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Program Report for 1991

INTERNATIONAL RICE RESEARCH INSTITUTE

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INTERNATIONAL RICE RESEARCH INSTITUTE

1992

IRRI

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Foreword

As well as being a research center in its own right, IRRI serves as a scientific clearinghouse for knowledge generated in both industrialized and agriculture-dominated economies, as a promoter of across-national-boundaries cooperation in rice research, and as a facilitator in bridging the gaps between scientific disciplines, rice ecosystems, and agricultural research institutions.

Over the years, we have learned more about how to use knowledge developed elsewhere, even outside agricultural research institutions, to strengthen our own activities and those of our partners in rice-growing countries. The growing complexity of the problems and the necessity of seeking environmentally friendly solutions challenge us to seek innovative opportunities.

IRRI's role in the global rice research community is being defined more and more by strong involvement of the Institute's scientists in strategic research, and in collaboration with scientists in national rice research programs and other advanced institutions and laboratories all over the world.

At the same time, we must ensure that our research continues to contribute to achieving the Institute's objectives and goal. Through enhanced linkages with non governmental organizations and the private sector, we seek to design research of relevance to the rice farming community. This will increase the efficiency of the research agenda in a time of shrinking resources.

This Program Report for 1991 is the definitive record of achievement in the research undertaken by IRRI, much of it in collaboration with others. It is intended to account to donors and to make available to rice researchers everywhere current information about the outcome of activities projected in the Institute's Work Plan for 1990-1994.

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[4]Joined during the year.
[5]Cooperative research staff.
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Using this report

This *Program report for 1991* includes capsule summaries of research undertaken by the Institute during the past year, plus discussions of the international programs that interconnect with the research programs. It is similar to the *Annual reports* published 1961-1988 in being the primary, definitive record of progress made by the Institute.

The research reported here follows the ecosystem-based organization that went into effect on 1 January 1990. All research activities are reported under one of the five research programs: Irrigated Rice, Rainfed Lowland Rice, Upland Rice, Deepwater and Tidal Wetlands Rice, and Cross-Ecosystems Research. Other activities are reported under the five international programs: Germplasm Conservation and Dissemination, Information and Knowledge Exchange, Networks, Training, and Country and Regional Projects.

Not all work done by the Institute in 1991 is reported here. The report is limited to activities that had reached a reportable stage involving analysis, interpretation, and conclusions. A few significant interim results are reported because it was felt they would be useful to other rice workers.

The international programs are administered through five entities, which can be contacted for further information:

- Genetic Resources Center (Germplasm Conservation and Dissemination Program)
- Information Center (Information and Knowledge Exchange Program)
- Deputy Director General for International Programs (Networks)
- Training Center (Training Programs)
- International Programs Management Office (Country and Regional Projects)

Information on the research programs can be obtained from the program leaders or the research divisions noted on the table of contents for each program (pp. 3-4, 51, 83, 105, 123-124), following these abbreviations:

AE	=	Agricultural Engineering Division
APA	=	Agronomy, Physiology, and Agroecology Division)
E	=	Entomology Division
PBGB	=	Plant Breeding, Genetics, and Biochemistry Division
PP	=	Plant Pathology Division
SM	=	Soil Microbiology Division
SS	=	Social Sciences Division
SWS	=	Soil and Water Sciences Division

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

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

Pedigrees are indicated by a slant bar (/) rather than by a multiplication sign (×). For example, (PTB33×IR30)×IR36 is written PTB33/IR30//IR36. Fourth and further crosses are designated /4/,/5/, and so on. Backcrosses are designated by an asterisk (*)

and a number indicating the dosage of the recurrent parent. The asterisk and the number are placed adjacent to the crossing symbol, which divides the recurrent and donor parents.

Unless otherwise noted, scoring of morphological characters and of damage attributed to rice pests and physiochemical stresses is based on scales in *Standard evaluation system for rice* (SES), 3d edition, 1988. Copies are available from the International Network for Genetic Evaluation of Rice, IRRI.

In tables, a single asterisk (*) means a 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 program. To use it, bend the book slightly and follow the margin index to the page with the black edge marker.

Abbreviations and acronyms

AC = amylose content
AE = Agricultural Engineering Division
ai = active ingredient
AIRAT = African Irrigated Rice Advanced Trial
AIRON = African Irrigated Rice Observational Nursery
AIRPSS = African Irrigated Rice Preliminary Screening Set
APA = Agronomy, Physiology, and Agroecology Division
ARBN = African Rice Blast Nursery
ARFSN = Asian Rice Farming Systems Network
ARLESS = African Rainfed Lowland Rice Evaluation and Screening Set
ASL = Analytical Service Laboratories
AURAT = African Upland Rice Advanced Trial
AURPSS = African Upland Rice Preliminary Screening Set
AUYT = Acid Upland Yield Trial

BB = bacterial blight
BGA = blue-green algae
Bl = blast
BLS = bacterial leaf streak
BM = barnyard manure
BNF = biological nitrogen fixation
BPH = brown planthopper
BRIARC = Bicol Regional Integrated Agricultural Research Center
BRRI = Bangladesh Rice Research Institute

CABO = Center for Agrobiological Research
CIAT = International Center for Tropical Agriculture
CIMMYT = International Maize and Wheat Improvement Center
CIRP = Cambodia-IRRI Rice Project
CLSU = Central Luzon State University
CMC = critical moisture content
CMS = cytoplasmic male sterile (sterility)
CNPAF = Centro Nacional de Pesquisa—Arroz, Feijão
CP = coupling points
CPS = Communication and Publications Services
CRF = Central Research Farm
CSIRO = Commonwealth Scientific and Industrial Research Organization
CT = cold tolerance

DAD = days after draining
DAS = days after sowing (seeding)
DAS-ELISA = double antibody sandwich enzyme-linked immunosorbent assay
DE = days after emergence
DH = doubled haploid
DLA = diseased leaf area
DNA = deoxyribonucleic acid
DRT = drought score
DS = dry season
DSI = disease severity index
DSR = direct seeded rice, dry seeded rice
DSSAT = Decision Support System for Agrotechnology Transfer
DT = days after transplanting
DWR = deepwater rice
DWT = dry-to-wet transition period

E = Entomology Division
EC = electrical conductivity
ELISA = enzyme-linked immunosorbent assay
ELON = elongation
ESL = English as a Second Language
ET = evapotranspiration

FLOD = flooding
FMP = fused magnesium phosphate
FSR = farming systems research
FYM = farmyard manure

GA_3 = gibberellic acid
GC = gel consistency
GCA = general combining ability
GEU = genetic evaluation and utilization
GIS = Geographic Information Systems
GLD = glume discoloration
GLH = green leafhopper
GM = green manure
GRC = Genetic Resources Center
GT = gelatinization temperature

HI = harvest index

ICAR = Indian Council of Agricultural Research
ICLARM = International Center for Living Aquatic Resources Management
IDRON = International Deepwater Rice Observational Nursery
IDRYN = International Deepwater Rice Yield Nursery
IFDC = International Fertilizer Development Center
IIRON = International Irrigated Rice Observational Nursery
IIRYN-E = International Irrigated Rice Yield Nursery-Early
IIRYN-M = International Irrigated Rice Yield Nursery-Medium
IIRYN-VE = International Irrigated Rice Yield Nursery-Very Early
INGER = International Network for Genetic Evaluation of Rice
INSURF = International Network on Soil Fertility and Sustainable Rice Farming
IPM = integrated pest management
IPMO = International Program Management Office
IRALON = International Rice Acid Lowland Observational Nursery
IRAT = Institute for Research in Tropical Agriculture
IRBBN = International Rice Bacterial Blight Nursery
IRBN = International Rice Blast Nursery
IRBPHN = International Rice Brown Planthopper Nursery
IRCTN = International Rice Cold Tolerance Screening Nursery
IRDTN = International Rice Drought Tolerance Screening Nursery
IRG = irrigated environment
IRGC = International Rice Germplasm Center
IRGDB = International Rice Genealogy Data Base
IRGMN = International Rice Gall Midge Nursery
IRLYN-E = International Rainfed Lowland Rice Yield Nursery-Early
IRLYN-M = International Rainfed Lowland Rice Yield Nursery-Medium
IRSBN = International Rice Stem Borer Nursery
IRSTON = International Rice Salinity Tolerance Observational Nursery
IRTN = International Rice Tungro Nursery
IRUN = International Rice Ufra Nursery
IRWBPHN = International Rice Whitebacked Planthopper Nursery
ITRON = International Tidal Wetland 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

LAN = Local Area Network
LEU = land equivalent unit
LF = leaffolder
LSS = Literature Search System
LT_{50} = time required to kill 50% of population exposed to a constant lethal temperature
LTFE = long-term fertility experiments

MAALs = monosomic alien addition lines
MAC = maximum allowable concentration
MARDI = Malaysian Agricultural Research and Development Institute
MBPS = modified bulk pedigree selection
MC/ha = million culms per hectare
MDH = malate dehydrogenase
MLO = mycoplasma-like organism
MNU = mutagen N-methyl-N-nitrosourea
MS = Murashige Skoog
MV = modern variety

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NAA = naphthalene acetic acid
NARC = National Agricultural Research Center
NARS = national agricultural research systems
NBS = narrow brown spot
NCP = noncapsid protein
NILs = near-isogenic lines
NRD = Noakhali Rural Development Project
NSSL = National Seed Storage Laboratory

ORSTOM = Institut Français de la Recherche Scientifique pour le Developpement en Cooperation

PACC = Publications and Communication Committee
PBGB = Plant Breeding, Genetics, and Biochemistry Division
PBH = plowing, broadcasting, harrowing
PBI = panicle blast
PCR = polymerase chain reaction
PGD = phosphogluconate dehydrogenase
PGF = Plant Growth Facilities
PGMS = photosensitive genic male sterile (sterility)
PhilRice = Philippine Rice Research Institute
PI = panicle initiation
PMSB = Project Management Services and Biometrics
PNG = Papua New Guinea
PP = Plant Pathology Division
PR = phosphate rock
PRC = Prachinburi Rice Research Center
PRRI = Philippine Rice Research Institute
PRTD = protein, dry season
PRTW = protein, wet season
PS = pedigree selection

RADPC = relative area under the disease progress curve
RAPD = randomly amplified polymorphic DNA
RAVC = returns above variable cost
RFLP = restriction fragment length polymorphism
RG = rate of germination
RGSV = rice grassy stunt virus
RI = recombinant inbred
RLF = rice leaffolder
RRSV = rice ragged stunt virus
RSHT = routine seed health tests
RTBV = rice tungro bacilliform virus
RTD = rice tungro disease
RTD SS = rice tungro disease screening set
RTSV = rice tungro spherical virus
RVA = rapid VISCO analyzer
RWM = rice whorl maggot
RYD = rice yellow dwarf
RYT = rice yield trial

SACCAR = Southern African Center for Cooperation in Agricultural Research
SADCC = Southern African Development Coordination Conference
SAL = salinity
SARIF = Sukarami Agricultural Research Institute for Food Crops
SARP = Systems Analysis and Simulation in Rice Production
SAWAH = Simulation Algorithm for Water Flow of Aquic Habitats
SB = stem borer
SBSD = striped stem borer
SBYD = yellow stem borer
SCA = specific combining ability
SDS-PAGE = sodium dodecyl sulfate polyacrylamide gel electrophoresis
SES = *Standard evaluation system for rice*
ShB = sheath blight
ShR = sheath rot
SHU = Seed Health Unit
SM = Soil Microbiology Division
SMT = soil moisture tension
SR = stem rot
SS = Social Sciences Division
SURIF = Sukamandi Research Institute for Food Crops
SWS = Soil and Water Sciences Division

