; and Dr. H. U. Neue, soil chemist and head, Soils Department.

Screening rices for adverse soils tolerance. Ms. C. C. Quijano.

Drought response of soybean genotypes during reproductive growth phase under irrigation gradient. Dr. C. Senthong, postdoctoral fellow; Mr. K. Tedia, research fellow; Mr. E. A. Barlaan, research assistant; and Dr. R. K. Pandey, agronomist/breeder, Rice Farming Systems Program.

Variability in dormancy and tolerance to accelerated seed ageing in rice. Dr. S. B. Siddique, research fellow; and Dr. D. V. Seshu, plant breeder and IRTP coordinator, International Rice Testing Program.

Factors affecting the longevity of rice cultivars (*Oryza sativa* L.). Ms. F. de Guzman, Ms. V. T. Tolentino, and Dr. T. T. Chang.

Quarantine aspect of rice seed health test. Mr. S. Merca, Ms. E. Gergon, and Dr. T. W. Mew.

Ways of reducing herbicide toxicity in wet-seeded rice. Ms. M. O. Mabbayad and Dr. K. Moody.

Weeds and their control in farmers' transplanted ricefields. Dr. A. N. Rao, postdoctoral scientist; and Dr. K. Moody, agronomist, Agronomy Department.

Effect of urease inhibitors on nitrogen fertilizer loss and rice yield. Mr. J. L. Padilla, Dr. R. J. Buresh, Dr. S. K. De Datta, Ms. M. Samson, and Ms. T. Chua.

Effects of direct-seeding on canopy gas exchange, development, and yield in IR64. Dr. M. Dingkuhn, collaborative research scientist, Agronomy Department.

A simplified technique to estimate ammonia volatilization in lowland rice. Ms. W. N. Obcemea, senior research assistant; Mr. J. G. Real, research assistant; Dr. S. K. De Datta, principal scientist and head, Agronomy Department; Dr. A. C. F. Trevitt, visiting scientist, Drs. J. R. Freney and J. R. Simpson, senior principal scientists, Division of Plant Industry, CSIRO, Canberra, Australia.

Use of farm reservoirs for increasing riceland productivity and farmer income in rainfed areas. Mr. W. C. dela Viña, Dr. S. I. Bhuiyan, and Mr. T. B. Moya.

Excess water problems in rice production in the Bicol River Basin. Mr. M. M. Agua, research assistant; Dr. R. C. Undan, postdoctoral fellow; and Dr. S. I. Bhuiyan, agricultural engineer and head, Water Management Department.

A simulation model for optimizing the operation of multipump irrigation systems for rice production. Mr. A. L. Galang and Dr. S. I. Bhuiyan.

Epidemiology of blast in upland rice. Mr. H. Pinnschmidt, research fellow; and Dr. J. M. Bonman, associate plant pathologist, Plant Pathology Department.

Electron microscopy: techniques and applications. Ms. F. C. Sta. Cruz.

Effect of plant age on the expression of resistance to *Pyricularia oryzae* Cav. in upland rice cultivars. Mr. C. Q. Torres.

Prospects for integrated rice sheath blight management. Dr. A. K. M. Shahjahan, postdoctoral fellow; Mr. N. G. Fabellar, research assistant; and Dr. T. W. Mew, plant pathologist and head, Plant Pathology Department.

Observations on genetic purity and growth characteristics of some IR cultivars. Dr. S. Akita.

Special seminars

Recent trends in automatic designing techniques. M. Koike, Mie University, Japan.

The rural unemployment problem. R. Sinha, International Exchange Department (IDE), Tokyo, Japan.

Chemodynamics of pesticides in ecosystems. Dr. J. Jayaraman, professor of biochemistry, Madurai Kamaraj University, Madurai, India.

Science and human values. Shri Swami Ranganathananda, Ramakrishna Mission, Hyderabad, India.

A total genetic map of tomato. Dr. S. Tanksley, Department of Plant Breeding, Cornell University, USA.