TC = traditional cultivars
TDM = total dry matter
TDMY = total dry matter yield
TGMS = thermosensitive genic male sterile (sterility)
TPR = transplanted rice
TRL = total root length
TSP = triple superphosphate
TV = traditional variety

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ULV = ultralow volume
UPLB-NAAP = University of the Philippines at Los Baños-National Azolla Action Program
UPRIIS = Upper Pampanga River Integrated Irrigation System
UR = upland rice
URRC = Ubon Rice Research Center
USG = urea supergranule
UV-B = ultraviolet-B

VES = Visayas Experiment Station

WA = wild abortive
WAI = weeks after inoculation
WBPH = whitebacked planthopper
WE = weeks after emergence
WH = whiteheads
WIRFS = Women in Rice Farming Systems
WS = wet season
WSR = wet seeded rice

YCES = Yeongnam Crop Experiment Station
Y/MEP = yield per million emerged plants
Y/MHC = yield per million harvested culms
YSB = yellow stem borer

ZLH = zigzag leafhopper

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Research Programs

Research programs
Irrigated rice ecosystem

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Irrigated rice ecosystem

Subprogram I: Germplasm improvement

Integrated germplasm improvement

The main focus of this project is to develop improved germplasm with high yield potential, superior grain quality, multiple resistance to major diseases and insects, growth duration of 100-140 d; and to share this germplasm with national programs

During 1991, 587 crosses were made, F_2 populations were grown from 316 crosses, 69,256 pedigree nursery rows were evaluated, and 690 advanced generation lines were tested in replicated yield trials (RYTs).

We evaluated 32 elite breeding lines in lowland rice performance trials of the Rice Varietal Improvement Group of the Philippine Seed Board. About 200 elite breeding lines were evaluated internationally in INGER nurseries. In response to 59 seed requests, IRRI supplied 5,449 seed packets to national program scientists, thus sharing the improved germplasm with numerous national programs.

Yield potential

Development of rice prototypes with higher yield potential is the top priority of this project. The objective is to develop a new plant type with large panicles, sturdier stems, fewer tillers, and thick, dark green leaves. We made 275 crosses aimed at developing the new plant type. Most of the donors for the desired traits are tall and belong to the tropical japonica group. As a first step we are trying to shorten their stature. Initially, our donor for dwarfism was MD2, a short-statured japonica from Madagascar; however, it showed poor combining ability. We are now using Shen Nung 89-366, a short-statured japonica from China, which combines well with tropical japonicas. Short-statured progenies from its crosses are being evaluated in the F_3 pedigree nursery. Some of the progenies have a number of desired traits.

Most of the donors for the new plant type have short bold grains. To develop germplasm of new plant type with long grains, we are using some long-grain japonicas in the hybridization program. The new lines will be evaluated for yield potential in 1993 dry season (DS).

Modified bulk pedigree selection procedure in selecting for yield

During 1990, the modified bulk pedigree selection (MBPS) procedure proved to be a superior method to select for yield potential in rice (Program report for 1990).

In RYTs during DS and wet season (WS), 15 MBPS-derived elite lines (8 short-duration and 7 medium- to long-duration) were compared with check varieties derived by pedigree selection (PS) procedure. The mean yield of the MBPS-derived lines was significantly higher than that of the PS-derived checks in DS, but comparable during WS. During DS, the highest MBPS-derived lines in the two maturity groups yielded 1.0 and 0.4 t/ha more than the two highest yielding checks (Table 1). The results reconfirmed the superiority of the MBPS procedure over the PS procedure in selecting for higher yield potential in rice.

Growth and yield potential of irrigated rice

The grain yield of irrigated rice is influenced largely by solar radiation and N supply, but only N supply can be modified by management. Results from the long-term continuous cropping experiments at IRRI and other Philippine sites indicate that plant N up-

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take constrains rice yields when N fertilizer input levels and timing are heid constant. Evidence for this hypothesis is reported under Systems productivity and sustainable rice systems (p. 34). This constraint will impede efforts to identify and select improved germplasm with greater yield potential because selections are made in field trials at suboptimal growth conditions.

Table 1. Yields of some rice cultivars derived through modified bulk pedigree selection and check varieties bred through pedigree selection. IRRI, 1991.

Cultivar	Yield (t/ha)		
	Dry season	Wet season	Mean
Early group			
IR54790-B-B-38	4.9	4.6	4.8
IR54791-B-B-1	5.0	4.4	4.7
IR54819-B-B-172	5.1	4.4	4.8
IR54819-B-B-226	5.0	4.5	4.7
IR54819-B-B-232	5.2	4.6	4.9
IR58100-B-B-198	5.4	4.6	5.0
IR58125-B-B-44	5.8	4.1	5.0
IR58125-B-B-42	5.6	4.6	5.1
Mean	5.2	4.5	4.9
IR50 (check)	4.4	-	4.4
IR66 (check)	4.8	3.9	4.4
IR72 (check)	4.8	4.8	4.8
PSB4 (check)	-	3.7	3.7
Mean	4.6	4.4	4.5
LSD (0.05)	0.6	0.7	
Late group			
IR54791-B-B-134	5.5	4.1	4.8
IR54853-B-B-54	5.3	4.8	5.1
IR54853-B-B-294	5.9	4.6	5.3
IR54896-B-B-85	6.0	4.1	5.1
IR54896-B-B-272	6.0	4.9	5.4
IR58100-B-B-33	5.8	4.7	5.2
IR58125-B-B-6	5.8	4.4	5.1
Mean	5.8	4.5	5.1
IR68 (check)	5.6	4.2	4.9
IR74 (check)	4.9	5.0	5.0
Mean	5.2	4.6	5.0
LSD (0.05)	0.6	0.6	

The seasonal pattern of plant N uptake is governed by 1) the supply of N from soil and applied fertilizer to the root system, and 2) the rate of N uptake by the root system. Our goal in 1991 was to determine the degree to which N uptake by rice could be modified by changing the N supply to the root system, especially from anthesis to physiological maturity.

To test the hypothesis that present N fertilizer recommendations can result in a deficient late season N supply, a field experiment in 1991 WS compared the recommended N application practice (2/3 of the total applied basally and 1/3 at panicle initiation [PI]) with an N management strategy that more evenly distributes N supply: three split applications from transplanting to PI and an additional application at anthesis (Table 2). With the increase of 30 kg N/ha in the multisplit N fertilization treatment, yields increased by 0.5 t/ha for IR72 and 0.9 t/ha for IR58109-113-3-3-2. The increases are equivalent to a marginal agronomic efficiency of 17 (IR72) and 30 (IR58109-113-3-3-2) kg rice per kg of N applied above the recommended dose. The increases were closely associated with greater flag leaf N concentration during grain filling and with longer duration of grain filling (Table 2). Regression of grain yield on flag leaf N concentration 7 d after anthesis indicated that yield was closely associated with the N status of the flag leaf (r^2 = 0.94 for IR72, r^2 = 0.88 for IR58109-113-3-3-2, n = 12).

Because the flag leaf is a primary source of assimilates for grain filling and net C assimilation in the flag leaf is largely determined by N content, the results suggest that the additional N applied at anthe-

Table 2. Effect of timing and quantity of applied N on flag leaf N content 7 d after anthesis and yield of short-duration IR72 and medium-duration IR58109-113-3-3-2. IRRI, 1991 wet season (WS).

N (kg /ha) input and timing					Variety	Duration of grain filling (d)	Flag leaf N concentration (%) 7 d after anthesis	Grain yield (t/ha)
Basal	Mid-tiller	PI[a]	Anthesis	Total				
0	0	0	0	0	IR72	25	2.05 c	3.8 c
50	0	30	0	80[b]	IR72	28	2.34 b	4.8 b
30	20	30	30	110	IR72	28	2.63 a	5.3 a
0	0	0	0	0	IR58109-113-3-3-2	23	1.99 c	4.1 c
50	0	30	0	80[b]	IR58109-113-3-3-2	26	2.19 b	5.2 b
30	20	30	30	110	IR58109-113-3-3-2	29	2.63 a	6.1 a

[a]Panicle initiation. [b]Presently recommended N timing and quantity.

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sis was the dominant factor contributing to the yield of the multisplit N treatment. Likewise, the higher response of the long-duration IR58109-113-3-3-2 to the additional N applied at anthesis may reflect the greater N demand of long-duration genotypes, which accumulate more dry matter during the longer vegetative growth phase. Greater vegetative biomass requires greater total N uptake to maintain leaf photosynthesis, and late-maturing genotypes depend on indigenous soil N for a longer period than do early-maturing varieties.

To test our hypotheses, we are evaluating seasonal dry matter and N accumulation patterns. Work plans for 1992 include more field experiments at IRRI and at PhilRice in Central Luzon as a follow-up to this initial study. The work will also contribute to an understanding of the fundamental processes that govern the growth and yield potential of irrigated rice. The knowledge can be used to improve existing simulation models and facilitate their use in identifying plant characteristics that are most important for increasing the yield potential of modern rice genotypes. The work can lead to improved N management strategies based on a dynamic concept of the N supply environment, which is quantified by the N supply from indigenous soil resources and applied fertilizer, and by plant N demand determined by the rate of dry matter accumulation, dry matter partitioning, and grain yield.

Grain quality

Aromatic rices are prized in most rice-growing countries. They command higher prices in domestic as well as international markets. Aromatic rices are characterized by intermediate amylose content (AC) and gelatinization temperature (GT) and soft gel consistency. During cooking, the grains of Basmati rices of India, Pakistan, and Afghanistan and of Sadri rices of Iran elongate to twice their uncooked length. Very few improved aromatic varieties have been developed and farmers continue to grow tall traditional aromatic rices to meet the demand. The higher price these varieties command compensates for their low productivity.

During the last several years we have attempted to improve the yield potential of Basmati rice while retaining its cooking characteristics. Progress has been slow because intervarietal hybrids are frequently sterile and a full spectrum of recombinants is not available in such crosses. However, we now have breeding lines that approach Basmati varieties in grain quality and have short stature (Table 3). These lines are being evaluated for yield potential.

Disease resistance

IRRI has always placed high priority on the incorporation in the elite germplasm of durable resistance to major diseases, especially blast (Bl), bacterial blight (BB) and rice tungro disease (RTD).

Evaluation of partial resistance to rice blast. Enhanced durability of host resistance to Bl is apparently associated with the combination of broadly effective qualitative resistance that is controlled by one or more major genes, and a high level of partial resistance. The efficiency and stability of partial resistance, however, should be assessed under a wide range of environments and with diverse populations of *Pyricularia grisea*. The presence of a

Table 3. Improved breeding lines with aroma and grain elongation.

Breeding line	Growth duration (d)	Amylose content (%)	Gelatinization temperature[a]	Grain elongation ratio
IR61972-111-2-1	115	23	L	1.80
IR62100-136-3	110	23	I	1.85
IR62871-13-3-2	120	22	L	1.90
IR62871-175-1-1	120	23	I	2.00
IR62871-275-2-6	125	23	L	1.95
IR62871-354-2-5	122	22	L	2.00
IR62873-214-3-3	115	22	L	1.90
IR62873-227-1-2	120	22	L	1.85
IR62873-278-4-3	115	21	L	2.00
IR62873-417-4-10	115	23	I	2.10
IR62898-20-3-2	120	23	L	2.00
Basmati 370 (check)	125	21	I/L	2.20

[a]I = intermediate, L = low.

highly adapted aggressive strain or an unusually high frequency of compatible isolates would affect the stability and efficiency of partial resistance.