Can algicides improve nitrogen use efficiency in rice by reducing ammonia volatilization? Dr. W. A. Muirhead, principal research assistant, CSIRO Centre for Irrigation Research, Griffith, N. S. W., Australia, and visiting scientist, Agronomy Department.

Epidemiological crop loss assessment: elements of a systems approach to pest management in the tropics. Dr. P. S. Teng, associate professor and technical assistance specialist, Consortium for International Crop Protection, College Park, Maryland, USA.

The scientist-editor relationship: an interactive seminar. Dr. S. J. Banta, visiting editor, Communication and Publications Department.

The role of international agricultural research centers (IARCs) in the improvement of the seed sector. J. E. Douglas, head, Seed Unit, CIAT, Palmira, Colombia.

The application of alien germplasm for wheat improvement. Dr. L. A. Sitch, postdoctoral fellow, Wheat Wide Cross Programme, International Maize and Wheat Improvement Centre (CIMMYT), Mexico.

The Aquino government: constraints and possibilities. Dr. R. S. David, director, Third World Studies Center, University of the Philippines, Diliman, Quezon City.

DNA-mediated transformation studies in rice and tobacco. Dr. H. Uchimiya, associate professor of plant biology, Institute of Biological Sciences, University of Tsukuba, Ibaraki, Japan.

Integrated new breeding procedures and ecological breeding for rice in China. Dr. Huang Yao-xiang, research scientist (rice breeding), China.

The law of the seed. Mr. P. R. Mooney, Rural Advancement Fund International, Manitoba, Canada.

The role of African universities in national development: the case of agricultural universities Prof. G. R. V. Mmari, vice chancellor, Sokoine University of Agriculture, Morogoro, Tanzania.

Finances

Summary of financial support to IRRI core and to special and collaborative projects received in 1986.[a]

Donor or agency	US$			
	Core		Special and collaborative projects	Total
	Unrestricted	Restricted		
	Grants			
United States Agency for International Development	6,050,000		2,231,825	8,281,825
Japanese Government		5,205,670	884,182	6,089,852
International Bank for Reconstruction and Development	1,500,000			1,500,000
Canadian International Development Agency	1,229,950		1,196,259	2,426,209
United Nations Development Programme		2,183,900	42,937	2,226,837
European Economic Community		**3,574,980**		3,574,980
Overseas Development Administration, United Kingdom	1,140,102			1,140,102
Federal Republic of Germany	460,793	150,000	235,440	846,233
International Development Research Centre, Canada		**110,190**	624,822	735,012
Australian Government	573,549		123,391	696,940
Government of Italy	173,853	**537,307**		711,160
Asian Development Bank			300,000	300,000
Government of Sweden	440,964			440,964
Government of the Netherlands			141,692	141,692
International Fund for Agricultural Development		**300,000**		300,000
Government of the Philippines	108,820		82,029	190,849
Ford Foundation	**300,000**	**70,000**	98,500	468,500
Government of Denmark	266,102			266,102
Office of Rural Development, Korea			98,000	98,000
Government of Mexico	**37,022**			37,022
Government of Norway	136,027			136,027
Government of China	100,000		20,000	120,000
Swiss Development Cooperation		**350,000**	45,000	395,000
Rockefeller Foundation		**704,740**	86,853	791,593
Government of Spain	**35,000**			35,000
Government of New Zealand	12,537			12,537
Government of France			74,074	74,074
Miscellaneous research grants			102,374	102,374
Funds reimbursed under collaborative research program				
Resources Management International, Indonesia			134,018	134,018
International Food Policy Research Institute			104,318	104,318
International Institute of Tropical Agriculture			61,729	61,729
International Centre of Insect Physiology and Ecology		**120,221**		120,221
International Fertilizer Development Center			30,769	30,769
International Board for Plant Genetic Resources			21,647	21,647
Food and Agriculture Organization of the United Nations			14,000	14,000
Total	12,564,719	13,307,008	6,753,859	32,625,586

[a]Receipts are accounted for on a cash basis. Amounts shown in boldface differ from 1986 pledges from grantors in that they may reflect 1985 or 1987 pledges received in 1986, or may not reflect the full amount of 1986 pledges that are anticipated to be received in 1987. The Government of France (through the research organizations ORSTOM and IRAT) provided IRRI the services of two resident scientists; the value of their services cannot be quantified.