In an upland miniplot, 26 cultivars with low disease severity index (DSI) and 6 with high DSI in the International Rice Blast Nursery (IRBN) were evaluated for Bl resistance relative to the partially resistant check IR36 and the susceptible check IR50. The experiment was in a randomized complete block design with four replications. Each entry was inoculated initially by transplanting naturally infected plants of the same entry in the Bl nursery. The percentage of affected leaf area was visually assessed 30 d after seeding.

All but five rice cultivars with low DSI had damage less than or equal to that of IR36, regardless of the frequency of incompatible reaction (0-3) by the *Standard evaluation system for rice* (SES) (Table 4). However, IR56 showed extremely high susceptibility although its DSI in IRBN is similar to that of IR36. This suggests the presence of one or more highly aggressive isolates adapted to IR56. All cultivars with high DSI were highly susceptible. Cultivars with low DSI in IRBN may be used in preliminary selection of cultivars with high partial resistance.

Selective increase of an aggressive strain of *P. grisea* and its effect on the stability of partial resistance need to be studied further.

We evaluated 48,491 pedigree nursery rows for durable resistance to Bl in 1991. F_2 populations were first planted in the Bl nursery. Only the resistant seedlings were transplanted in the field. All the elite lines were evaluated for durable resistance.

Durable resistance to tungro. We have selected improved-plant-type lines with RTD resistance from crosses involving resistance donors such as Habiganj DW8, Utri Merah, ARC11554, and Balimau Putih. Resistance to other diseases and insects is being incorporated into these lines.

Inheritance of resistance to tungro. We studied the inheritance of resistance to RTD in Utri Merah (acc. no. 16680), ARC11554 (acc. no. 21473), and ARC12596 (acc. no. 22176). Thirty seedlings (10 d old) in each F_3 or BC_1F_2 population were inoculated for 4 h with 10 viruliferous green leafhopper (GLH) adults/seedling. Leaves were individually sampled 2 wk after inoculation to test by enzyme-linked immunosorbent assay (ELISA) for infection with rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV).

Table 4. Varieties with blast infection compared with that of IR36 in an upland miniplot.[a] IRRI, 1991.

Group[b]	Lower infection		Similar infection		Higher infection	
	Variety	Affected leaf area (%)	Variety	Affected leaf area (%)	Variety	Affected leaf area (%)
Low DSI (≤ 5.6) and high FI (≥ 60%)	IR64	5.0	IR35410-16-3-2-2-2-2	25.0	INIAP 415	32.5
	IR32844-17-3-3-1	7.5	IR42	25.8		
	Kataktara DA 2	11.0	IR36	26.3		
	IR60	14.3	IR9761-19-1	31.3		
	IR22103-26-6-2	17.0				
	BG379-2	17.3				
	Samgangbyeo (Milyang 55)	17.5				
Low DSI (≤ 5.6) and low FI (≤ 60%)	IR3880-29	11.0	IR1529-680-3	22.3	IR13539-100-2-2-2-3	34.5
	KMP 34	14.3	BW295-4	23.8	IR25890-85-5-3	36.8
	IR19819-31-2-3	15.3	IR66	26.3	IR56	60.0
	B301613-TB-260-3-2-1-1-3	17.5	HPU5010-PLP21-2-1B	29.3	IR19743-46-2-3-3-2	33.8
	Chianung Si-Pi-661020	18.7	IR27325-63-2-2	30.8		
High DSI (> 5.6) and low FI (< 60%)					IR24	38.3
					HPU 741	38.8
					AD9246	42.5
					IR30	71.3
					IR19793-25-2	82.5
					IR50	86.3

[a]Means of 4 replications. Cultivars in other groups are significantly different from IR36 (P = 0.05). [b]DSI = disease severity index, FI = frequency of incompatible reaction.

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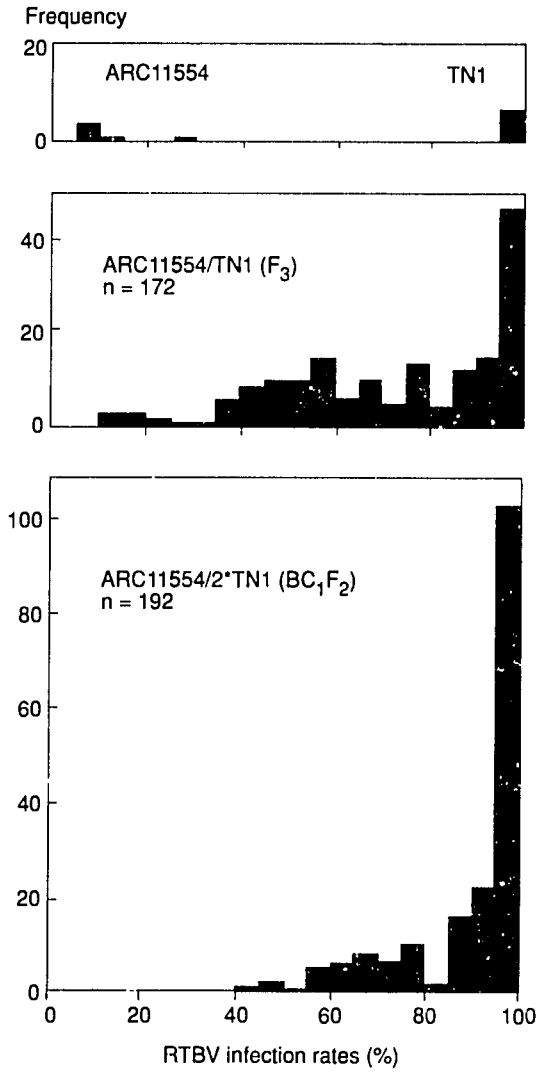
Utri Merah (acc. no. 16680). While Utri Merah may not have resistance to RTBV infection, the infected plants always show low absorbance value with RTBV, suggesting that Utri Merah may be resistant to RTBV multiplication. In the F_3 of Utri Merah/TN1, the segregation mode of mean absorbance values fit well the 1:8:7 ratio for resistant, segregating, and susceptible plants (χ^2 = 0.320, 0.80<P<0.90), indicating that resistance to RTBV multiplication in Utri Merah is controlled by two recessive complementary genes. On the other hand, the values for RTSV infection in the same F_3 did not fit 1:3 or 7:9 ratios, but did fit the 6:10 ratio (χ^2 = 0.113, 0.70<P<0.80), suggesting that at least two genes govern the resistance to RTSV infection in Utri Merah. The F_1 plants were susceptible to RTSV infection and therefore the resistance in Utri Merah must be controlled by one or more recessive genes. Similarly, the segregation mode of mean absorbance values to RTSV in the F_3 also fit the 6:10 ratio (χ^2 = 0.050, 0.80<P<0.90), suggesting two-gene segregation. The correlated diagram of the mean absorbance values and infection rates to RTSV showed that the F_3 lines with lower infection rates were not necessarily low in absorbance value, and vice versa. It suggests that the genes for resistance to RTSV infection are not necessarily identical to the genes controlling resistance to RTSV multiplication.

ARC11554. In the F_3 of ARC11554/TN1, the segregation of resistant, segregating, and susceptible lines for RTBV infection fit the 1:8:7 ratio (χ^2 = 0.397, 0.80<P<0.90), indicating that the resistance to RTBV infection in ARC11554 is controlled by two recessive complementary genes (Fig. 1). The BC_1F_2 progenies from the cross ARC11554/2*TN1 segregated in a ratio of 1 resistant:3 susceptible, suggesting two recessive complementary genes. These results agree with those of F_3 analysis, showing that two recessive genes convey resistance to RTBV infection in ARC11554. The histogram of RTSV infection rates of F_3 lines from ARC11554/TN1 showed that the segregation of resistant, segregating, and susceptible lines fit the 12:3:1 ratio (χ^2 = 3.915, 0.10<P<0.20). This indicates two dominant genes with action different from that of genes which confer resistance.

The BC_1F_2 lines of ARC11554/2*TN1 were classified roughly into four groups of RTSV infection rates; their segregation fit the 1:1:1:1 ratio, which is the segregation ratio of two genes with additive effect in BC_2F_1. Therefore, resistance to RTSV infection in ARC11554 is controlled by two dominant genes that have an additive effect. The lines resistant to RTBV infection always showed resistance to RTSV infection, but the converse was not always true. This suggests that the resistance to RTBV infection in ARC11554 is epistatic to the resistance to RTSV infection.



1. Histogram of RTBV infection rates in ARC11554/TN1 F_3 lines and in ARC11554/2*TN1 BC_1F_2 lines.

ARC12596. ARC12596 is resistant to RTSV infection but susceptible to RTBV infection. In the F_3 of ARC12596/TN1, the segregation of resistant, segregating, and susceptible lines for RTBV infection fit well the ratio of 1:3:12 (χ^2 = 0.343), suggesting that ARC12596 may have a resistance gene and

an inhibitory gene. The resistant F_3 lines might come from recombinants with the resistance gene but without the inhibitory gene. The segregation for RTSV infection of resistant, segregating, and susceptible lines fit the ratio of 1:2:1 (χ^2 = 5.074), indicating that resistance to RTSV infection in ARC12596 is controlled by a single gene.

Development of isogenic lines for tungro resistance. Isogenic lines are useful for identifying races or strains of virus, for studying the mechanism for resistance, and for tagging resistance genes with restriction fragment length polymorphism (RFLP) markers. Genes for resistance from different donors are being transferred to the genetic background of TN1 and IR22, both of which are highly susceptible to RTD. Our most advanced generation is BC_6F_1. The homogeneity of these lines for RTD resistance will be tested in the BC_6F_2 and BC_6F_3.

Mutation breeding for tungro resistance. To induce mutations for RTD resistance, susceptible varieties IR22 and IR64 were treated with the chemical mutagen N-methyl-N-nitrosourea (MNU). IR22 was also treated with sodium azide. The M_2 and later generations of all lines have been screened for RTD resistance in the field.

In 1990, 2,640 M_2 lines from IR22 treated with MNU were transplanted in the field and 124 M_2 lines were selected. Of 124 M_3 families, 107 were tested in the same field and 6 lines from one family were selected as highly tolerant of tungro.

Selected M_4 lines and an additional 17 families (M_3) were planted in the field in February 1991. Although the M_4 lines did not show good resistance to RTD, 1 of 17 M_3 families did. To confirm the resistance, the progeny lines of the resistant M_3 family were planted in the field in July 1991. These M_4 lines showed good resistance to RTD in the field.

The leaves of resistant plants were tested with ELISA to check for infection. Most samples were not infected with RTBV and were resistant to RTSV infection (Table 5). To check whether the RTD resistance in each M_4 line depends on vector resistance, we performed the antibiosis test for GLH. The lines' reactions to GLH varied from low to high levels of antibiosis. After comparing the results of ELISA and antibiosis tests, we selected plants that were resistant to RTD but susceptible to GLH. Using the M_4 seeds, we retested the selected M_4 lines by artificially inoculating them in the laboratory (Table 5). The laboratory results did not coincide with those

Table 5. Reaction of mutant lines to RTD[a] in the field and in the laboratory. IRRI, 1991.