Staff changes

January

Dr. Surajit K. De Datta, agronomist and head of the Agronomy Department, was appointed principal agronomist.

Dr. Gurdev S. Khush, plant breeder and head of the Plant Breeding Department, was appointed principal plant breeder.

Dr. Glenn L. Denning, visiting associate field specialist, was appointed associate scientist - Technology Transfer.

Dr. Francisco J. Zapata, associate plant physiologist, was appointed plant physiologist.

Dr. Stephen J. Banta, editor-in-chief, Island Publishing House, began a 6-mo assignment as visiting editor with the Communication and Publications Department.

Dr. Hei Leung, formerly with the University of California, Department of Vegetable Crops, arrived to assume the position of associate plant pathologist in the Plant Pathology Department.

Dr. Warren Muirhead, Centre for Irrigation Research, CSIRO, arrived to begin a 6-mo assignment as visiting scientist in the Agronomy Department.

Dr. D. Hammond Murray-Rust, associate agricultural engineer, Water Management Department, resigned to join the International Irrigation Management Institute in Sri Lanka.

February

Mr. Robert L. Bourquein, former controller, USAID Sudan, arrived to assume the position of director for administration.

Mr. Edwin A. Tout, associate editor, Communication and Publications Department, resigned.

March

Dr. Chung Ik Cho, visiting scientist, Plant Breeding Department, left IRRI to join the Honam Crop Experiment Station, Republic of Korea, as director general.

Dr. Clarence W. Bockhop, agricultural engineer and head, Agricultural Engineering Department, retired.

April

Mr. R. Vaidyanathan, manager, Purchase and Supplies Division of ICRISAT, left IRRI after completing a 6-mo consultancy assignment in the Administration.

Dr. M. D. Pathak, director, research and training, left to begin a 6-mo study leave.

Dr. Chong Ho Kim, senior researcher, Crop Experiment Station, Rural Development Administration, arrived to begin an assignment as visiting scientist in the Plant Breeding Department.

May

Dr. M. A. Choudhary, Massey University, left after completing a 6-mo sabbatic leave with the Agricultural Engineering Department.

Dr. B. Merle Shepard, head, Entomology Department, rejoined IRRI after a leave of absence

June

Dr. Higino A. Ables, professor, College of Agriculture, University of the Philippines at Los Baños, arrived to begin a 5-mo assignment as visiting scientist in the Office of the Director for Research and Training.

Dr. Anwar A. Khan, New York State Agricultural Experiment Station, Cornell University, left after completing a 1-yr assignment as visiting scientist in the International Rice Testing Program.

Dr. Paul R. Bloom, associate professor, University of Minnesota, arrived to begin a 1-yr sabbatic leave as visiting scientist in the Soils Department.

July

Dr. Stephen J. Banta was appointed editor in the Communication and Publications Department after a 6-mo assignment as visiting editor.

Dr. LaRue Pollard, former professor of Journalism and Mass Communication, Iowa State University, arrived to assume the position of editor in the Communication and Publications Department.

Dr. Marlin G. Van Der Veen, agricultural economist, left upon termination of his project.

Dr. Rosendo K. Palis rejoined the Institute staff as farming systems agronomist and project leader in the IRRI-Burma Farming Systems Project.

Dr. Keijiro Otsuka, associate professor of the Faculty of Economics, Tokyo Metropolitan University, arrived to begin a 1-yr sabbatic leave as visiting scientist in the Agricultural Economics Department.

Dr. Richard A. Morris, agronomist and head, Multiple Cropping Department, resigned to join Oregon State University.