Line and variety[b]	Pedigree	Field, 1991 WS				Inoculation in laboratory			
		Plants tested (no.)	B+S	B	S	Plants tested (no.)	B+S	B	S
M4 453	124-1-2	24	5	0	19	28	4	78	0
M4 455	124-1-4	18	0	0	11	27	4	85	0
M4 456	124-1-5	19	0	0	26	25	0	80	0
M4 457	124-1-7	20	0	0	10	12	0	92	0
M4 458	124-1-8	23	0	0	17	12	8	75	8
M4 460	124-1-10	22	0	0	23	16	6	94	0
M4 461	124-1-11	24	0	0	25	13	8	85	0
MK2 3	1-6	24	4	17	4	26	27	73	0
MK2 4	1-10	24	0	13	8	23	4	83	0
MK2 6	2-5	22	0	27	5	17	0	82	0
MK2 7	2-10	24	0	17	0	29	14	76	0
MK2 8	2-11	24	4	8	33	29	10	83	0
IR22	Original	24	88	4	4	30	43	53	0
TN1	Susceptible check	20	95	0	5	30	85	15	0
ARC11554	Resistant check	20	5	10	0	30	0	15	0

[a]B = RTBV, S = RTSV. [b]M4 453-461 = M_4 generation from IR22 treated with MNU, MK2 3-8 = M_3 generation from IR22 treated with NaN_3.

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from field-grown plants—all M_4 lines with no RTBV infection in the field showed susceptibility in the laboratory. We are now studying the reasons for the discrepancy. If the resistance in these mutant lines is expressed only after transplanting, these lines may have adult plant resistance and may not be resistant at the seedling stage.

The M_2 lines from IR22 treated with sodium azide were also tested for RTD resistance in the field at IRRI and six plants from two M_2 lines were selected. The six progeny lines and one bulk line were retested in the field. The M_3 lines showed segregation for RTD resistance and for morphological traits. They also differed in reaction to RTBV in the field and in the laboratory (Table 5).

More than 5,000 M_2 lines from IR64 treated with N-methyl-N-nitrosourea were planted at the Phil-Rice experiment station in Midsayap, Mindanao. In Mindanao, IR64 has been highly susceptible to RTD since 1988. Eighty-four M_2 plants were selected visually and samples of three leaves from each selected plant were tested by ELISA. All leaves were found to be infected with both RTBV and RTSV. Thus, the mutants may be highly tolerant of RTD. The plants with relatively low ELISA data will be used for progeny testing to confirm the resistance to RTD virus multiplication.

Insect resistance

We continued to evaluate early generation as well as elite lines for resistance to three biotypes of brown planthopper (BPH) and to GLH. Elite lines were also evaluated for resistance to the yellow stem borer (YSB). Data in Table 6 show that most of our breeding materials are resistant to BPH and GLH and some have resistance to YSB.

Cold tolerance

During the 1991 DS in Banaue, Ifugao (950 m above sea level), we tested the yielding ability of advanced breeding lines with high cold tolerance at seedling stage and moderate tolerance at reproductive stage. We conducted two RYTs with 40 lines and the local variety Pinidua as the check. The daily average temperature during the first 4 mo of the crop was below 20 °C. Soil at the test location is deficient in N, P, and Zn but only N (25 kg/ha) was added (4 wk after transplanting).

All test entries flowered 3 wk earlier than the check and matured before the onset of WS, thus indicating their high level of cold tolerance during seedling and vegetative stages. Because Pinidua lodged into standing water due to heavy rains during ripening, we could not estimate its yield. Therefore, yields were compared with test entry IR8866-30-3-1-4-2 (IR8866), a cold-tolerant, high-yielding line developed at IRRI several years ago. Yields of 30 test lines were not significantly different (at the 5% level) from that of IR8866. Considering plant height, grain quality, and reaction to Bl, 16 of the 30 lines were selected for distribution to some national programs and nomination to the International Rice Cold Tolerance Nursery (IRCTN) of INGER. Table 7 lists some agronomic characteristics of the lines.

Elite breeding lines

During DS and WS, 690 elite breeding lines were evaluated in RYTs at IRRI. They were also evaluated for grain quality, disease and insect resistance, and tolerance for abiotic stresses. Thirty-two promising lines were evaluated in RYTs at 10 Philippine locations as part of multilocation trials conducted by the Philippine Seed Board. Some of the most promising lines are characterized. All are resistant to Bl, BB, GLH, and three biotypes of BPH and have field tolerance for RTD.

- IR50404-57-2-2-3 is one of the earliest maturing lines—its growth duration is 105 d. It has shown superior performance in the Philippine Seed Board trials and in the INGER nurseries. This line has

Table 6. Breeding materials evaluated for resistance to BPH, GLH, and YSB. IRRI, 1991.

Insect	Pedigree lines		Advanced lines	
	Tested (no.)	Resistant (%)	Tested (no.)	Selected (%)
Brown planthopper				
Biotype 1	6,472	42.2	1,855	94.3
Biotype 2	19,735	85.7	1,849	78.4
Biotype 3	21,545	83.6	1,847	76.6
Green leafhopper	59,450	53.8	1,859	51.9
Yellow stem borer	-	-	1,135	31.4

Table 7. Some agronomic traits of cold-tolerant lines selected from replicated yield trials. Banaue, Philippines, 1991 dry season (DS).

Designation	Culm ht (cm)	Days to flowering	Panicles (no./hill)	Yield (t/ha)	
				Trial I	Trial II
IR52410-B-B-B-6-1-1-2	71	126	22		5.3
IR52418-B-B-B-6-2-1-3	69	131	16		4.6
IR54465-B-B-3-2-2-2	76	128	11		5.3
IR55259-B-B-3-3-2-2	76	132	16	4.9	
IR55274-B-7-3-3	71	131	19	5.9	
IR57080-B-B-12-2-1	102	125	11		5.5
IR57094-B-B-6-2-3-2	66	129	15		4.2
IR57096-B-B-7-2-1-2	77	127	12		4.1
IR57098-B-B-10-2-3-1	63	124	15		4.6
IR57107-B-B-20-1-2-2	89	132	8		
IR58614-B-B-5-3	78	130	8	5.9	
IR58614-B-B-6-2	81	129	14	6.1	
IR58614-B-B-8-2	84	129	18	6.1	
IR58614-B-B-20-1	86	129	15	6.1	
IR59480-B-B-8-1	72	126	16	4.8	
IR59486-B-B-11-3	68	128	18	4.9	
IR8866-30-3-1-4-2	72	131	17	4.8	4.3
Pinidua[a] (local check)	140	153	7	-	-

[a]Lodged prior to harvest time.

long slender, and translucent grains with high AC and low GT.

- IR56450-4-2-2 is a high-yielding line that matures in 110 d. It has long slender grains with intermediate AC and GT.
- IR54883-152-3-3 is an elite line that matures in 105 d. It has long slender and translucent grains with intermediate AC and GT.
- IR56381-139-2-2 is an elite line that matures in 110 d. It has excellent long slender grains with intermediate AC and GT.
- IR57301-195-3-3, an elite line, matures in 115 d. It has long slender and translucent grains with intermediate AC and GT.
- IR51672-62-2-1-1-2-3, an elite line, matures in 125 d and has very slow leaf senescence. It has well-exserted panicles with long slender and translucent grains. It has intermediate AC and GT.
- IR51678-93-2-2-2-1 is an elite line with medium growth duration (130 d). It has large panicles and long, slender, translucent grains with intermediate AC and GT.

IRRI LINES NAMED VARIETIES

In 1991, 14 IRRI breeding lines from the irrigated breeding program were given varietal names in seven countries (Table 8), bringing to 225 the number of IRRI lines named as varieties worldwide.

Table 8. Irrigated rice breeding lines released as varieties in 1991.

Breeding line	Name given	Country where released
IR32809-26-3-3	PSBRc 2	Philippines
IR41985-111-3-2-3	PSBRc 4	Philippines
IR19274-26-2-3-1-2	Xiangwanxian	China (Hunan)
IR19661-131-1-3-1-3	Barumun	Indonesia
IR32453-20-3-2-2	IR74	Indonesia
IR29723-3-2-1	MTL 83	Vietnam
IR39323-110-5-2-2	MTL 85	Vietnam
IR32307-107-3-2-2	IR66	Vietnam
IR28224-3-2-3-2	IR68	Vietnam
IR35366-90-3-2	IR72	Vietnam
IR19728-9-3-2-3-3	MTL 61	Vietnam
IR13240-108-2-3	Theedatyin	Myanmar
IR9224-117-2-3-3	Shwe Thwe Yin	Myanmar
IR841-85-1-1-3	IR841	Brunei

- IR32809-26-3-3 was released as PSBRc 2 by the Philippine Seed Board. This line matures in 130 d. It has sturdy stems with excellent lodging resistance and high yield potential. It has long slender, translucent grains with high AC and intermediate GT. It is resistant to Bl, BB, GLH, and three biotypes of BPH and has field tolerance for RTD.

Prior to 1990, IRRI breeding lines named by the Philippine Seed Board were released with the IR designation. IR74 was the last IR line so

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designated. Under the new system adopted by the Board, rice varieties are designated as PSBRc followed by a number.

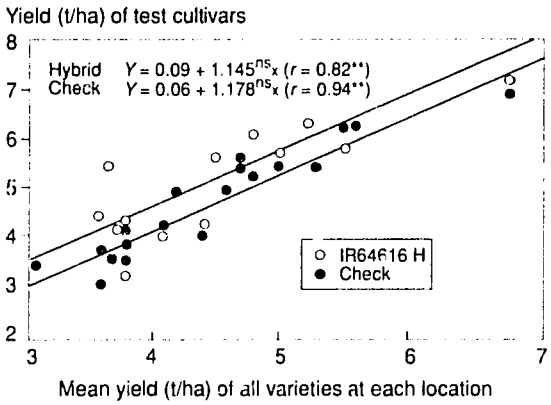
- IR41985-111-3-2-3 was named PSBRc 4 by the Philippine Seed Board. This high-yielding line matures in 105 d. It has long slender, translucent grains with intermediate AC and GT. It is resistant to Bl, BB, GLH, and three biotypes of BPH and has field tolerance for RTD.
- IR19274-26-2-3-1-2 was named Xiangwanxian in Hunan, China. It matures in 100 d at IRRI but 120 d in Hunan. It has long slender, translucent grains and high yield potential.
- IR19661-131-1-3-1-3 was released as Barumun in Indonesia. It matures in 130 d. This line has excellent long slender, translucent grains with high AC and low GT. It is resistant to Bl, GLH, and three biotypes of BPH.
- IR32453-20-3-2-2 was released as IR74 in Indonesia. It was earlier named IR74 in the Philippines where it is now widely grown. This line is particularly suitable for gogorancah (dry seeded) rice culture.
- IR29723-3-2-1 was released as MTL 83 in Vietnam. This line has long, well-exserted panicles, and long slender, translucent grains with high milling recovery. It is resistant to Bl, GLH, and three biotypes of BPH. It attains a height of about 120 cm and has been recommended for rainfed lowland areas where water depth may reach 50 cm.
- IR39323-110-5-2-2 was named MTL 85 in Vietnam. This medium-duration selection has excellent yield potential and long slender, translucent grains. It is resistant to Bl, BB, GLH, and three biotypes of BPH.
- IR32307-107-3-2-2 was released as IR66 in Vietnam. This early-maturing selection with long slender, translucent grains was earlier named IR66 in the Philippines.
- IR28224-3-2-3-2 was named IR68 in Vietnam. It had been released under the same name in the Philippines in 1988. It has long slender, translucent grains and is recommended for rainfed lowland areas.
- IR35366-90-3-2, named IR72 in Vietnam, had been released under the same name in the Philippines, Indonesia, and Cambodia. It has very high yield potential, a growth duration of 115 d, and multiple resistance to diseases and insects.
- IR19728-9-3-2-3-3 was released as MTL 61 in Vietnam. This very early-maturing selection has excellent long slender and translucent grains.
- IR13240-108-2-3, named Theedatyin in Myanmar, is early maturing and has excellent yield potential. It was earlier released as MTL 58 in Vietnam, where it is the most widely grown variety in the Mekong Delta.
- IR19224-117-2-3-3, released as Shwe Thwe Yin in Myanmar, had been released as IR50 in the Philippines, Indonesia, and India. This early-maturing selection has excellent long slender grain and is recommended for rice double cropping in Myanmar.
- IR841-85-1-1-3 was released as IR841 in Brunei. It has aromatic grains and a high yield potential. It has been named Jasmine 85 in the USA.

Hybrid rice

The hybrid rice project aims to increase rice yield potential in the tropics and subtropics through exploitation of hybrid vigor. During 1991, 1) several IRRI-bred rice hybrids were tested in some national agricultural research systems (NARS), 2) the search for new cytoplasmic male sterile (CMS) and restorer lines for developing new hybrids was continued, 3) some additional guidelines for hybrid rice seed production technology for the tropics were developed, 4) the *Manual for hybrid rice seed production* was prepared for publication at IRRI, and 5) training courses were held at IRRI and in NARS to transfer hybrid seed production technology.

Performance of IRRI rice hybrids

Two IRRI-bred rice hybrids—IR64616 H and IR64685 H—were evaluated during national coordinated trials in the Philippines. IR64685 H was a new hybrid, while IR64616 H was evaluated for the second consecutive season. With results from the 1990 WS and 1991 DS trials, the regression of yields of hybrid IR64616 H and check rice cultivars was calculated over an environment index, represented by the mean yield of all cultivars at each location. The check cultivar was IR57301-195-3-3 in the 1990 DS and IR72 in the 1991 DS. For drawing the regression line, the two checks were considered as one. The hybrid tended to yield more than the check cultivars in both low-yielding and high-yielding environments (Fig. 2); however, the hybrid's devia-



2. Regression of yield of hybrid and inbred check on location mean yield in National Coordinated Trials (NCT) of irrigated rice cultivars in the Philippines (source: PhilRice, NCT, Rice Varietal Group, 1990 wet season [WS], 1991 dry season [DS]).

tion from the regression slope appeared to be higher than that of the checks, indicating its instability. The instability may be attributed to the agronomic management bias in trials that are usually designed to evaluate inbred rice cultivars. In this context, it is important to compare the agronomic management of rice hybrids and of inbred rices.

Results from India and Malaysia also indicated yield superiority of IRRI-bred rice hybrids IR64616 H and IR64615 H over local checks at certain locations and fertility levels (Table 9).

Several other experimental rice hybrids also yielded significantly more than check varieties in preliminary yield trials at IRRI during 1991 (Table 10).

Identifying maintainers and restorers among elite lines

To identify maintainers and restorers, we testcrossed about 900 elite rice cultivars originating from IRRI and several from NARS with CMS lines IR62829 A and IR58025 A, which have wild abortive (WA) cytoplasm, and IR66707 A, which has *O. perennis* cytoplasm. For irrigated and rainfed lowland ecosystems, the frequency of maintainers for WA CMS lines continued to be low (2-4%) among lines bred at IRRI and NARS (Bangladesh, Brazil, Colombia, India, Indonesia, Malaysia, Philippines, Sri Lanka, and Thailand). But maintainer frequency was high (36%) among lines bred at IRRI for upland ecosystems. The higher frequency of maintainers among upland rice breeding lines may be due to extensive use of tropical japonica germplasm in developing

Table 10. Promising experimental rice hybrids identified in preliminary yield trials. IRRI, 1991.

Hybrid and check	Maturity (d)	Yield (t/ha)
1991 DS		
IR62829 A/IR35366-62-1-2-2-3 R	112	4.7
IR62829 A/IR34631-123-2-3 R	114	4.9
IR58025 A/IR54742-11-1-9-15-2	112	4.7
IR58025 A/IR35366-62-1-2-2-3 R	112	4.7
IR62829 A/IR44675-101-3-3-2-4 R	110	4.5
IR50 (check)	112	4.0
PSB4 (check)	106	4.0
LSD (0.05)		0.5
(0.01)		0.6
IR58025 A/IR54745-2-45-3-2-4 R	122	5.4
IR58025 A/IR39323-182-2-3-3 R	126	4.9
IR68 (check)	126	4.2
LSD (0.05)		0.6
(0.01)		0.8
1991 WS		
IR58025 A/IR19058-107-1 R	113	6.4
IR50404-57-2-2-3 (check)	112	5.2
PSB4 (check)	111	4.5
LSD (0.05)		0.6
(0.01)		0.8
IR62829 A/IR47310-94-4-3-1 R	120	5.1
IR70 (check)	129	4.0
IR68 (check)	132	3.1
LSD (0.05)		0.7
(0.01)		1.0

Table 9. Yield of promising IRRI-bred rice hybrids and local check varieties. India and Malaysia, 1991 DS.

Hybrid and check	Yield (t/ha)					
	India			Malaysia		
	Mandya	Hyderabad	Maruteru	With 90-30-30 kg NPK/ha	With 180-60-30 kg NPK/ha	Mean
IR64615 H	7.1	6.2	4.4	5.1	5.5	5.7
IR64616 H	6.4	6.4	5.1	4.1	4.2	5.2
Local check	5.7[a]	5.3[b]	5.5[c]	4.2[d]	4.1[d]	5.0
LSD (0.05)	0.9	1.0	ns	1.0	0.7	

[a]Jaya. [b]Rasi. [c]IR64. [d]MR84.

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such lines. Among IRRI-bred lines for irrigated and rainfed lowland ecosystems, maintainer frequency was so high (92-94%) for CMS line IR66707 A (*O. perennis* cytoplasm) that not a single restorer was identified among 173 lines testcrossed for the purpose. For WA CMS lines, however, there was no dearth of restorers; we identified 330 restorers among 718 elite lines originating from IRRI and NARS.

To enhance maintainer frequency for WA cytoplasm among elite lines bred at IRRI, a maintainer breeding program was initiated in 1989. We selected 277 promising lines during 1991 to testcross with CMS lines which have WA cytoplasm. About 70% of these lines were found to be maintainers, and are being used for the CMS line conversion program. The results demonstrate the importance of breeding maintainers for a hybrid rice breeding program in the tropics.

Inducing thermosensitive genic male sterile mutants in indica rice

Thirty-three male sterile mutants were isolated in the M_2 of seven rice cultivars: IR46 R, IR64 R, IR72 R, IR62829 B, IR54752B, IR32364-20-1-3-2 B, and BG90-2. Clones of some of these mutants were subjected to different daylengths (10 and 14 h, using the screenhouse darkroom facilities of the Agronomy, Plant Physiology, and Agroecology Division) and three temperature regimes (32/24 °C, 27/21 °C, 24/18 °C in the phytotron). The spikelet sterility of some mutants was reduced by 1-14% under certain daylength and temperature treatments. Hence, these were suspected as thermosensitive genic male sterile (TGMS) and/or photosensitive genic male sterile (PGMS) mutants. Seeds harvested from suspected TGMS and PGMS M_2 mutants from IR62829 B, IR54752 B, and IR32364-20-1-3-2 B were used to raise M_3 plants. At tillering stage, each plant was divided into 2-3 parts and tested under two daylengths and three temperature regimes during April-May 1991. Results (Table 11) showed differential responses to temperature treatments for pollen and spikelet fertility of M_3 plants derived from clone 31 of IR32364-20-1-3-2 B. Other clones of IR32364, IR62829 B, and IR54752 B did not conform with their M_2 behavior. Clone 31 of IR32364-20-1-3-2 B

Table 11. Behavior of M_3 male sterile mutant progenies raised from seeds borne on suspected M_2 - PGMS and TGMS lines. IRRI greenhouse-phytotron, Mar-May 1991.

Genotype	M_2	M_3	Pollen or spikelet[a] fertility (%)					Remarks[b]
			Daylength (h)		Temperature (°C)			
			10	14	24/18	27/21	32/24	
IR62829 B	PGMS and TGMS	1-1	26.3 (10.4)	33.5 (29.2)	50.0 (5.6)	76.5 (17.5)	63.5 (54.4)	None
		1-2	43.8 (3.2)	55.1 (11.9)	- (21.3)	44.4 (15.5)	54.4	
		1-3	65.5 (0)	-	11.1 (0)	58.0 (10.8)	77.1 (19.5)	
		1-4	47.8 (27.8)	69.1 (27.8)	6.6 (0)	75.6 (31.6)	61.5 (77.0)	
		1-5	72.9 (15.0)	91.3 (28.4)	76.0 (30.1)	43.0 (10.5)	-	
IR54752 B	PGMS	6-1	49.0 (13.6)	60.7 -	49.6 (40.0)	69.3 (27.2)	66.0 (57.0)	None
		6-2	31.3 (18.2)	47.5 (24.7)	2.9 (15.9)	43.9 (8.6)	55.5 (28.3)	
IR32364-20-1-3-2 B	PGMS	26-1	0 (0)	0 (0)	75.4 (57.7)	60.2 (22.1)	83.5 (46.7)	
		26-2	28.3 (0)	30.3 (0)	11.3 (0)	52.8 (8.9)	5.7 (0)	TGMS
	PGMS and TGMS	31-1	0 (0)	0 (0)	23.7 (10.7)	29.7 (2.0)	0 (0)	TGMS
		31-2	1.6 (0)	0 (0)	26.2 (4.3)	54.4 (5.1)	0 (0)	
		31-3	28.9 (0)	0 (0)	37.5 (2.7)	60.6 (0)	7.2 (0)	
		31-4	6.0 (0)	0 (0)	-	38.4 (0.68)	28.9 (0)	

[a]Figures in parentheses are for spikelet fertility. [b]Blank space indicates no data. "None" means that the M_3 line was neither PGMS nor TGMS.

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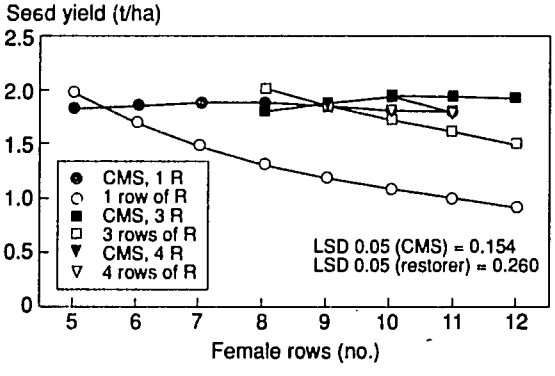
was, therefore, designated as a TGMS mutant. Seeds produced on M_3 plants of this mutant are being multiplied in the phytotron at 27/21 °C for field evaluation in different countries.