Dr. B. P. Ghildyal, former program officer, the Ford Foundation, India, joined the Institute as IRRI liaison scientist in India.

Dr. Earl H. Tryon, visiting associate scientist, Entomology Department, left upon completion of his assignment.

August

Dr. Warren Muirhead, CSIRO, Australia, left upon completion of a 6-mo assignment in the Agronomy Department.

September

Dr. Fred E. Nichols, agricultural engineer, CIAE/IRRI Industrial Extension Project, left upon termination of the project.

October

Dr. Alastair Orr, formerly consultant-economist, Overseas Development Administration, Bangkok, joined the Institute as visiting associate economist, Agricultural Economics Department.

Dr. Lesley A. Sitch of the Rockefeller Foundation joined the Institute as associate plant breeder in the Plant Breeding Department.

Dr. Kissen Kanungo, adviser, Agriculture Planning Commission, Government of India, joined the Institute staff as a consultant for 6 mo, to prepare a comprehensive paper on "Strengthening the National Systems."

Dr. Heinz-Ulrich Neue was appointed head of the Soils Department.

Dr. Amir U. Khan was appointed head of the Agricultural Engineering Department.

Dr. Higino A. Ables, visiting scientist, Office of the Director for Research and Training, left after the completion of his assignment.

Dr. M. D. Pathak, director, training and research, arrived from a 6-mo study leave.

December

Dr. Robert E. Huke, Dartmouth College, arrived as visiting scientist in the Agricultural Economics Department for 3 mo.

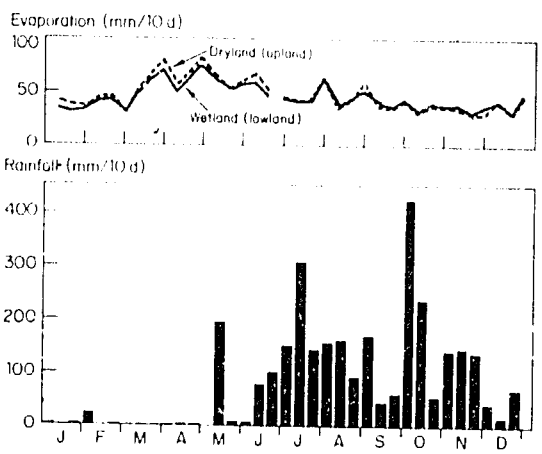
Dr. F. W. T. Penning de Vries, formerly acting head of the Department of Crop Sciences, CABO, joined the Institute as visiting scientist in the Multiple Cropping Department.

Dr. Marcos R. Vega, deputy director general of the Institute, retired.

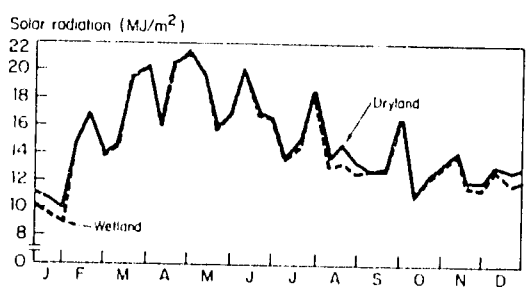
Weather summary

The 1986 annual rainfall totals were 3,092 mm for the dryland (upland) site and 2,821 mm for the wetland (lowland) site (Table 1). The rainfall in 1986 was about 50% higher than normal (2,074 mm) although prolonged dryness was experienced between March and early May (Fig. 1). October was exceptionally wet, with 731 mm rainfall at the dryland site and 792 mm at the wetland site, because of 3 tropical storms — Oyang, Pasing, and Rusing.