Female:male ratio and hybrid seed yield

An experiment involving CMS lines IR58025 A and IR62829 A, and the restorer IR29723 R as pollinator was conducted during 1991 DS in a split-plot design. Genotypes were in the main plot and varying female:male ratios (1-12:1, 1-12:2, 1-12:3, and 1-12:4) were in the subplots, replicated three times.

Seed yield was computed for all the row ratios (A:R) ranging from 1:1 to 12:4 for both CMS lines. In IR58025 A, row ratios 5:1 to 11:1, 8:3 to 12:3, and 10:4 to 11:4 gave seed yields of 1.8-2.0 t/ha, which were significantly higher than those for the other row ratios. In IR62829 A, row ratios 4:1 to 12:1, 6:2 to 12:2, 7:3 to 12:3, and 7:4 to 12:4 gave significantly higher yields (1.1-1.3 t/ha) than the other row ratios. Restorer yield ranged from 0.9 t/ha in 12 A:1 R to 5.9 t/ha in 1 A:1 R in the IR58025 A/IR29723 R combination, and from 1.0 t/ha in 12 A:1 R to 6.6 t/ha in 1 A:1 R in the IR62829 A/IR29723 R combination. The highest yield (1.95 t/ha) of CMS line IR58025 A was obtained with a row ratio of 11:3, followed by 1.93 t/ha with row ratio 10:3 (Fig. 3). As the yield of the restorer line was higher by 0.17 t/ha in the 10:3 ratio than the 11:3 ratio, we conclude that the 10:3 ratio is the most economical for hybrid seed production involving IR58025 A. Similar results were obtained with IR62829 A.

Interestingly, the 1:1 row ratio gave a hybrid seed yield of 0.6-0.8 t/ha with a restorer yield of 5.9-6.5 t/ha. These results need further confirmation.

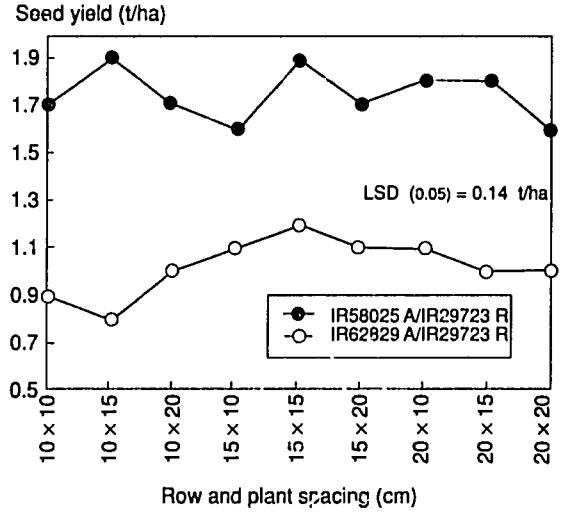


3. Effect of row ratio on seed yield of CMS IR58025 A and restorer IR29723 R.

Effect of plant density on outcrossing rate and hybrid seed yield

To evaluate the effect of plant density on outcrossing rate and hybrid seed yield, CMS lines IR58025 A and IR62829 A and the restorer IR29723-143-3-2-1 R as pollinator were transplanted in a 6:2 row ratio using varying row and plant spacings (10, 15, and 20 cm) in CMS lines. The split-plot design (with CMS lines in the main plots and row and plant spacings in the subplots) was used with four replications. We observed seed set percentage and seed yield.

Plant density did not affect the outcrossing rate (34.0-37.3%) in CMS lines. The seed yield increased significantly with increased plant density up to 44.4 hills/m^2 (i.e., 15- × 15-cm row and plant spacings) and thereafter declined (Fig. 4). Seed yields were 1.9 t/ha for IR58025 A and 1.2 t/ha for IR62829 A at 15-cm row and 15-cm plant spacings. Seed yields in other plant and row spacings ranged from 1.60 t/ha to 1.9 t/ha from IR58025 A and 0.9 t/ha to 1.1 t/ha from IR62829 A. The yield of the restorer was significantly higher (2.4 t/ha) from the IR62829A/IR29723 R combination at a plant density of 44 hills/m^2. At other plant densities, the restorer yielded 1.9-2.3 t/ha (except at 100 hills/m^2, which gave 2.4 t/ha). Based on the findings, we recommend a spacing of 15 × 15 cm (44.4 hills/m^2) to obtain high seed yields from the CMS lines.



4. Effect of row and plant spacings of CMS plants on hybrid seed yield. IRRI, 1991 DS.

Economizing gibberellic acid dosage in hybrid rice seed production

Sixty to ninety ppm gibberellic acid (GA_3), applied with knapsack sprayers at the rate of 500 liters of water and 45 g GA_3/ha, was found useful for hybrid rice seed production in the tropics. To reduce the dosage of GA_3, we compared the efficacies of an ultralow-volume (ULV) sprayer (Model Micro ULVA) and a knapsack sprayer in a trial involving CMS lines IR58025 A and IR62829 A and the restorer IR9761-19-1 R during the 1990 WS. Applying 45 g GA_3 with a knapsack sprayer or 10-20 g GA_3 with an ULV sprayer gave similar plant heights (89.5 and 91.1 cm), panicle exsertion percentages (72.5 and 73.0), numbers of seeds per panicle (15.9 and 16.8), and seed yield (680.7 and 679.6 kg/ha). These results indicate that the dose of GA_3 may be reduced by using an ULV instead of the knapsack sprayer.

In a follow-up experiment during 1991 WS, the efficacy of the ULV sprayer (using 15 g GA_3 with 20 liters water) was compared with that of the knapsack sprayer (using 45 g GA_3 in 500 liters water) in seed production plots with CMS lines, IR58025 A and IR62829 A, and IR29723-143-3-2-1 R as pollinator. GA_3 was applied in two sprays: the first (10 g GA_3 with the ULV sprayer and 30 g GA_3 with a knapsack sprayer) at 20% panicle emergence, and the second (5 g GA_3 with an ULV sprayer and 15 g GA_3 with a knapsack sprayer) a day after; the control was unsprayed. Plant height, seed set percentage, and seed yield in plots sprayed with the ULV (15 g GA_3/ha) and knapsack (45 g GA_3/ha) sprayers were nearly identical (Table 12) and both treatments were significantly better than the control. The results indicate that GA_3 dosage can be reduced from 45 g/ha to 15 g/ha by using the ULV instead of the knapsack sprayer.

Table 12. Comparative plant height, seed set, and yield of CMS lines sprayed with 45 g GA_3 with knapsack and 15 g GA_3 with ULV sprayers. IRRI, 1991 WS.

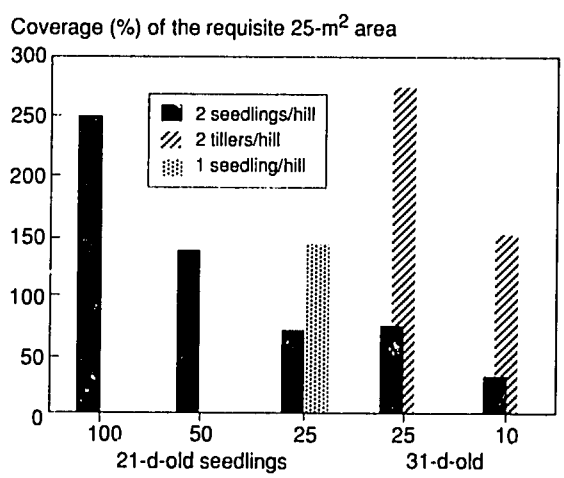
Treatment	Plant height (cm)	Seed set (%)	Seed yield (t/ha)
45 g GA_3/ha (sprayed with knapsack)	92 b	34 a	1.01 a
15 GA_3/ha (sprayed with Micro ULVA)	94 a	35 a	1.06 a
Control	82 c	27 b	0.86 b
CV (%)	1.6	8.0	11.3

Economizing seed rate

During the 1991 DS, 5 seeding rates varying from 100 to 10 g/m² of seedbed area were tried in inbreds IR50 and IR72, and in hybrids IR64616 H and IR65485 H. Seedlings from seeding rates of 100, 50, and 25 g/m² of seedbed were kept in the seedbed for 21 d and seedlings from 25 and 10 g/m² rates were kept in the seedbed for 31 d. All seedbed and field plantings were in a split-plot design with genotypes in the main plots and seeding rate in the subplots replicated thrice.

The tillers in the seedbed increased significantly from 1.4 to 4.7 as the seeding rate decreased from 100 to 10 g/m² and seedling age at transplanting increased from 21 to 31 d irrespective of genotype.

Seeding rates of 100 g/m² (equivalent to 40 kg/ha) and 50 g/m² (equivalent to 20 kg/ha) produced sufficient seedlings to cover 248 and 137% of the 25-m² requisite area with 2 seedlings/hill at 20- × 20-cm row and plant spacings (Fig. 5). Thus, the seed rate can be reduced to 20 kg/ha by transplanting 2 seedlings/hill at 20 × 20 cm or 20 × 15 cm. Sparse seeding at 25 g/m² produced almost 100% more tillers than the 100 g/m² seeding. Thus, transplanting a single seedling with 2-3 tillers instead of 2 seedlings/hill covered 142% of the requisite area and will further help reduce the seed rate to 10 kg/ha. Increasing the seedling age (to 31 d) and reducing the seeding rate (10 to 25 g/m²) resulted in 3.3-4.9 tillers/seedling. Transplanting 2 tillers/hill from 31-d-old seedlings resulted in 151.3 and 273% field coverage of the requisite 25 m² (Fig. 5). This indicates that



5. Area coverage by seedlings from different seeding densities (100, 50, 25, 10 g/m² in seedbed) and treatments involving tiller-splitting. IRRI, 1991 DS.

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31-d-old seedlings from a seeding density of 10 g/m² (4 kg/ha) would be more than enough to transplant 1 ha with 2 tillers/hill at 20- × 20-cm spacing. Seeding rates and transplanting 2 seedlings, 1 seedling, and even 2 tillers/hill of 31-d-old seedlings did not affect the grain yield (Table 13) of inbred or hybrid rice plants. The mean yield was 0.7-1.0 t/ha higher in hybrids than in the best inbred check. These results indicate the possibility of reducing seed rate for hybrid rice to 20 kg/ha provided seeding is done in a seedbed area recommended for seeding 40 kg seed. The seed rate can be reduced to as low as 4 kg/ha by raising vigorous seedlings with 4-5 tillers and transplanting 2 tillers/hill by splitting the 31-d-old seedlings. However, labor cost for splitting the seedlings would be a limiting factor.

Manual for hybrid rice seed production

With experience gained in hybrid rice seed production during the past 10 yr at IRRI, we drafted the *Manual for hybrid rice seed production* for co-publication in different languages. The manual, now being processed for publication, provides guidelines for hybrid rice seed production in the tropics.

Training courses in hybrid rice seed production

We organized two training courses at IRRI during 1991 to transfer technology of hybrid rice seed production. Twenty-five trainees from 10 countries participated in the courses. We also provided resource people and technical support for a training course on hybrid rice seed production held in India during October 1991 and another in the Philippines during November 1991.

International task force on hybrid rice

We submitted to the Government of Italy a project proposal to establish an International Task Force on Hybrid Rice involving IRRI and several NARS actively involved in hybrid rice research and development. The proposed task force would expedite the development and use of hybrid rice technology in countries outside China.

Next steps

We will strengthen our efforts to develop new CMS lines with diverse cytoplasmic and/or nuclear genetic backgrounds. A search for maintainers and restorers will be initiated among elite lines with new plant type and a tropical japonica background and which were developed in the Integrated Germplasm Improvement Project in the irrigated rice ecosystem. We will continue to test heterotic rice hybrids in national programs. Work on thermosensitive genic male sterility will be strengthened to study the inheritance of and allelic relationship between TGMS mutants developed in Japan and at IRRI. Also, IRRI-bred TGMS lines will be evaluated in some NARS to test the stability of their performance. To increase outcrossing rates of male sterile lines, we will select in backcross nurseries for floral traits such as stigma exsertion, stigma size, anther size, duration of floret opening, size of lodicules, etc. Also restorer lines will be evaluated for anther size, residual pollen, and peak anthesis time in relation to the available CMS

Table 13. Effect of seeding rate and number of seedlings/hill on grain yield of inbred and hybrid rice plants. IRRI, 1991 DS.

Seeding rate in seedbed (g/m²)	Seedling age at transplanting (d)	Seedlings (S) or tillers (T) (no./hill)	Grain yield (t/ha)			
			IR50[a]	IR72[a]	IR64616 H[b]	IR65485 H[b]
100 (= 40 kg seed/ha)	21	2 (S)	5.0	5.2	5.6	6.3
50 (= 20 kg seed/ha)	21	2 (S)	4.9	5.0	5.7	5.9
25 (= 20 kg seed/ha)	21	1 (S)	4.6	5.0	6.1	6.2
25 (= 10 kg seed/ha)	31	2 (T)	4.9	4.9	5.4	5.9
10 (= 4 kg seed/ha)	31	2 (T)	5.0	5.0	5.7	5.7
F-test			ns	ns	ns	ns
Mean			4.9	5.0	5.7	6.0

[a]Inbred. [b]Hybrid. LSD (0.05) for comparison of hybrids and inbreds: 0.3 t/ha, CV = 10.0%.

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lines. The search for apomixis will be continued in collaboration with the wide hybridization project. An international symposium on hybrid rice will be organized at IRRI to 1) review progress made in hybrid rice since 1986 when the first symposium was held in China, 2) propose future research needs, and 3) discuss areas and mechanisms for international collaboration, including the establishment of an international task force on hybrid rice.

Subprogram II: Crop, resource, and pest management

Efficient use of fertilizer, soil, and biologically fixed nitrogen

This project is concerned with increasing the efficiency with which irrigated rice uses soil N and inorganic and organic fertilizer N. It involves both experimental and simulation work and links with continuing work in the Rainfed Lowland Rice Program and the Cross-Ecosystems Program.

Azolla germplasm collection

In 1991, the IRRI azolla germplasm collection carried 518 strains that included 18 mutant strains from Iran and their parent and one tetraploid (*Azolla pinnata*) from Thailand, which were added this year. A total of 476 strains have been distributed to 21 researchers from 13 countries. Duplicates of the collection have also been sent to Iran and China.

Shoot-tip culture of azolla

The IRRI azolla germplasm collection has always been maintained in pure and healthy condition using N-free culture solution. Each strain is thinned, cleaned, and reinoculated to fresh medium every 2 wk; thus a large volume of culture medium is required. To conserve manpower, chemicals, and space, and to lessen the chance of cross contamination among the strains, we tried shoot-tip culture of azolla.

About 20-30 healthy fronds were selected from each strain and placed in small nylon net bags. They were then cleaned under continuously flowing tap water for about 30 min. About 30-50 azolla tips (3-5 mm long) were excised and placed in sterile nylon net bags, surface-sterilized for 3 min by soaking in a solution with 2.0% hypochlorite solution and 1.0% Triton X-100, then washed in sterile distilled water at least six times while stirring for 1 min. The azolla tips were placed on semisolid agar medium (0.5% bacto agar in 20-ml culture solution) in 50-ml erlenmeyer flasks. Ammonium nitrate was added to the medium for the anabaena-free azolla and other strains requiring combined N.

The azolla tips in the flasks were grown in a growth cabinet (at 26/18 °C day/night temperature, 75% relative humidity, 12 h photoperiod, and 5-6 klux light intensity) for 3-4 wk. Newly inoculated flasks were examined for algal contamination and all contaminated flasks were removed. Subsequent transfers were done every 12 wk.

The success of aseptic azolla transfers varied from species to species and among strains. Surface sterilization for 3 min with hypochlorite solution was suitable for most strains; it was varied when oversterilization or algal contamination occurred.

The anabaena-free strains of azolla require combined N to grow, but this also enhances contamination by green algae. These azolla strains are cleaned and transferred to fresh culture medium every 3-4 d. In shoot-tip culture, they are transferred to agar medium every 8 wk.

Of 518 strains, 173 (33%) were transferred to agar medium. Because *A. filiculoides*, *A. nilotica*, and *A. rubra* are sensitive to high temperature and mechanical damage, these species were transferred first. Transferred later were 79% of *A. filiculoides* strains, 34% of *A. mexicana*, 51% of *A. caroliniana*, 75% of *A. rubra*, 67% of *A. nilotica*, and 16% of *A. microphylla*. Only three strains of *A. pinnata* were transferred to an agar medium.

Sporulation and hybridization of azolla

In collaboration with the University of the Philippines at Los Baños-National Azolla Action Program (UPLB-NAAP), sporulation of 135 azolla strains was observed in a cool region of the Philippines (at the Benguet State University, Benguet Province). The objective was to induce sporulation for morphological studies and sexual hybridization work. In 1991, special efforts were made to observe sporulation of putative hybrids obtained at IRRI and UPLB-NAAP.

Observations were made 14 times from January to June 1991. *A. filiculoides* (FI) did not sporulate in this period. Only 19 strains formed sporocarps (Table 14). *A. caroliniana* (CA) 3514, hybrids *A. microphylla* (MI) 4135 and MI 4136 (MI 4018 × [MI 4018

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Table 14. Sporulation of azolla grown at Benguet State University, Benguet Province, Philippines, 1991.

Species[a]	Accession no.	Sporulation		Remarks
		Frequency[b]	Pattern[c]	
PI	5	8	micro > mega	
PP	7001	13	micro >> mega	
ME	2001	5	mega >> micro	
ME	2024	13	micro · mega	Hybrid 2001/4018
ME	2027	9	mega >> micro	Hybrid 2002//(2001/4018)
CA	3023	9	micro · mega	Hybrid 3522/4061
CA	3024	7	mega · micro	Hybrid 3522/4061
CA	3025	7	micro >> mega	Hybrid 3522/4061
CA	3026	8	mega · micro	Hybrid 3522/4061
CA	3027	10	mega · micro	Hybrid 3522/4061
CA	3514	7	no mega	From Université Catholique du Louvain
MI	4009	4	mega >> micro	
MI	4018	4	mega >> micro	
MI	4067	12	mega >> micro	
MI	4068	4	no micro	
MI	4069	3	mega >> micro	
MI	4135	4	no mega	Hybrid 4018/(4018/1001)
MI	4136	9	almost no mega	Hybrid 4018/(4018/1001)
MI	4137	4	no mega	Hybrid MI/ME

[a]PI = *Azolla pinnata* var. *imbricata*, PP = *A. pinnata* var. *pinnata*, ME = *A. mexicana*, CA = *A. caroliniana*, MI = *A. microphylla*. [b]Total observations = 14. [c]micro = microsporocarps, mega = megasporocarps. The following accessions did not sporulate during this period. FI = *A. filiculoides* (NI = *A. nilotica*, RU = *A. rubra*, XX = unclassified):

FI 1001, 1010, 1016, 1035, 1040, 1041, 1042, 1043, 1053, 1054, 1055, 1056, 1057, 1058, 1059, 1060, 1061, 1062, 1065, 1066, 1067, 1068, 1069, 1070, 1536, 1539, 1540, 1545, 1547
ME 2002, 2007, 2008, 2009, 2012, 2014, 2015, 2021, 2022, 2025, 2026
CA 3001, 3002, 3004, 3005, 3006, 3008, 3011, 3012, 3013, 3014, 3015, 3016, 3017, 3019, 3501, 3502, 3503, 3504, 3505, 3507, 3508, 3509, 3510, 3511, 3512, 3513, 3515, 3516, 3517, 3518, 3519, 3520, 3521, 3522, 3523, 3524, 3525, 3526, 3527, 3528, 3529, 3530, 3531, 3532, 3533, 3534, 3535, 3536, 3537, 3539, 3540
MI 4001, 4003, 4014, 4017, 4021, 4028, 4030, 4052, 4062, 4064, 4070, 4072, 4073, 4074, 4075, 4134, 4138
NI 5501
RU 6502
XX 8001, 8002, 8020, 8028, 8030, 8031

× FI 1001]), and hybrid MI 4137 (MI × ME) produced only microsporocarps.

Hybrids of CA 3522 (CA 3023 to CA 3027) produced male and female sporocarps at a high frequency, as did hybrids *A. mexicana* (ME) 2024 (ME 2001 × MI 4018) and 2027 (ME 2002 × ME 2024). Hybrids of FI 1001 with MI 4061 (from FI 1065 to FI 1070) did not produce sporocarps. The production of hybrids among three closely related species (CA × MI or ME × MI) implies that they may be one species, as was suggested by earlier IRRI work on biochemical and genetic characteristics.

Azolla fingerprinting

Twenty-five accessions were selected for a preliminary study to represent the diversity of germplasm within the genus: 13 strains belong to the Rhizosperma section and 12 strains represent 5 species of the *Azolla* section. Accessions are difficult to classify as azolla strains are difficult to distinguish by morphological characteristics alone. Molecular markers, including isozymes, are being used to characterize different strains, to identify redundancies and duplications within the collection, and to clarify evolutionary relationships among accessions.

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Plants were grown under temperature and humidity control in the phytotron and harvested for DNA extraction. Twenty-five primers containing 70% guanine + cytosine were used to generate random amplified polymorphic DNA (RAPD) profiles for the 25 accessions selected. An average of seven bands per genotype was visible for each primer used. Some primers gave up to 10 bands in some genotypes. The molecular weight of each band was recorded and the data are being analyzed using the HYPER RFLP program developed at Cornell University for phylogenetic analysis based on molecular markers.

Results to date have revealed 486 RAPD markers that were used to build a classification consisting of three main groups: the *A. pinnata* species, *A. nilotica* species, and the entire *Azolla* section.

A library of cloned DNA sequences is being prepared. DNA from anabaena-free azolla strains has been isolated, digested, and size fractionated using a sucrose gradient. The DNA has been cloned into the vector PUC119. Results of fingerprinting and phylogenetic studies using cloned DNA sequences as RFLP markers will be compared with results obtained using random primers in polymerase chain reaction-based assays. RAPD appears to be an efficient and fast way to characterize azolla germplasm. By screening both RFLPs and random primers, we hope to identify some markers that are particularly useful in distinguishing accessions or species in our germplasm collection. The entire germplasm collection will be examined once useful markers have been identified.

Blue-green algae germplasm collection

The IRRI collection of N_2-fixing blue-green algae (BGA) was initiated in 1979 as part of a collaborative research program of Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM, France) and IRRI to study the ecology of BGA and their possible use as biofertilizer in wetland rice culture. The collection comprises 204 strains originating from 21 countries (Table 15). In 1990-91, information regarding the strains was entered in a data base. A computer program was designed using Hypercard software to standardize and facilitate the visual and microscopic descriptions of cultures in liquid and on solid media. A Macintosh computer, a hard disk, and the Hypercard 2 program are needed to use the stacks.