The average solar radiation was 15.0 MJ/m^2 per day at the dryland site and 14.8 MJ/m^2 per day at the wetland site (Table 1). Solar radiation was highest in April (19.3 MJ/m^2) at both sites, and lowest in January (10.6 MJ/m^2 at the dryland site and 9.7 MJ/m^2 at the wetland site) (Fig. 2). Bright



1. Rainfall and evaporation by 10-d period. IRRI, 1986.



2. Solar radiation by 10-d period. IRRI, 1986.

Table 1. Monthly weather data at IRRI dryland and wetland sites. Los Baños (14°13'N, 121°15'E), Laguna, Philippines, 1986.

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total or daily average
Dryland site													
Rainfall (mm/mo)	13	33	7	14	210	198	615	421	278	731	439	133	3092
Total radiation (MJ/m^2 per day)	10.6	15.1	18.3	19.3	17.4	18.0	15.7	13.9	13.9	12.3	12.6	12.8	15.0
Windspeed (m/s)	2.3	1.7	1.9	2.0	1.5	1.3	1.5	1.9	1.5	1.5	1.4	1.7	1.7
Total evaporation (mm/mo)	119	125	198	207	181	166	148	139	115	105	95	117	1715
Wetland site													
Rainfall (mm/mo)	13	50	8	8	155	183	493	373	221	792	416	109	2821
Total radiation (MJ/m^2 per day)	9.7	15.1	18.2	19.5	17.6	17.7	15.6	13.1	14.2	12.0	12.4	12.2	14.8
Windspeed (m/s)	2.1	1.7	1.8	1.8	1.2	1.0	1.3	1.6	1.4	1.4	1.4	1.6	1.5
Wind direction[a]	ENE	VRBL	VRBL	ESE	VRBL	E	SSE	SW	VRBL	NNW	VRBL	VRBL	VRBL
Bright sunshine (h/d)	2.9	6.4	7.2	8.4	6.9	5.9	5.0	3.8	4.4	4.3	5.5	5.9	5.6
Total evaporation (mm/mo)	103	118	178	185	172	147	144	134	117	108	106	118	1630

[a] VRBL = variable.

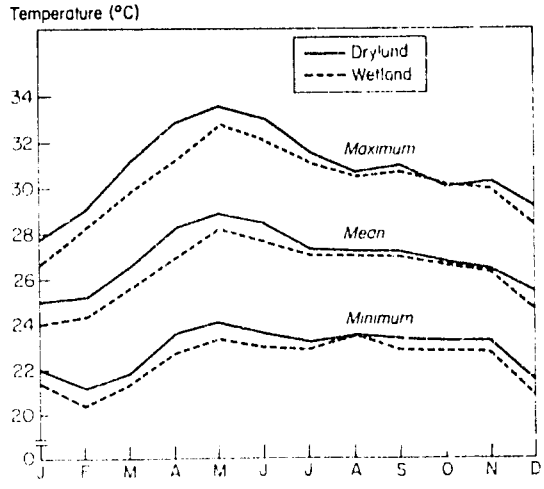
sunshine at the wetland site was also highest in April (8.4 h) and lowest in January (2.9 h) (Table 1).

The average maximum temperature was lowest in January, with 27.9 °C at the dryland site and 26.8 °C at the wetland site, and highest in May, with 33.6 °C at the dryland site and 32.8 °C at the wetland site (Fig. 3). The minimum temperature averages were lowest in February, with 21.2 °C at the dryland site and 20.5 °C at the wetland site. The average daily temperatures were 30.9 °C maximum and 22.9 °C minimum at the dryland site, and 30.2 °C maximum and 22.4 °C minimum at the wetland site.

Windspeed measured at 2 m above the ground was highest in January, with 2.3 m/s at the dryland site and 2.1 m/s at the wetland site (Table 1).

Total evaporation from the Class A pan was higher at the dryland site (1715 mm) than at the wetland site (1630 mm) (Table 1, Fig. 1).

Of the 21 tropical cyclones that passed through the Philippine area of responsibility during 1986, 15 affected Los Baños, although not directly, bringing forth intensified rainfall, moderate winds, and widespread flooding in low-lying areas.



3. Average monthly temperature. IRRI, 1986.