Information on the strains is compiled in six interconnected Hypercard stacks:

1. Cards of the main stack, "Collection" (486 kbyte, 206 cards), provide the following information:
   - genus, IRRI's code, and other codes when applicable;
   - country and location of origin, and habitat;
   - year of isolation, year of acquisition to IRRI's collection, and information on strain conservation;
   - soil properties of the environment from which the strain was isolated;
   - standardized description of the visual appearance of the culture in liquid and on solid media;
   - standardized microscopic description; and
   - additional notes including bibliographic references on the strain and its environment.

Table 15. Number and origin of strains in the BGA collection. 1991.

Genus	Number						
	Africa		Asia		Europe	Other regions	Total
	Senegal	Others	Philippines	Others			
Anabaena	13	5	7	15	5	5	50
Calothrix	23	2	11	7	1	1	45
Fischerella	4	2	4	3	1	0	14
Gloeotrichia	0	0	2	0	0	0	2
Nodularia	0	0	0	1	0	0	1
Nostoc	28	9	12	17	4	1	71
Scytonema	1	3	1	4	0	0	9
Tolypothrix	0	0	0	2	1	0	3
N_2-fixing	69	21	37	49	12	7	195
Nonfixing	8	0	0	0	1	0	9
Total	77	21	37	49	13	7	204

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2. The stack "Describe" (311 kbyte, 19 cards) is an on-screen tool to describe
   - cultures of strains growing on solid and liquid media (aspect and color), and
   - their morphological features under the microscope.
3. The stack "Keys" (172 kbyte, 69 cards) provides on-screen taxonomic keys for genera encountered in ricefields.
4. The stack "Glossary" (65 kbyte, 95 cards) provides definitions of specific terms or concepts including terms used for the description of BGA in the stack "Describe."
5. The stack "Methods" (32 kbyte, 8 cards) provides general information on methods for
   - the maintenance, mailing, and revival of the strains; and
   - estimating BGA abundance and activities in ricefields.
6. The stack "Sites" (25 kbytes, 12 cards) provides information on the environments from which the strains originated.

NEXT STEPS

We will continue to conserve and evaluate biofertilizer germplasm, and to investigate the dynamics of soil N and fertilizer N and the mechanisms by which the rice root system utilizes them. The project's activities will be transferred to integrated nutrient management in the Rainfed Lowland Rice Program.

Direct seeded rice

SEED VIGOR, GROWTH, AND GRAIN YIELD OF BROADCAST SEEDED, EARLY-MATURING RICE VARIETIES

A study was undertaken 1) to determine if varietal difference in seed vigor influences crop establishment and 2) to identify yield-determining processes of broadcast-seeded, early-maturing rice plants. Analysis of the results of seed vigor tests indicates that germination rate correlated most closely with the results of the other seed vigor tests (Table 16). Therefore, germination rate was used to classify the varieties into groups of high, intermediate, and low vigor (Table 16,17).

Crop establishment was lower in the low-vigor varietal group than in the high and intermediate groups; there was no difference between the high and intermediate groups (Table 18). Crop growth rate was lower in the low-vigor varietal group than in the high and intermediate groups at the early growth stage but not at the late growth stage (Table 19). This might be caused by the difference in crop establishment.

Grain yield was lower in the low-vigor varietal group than in the high and intermediate groups because of the low panicle-to-shoot ratio of the low-vigor group. The results suggest that high seed vigor is important not only for increasing crop establishment but also for high grain yield.

Table 17. Germination rate (RG) of varieties used in field experiment. IRRI, 1990 DS.

Variety	Germination rate (%)
High seed vigor variety	
RP1442-2-2-3-5-1	100.0 a
IR13240-108-2-2-3	99.3 a
BG1203	98.7 a
RNR1429	98.0 ab
IR25884-94-3-2	97.3 ab
Intermediate seed vigor variety	
IR39357-133-3-2-2-2	94.7 ab
IR21178-39-P1	93.3 ab
IR13429-299-2-1-3	89.0 b
IR25879-82-5-2	77.3 c
Laxmi	75.8 c
Low seed vigor variety	
IR21848-65-3-2-2	71.1 c
OS4	55.3 d
Giza 159	35.7 e
IRAT140	22.7 f
Dharial	15.2 f

Table 16. Mean value of different seed vigor tests for 3 varietal groups of varying seed vigor.

Varietal group	Germination rate	Percent germination	Aging test	Cold test	Shoot:root length
High seed vigor	99 a	99 a	38 a	18 a	0.26 a
Intermediate seed vigor	86 a	98 a	12 b	16 b	0.23 b
Low seed vigor	40 c	84 b	6 c	6 c	0.14 c
Max	100	100	57	25	0.43
Min	15	58	1	0	0.12

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Table 18. Mean values for growth parameters of 3 varietal groups.

Varietal group	Crop establishment (%)	Total shoot dry wt (kg/m²)	Panicle-to-shoot dry wt ratio	Yield (t/ha)
High seed vigor	52 a	0.93 b	0.52 a	4.7 a
Intermediate seed vigor	54 a	1.00 a	0.50 a	4.8 a
Low seed vigor	37 b	0.94 b	0.35 b	1.9 b

Table 19. Mean crop growth rate during growth stages. IRRI, 1991 DS.

Varietal group	Crop growth rate (g/m² per d)		
	19-33 d after seeding	Heading to 15 d after heading	15 d after heading to maturity
High vigor	4.4 a	13.4 a	10.9 a
Interrnediate vigor	4.7 a	10.9 a	10.2 a
Low vigor	3.2 b	11.9 a	9.1 a
Max	5.8	16.1	26.8
Min	1.3	3.2	3.5

Lock-lodging ratoon cropping

In many irrigated lowland areas, farmers produce two or three rice crops each year. Each main crop requires a puddling operation to prepare the land for planting, and puddling is a major cost in the production system. Where irrigation water comes from tubewells, pumping costs are a large variable cost. In contrast, water supplied from gravity-fed irrigation systems is cheaper although adequate supplies are often not assured in DS and moisture stress is a common production constraint. A ratoon crop provides an option to reduce the costs for land preparation and for irrigation because the ratoon matures more quickly than a main rice crop. Typically, however, ratoon crop yield and net return are so low that they are not competitive with another main rice crop.

We developed a novel ratooning technique that involves the systematic braiding of stubble to "lock-lodge" the straw flat against the soil surface after harvest of the main crop (Fig. 6). This method was compared with conventional ratooning where the stubble is left standing after harvest. One study was conducted at IRRI with IR66, and another in a farmer's field in Camarines Sur with IR74.

6. Uniform tillering of a lock-lodge ratoon crop 14 d after harvest of main rice crop.

Table 20. Main crop grain yield and yield, panicle number, and duration of a following ratoon crop established by lock-lodging (LL) or by conventional (C) ratooning at 2 sites.

Main crop yield (t/ha)	Ratoon method	N treatment	Ratoon performance[a]		
			Grain yield (t/ha)	Panicles (no./m²)	Duration (d)
		IRRI, 1990 WS[b]			
3.6	LL	Control, zero N	1.5 bc	206 b	66
3.5	LL	60 kg N/ha, T_1	1.6 b	275 ab	73
3.4	LL	60 kg N/ha, T_2	2.4 a	338 a	73
3.5	Mean		1.8 A	273 A	71
3.9	C	Control, zero N	1.1 cd	206 b	66
3.5	C	60 kg N/ha, T_1	0.8 d	212 b	73
3.8	C	60 kg N/ha, T_2	1.4 bc	281 ab	73
3.7	Mean		1.1 B	233 A	71
		Camarines Sur, 1991 DS[c]			
3.6	LL	Control, zero N	1.8 c	250 b	90 d
3.6	LL	90 kg N/ha[d]	3.6 a	364 a	99 b
3.6	Mean		3.3 A	307 A	97 B
3.6	C	Control, zero N	1.2 d	124 c	94 c
3.6	C	90 kg N/ha[d]	2.8 b	309 ab	106 a
3.6	Mean		2.5 B	272 B	103 A

[a]For each experiment, means followed by the same lowercase or uppercase letter do not differ significantly by DMRT, $P<0.05$. [b]Main crop planted in July and harvested in October 1990; ratoon crop harvested in December 1990. T_1 = 30 kg N/ha 2 wk before main crop harvest plus 30 kg N/ha 2 wk after harvest of main crop. T_2 = 30 kg N/ha at harvest of main crop and 30 kg N/ha 3 wk after harvest. [c]Main crop planted in September 1990 and harvested in January 1991; ratoon crop harvested in May 1991. [d]Pooled mean of 4 N timing treatments, all with split applications at harvest of main crop and at 3 and/or 6 wk after harvest.

At IRRI, lock-lodging resulted in grain yields that were 65% greater than with conventional ratooning regardless of the N fertilizer treatment (Table 20). Grain yield with lock-lodging was highest when N was applied in two equal splits, half immediately after harvest of the main crop and half 3 wk later. Improved performance of the lock-lodge ratoon was due to more uniform tillering at basal nodes, which increased panicle numbers. In conventional ratooning, tillering was irregular, originating at nodes 2-4 in the standing stubble. With the best N fertilizer treatment, yield from the lock-lodge ratoon was equivalent to 71% of the preceding main crop yield, but crop duration was 14 d shorter in the ratoon crop.

In Camarines Sur, treatments included a zero N control and four N timings, each totaling 90 kg N/ha. In contrast to the experiment at IRRI, none of the N timing treatments had N application before harvest of the main crop. Instead, N treatments differed in the timing of the split applications from immediately after harvest of the main crop to 3 and 6 wk after lock-lodging. As treatment effects due to N timing were not significant, pooled means for all N treatments are presented (Table 20). Mean yield with lock-lodging was 31% greater than with conventional ratoon. In treatments with N fertilizer, yield from the lock-lodge ratoon was comparable with the yield from the preceding main crop. Crop duration, moreover, was 16 d shorter in the lock-lodge ratoon. As in the results at IRRI, increased grain yield from lock-lodging reflected more uniform tillering and greater panicle numbers than from conventional ratooning. Grain filling was also more uniform in the lock-lodge crop so that crop duration was about 5 d shorter than in the conventional ratoon.

Production costs and returns were compared based on data from the Camarines Sur experiment in a gravity-fed irrigation system and data collected at another site with pump irrigation where a farmer established two adjacent blocks (one block with a lock-lodge ratoon and the other with a main crop). Time-adjusted productivity was estimated for the ratoon and main crop options when both were grown in the same season (Table 21). Although the main crop produced 14-24% more grain per day, the lock-lodge ratoon had considerably lower production costs so that net margins adjusted for crop duration were comparable or greater with the ratoon.

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Table 21. Time-adjusted estimates of grain yield, production costs, and gross and net returns for a main crop and lock-lodge or conventional ratoon crops at 2 locations with pump or gravity-fed irrigation systems in Camarines Sur, Philippines, 1991 DS.[a]

Establishment method	Crop duration (d)	Grain yield (kg/ha per d)	Total cost ($/ha per d)	Gross return ($/ha per d)	Net margin ($/ha per d)
Pump-irrigated (IR72)					
Main crop	105	40	5.5	8.9	3.4
Lock-lodge ratoon	90	35	2.9	7.8	4.9
Gravity-irrigated (IR74)					
Main crop	115	46	1.9	10.2	8.3
Lock-lodge ratoon	99	37	0.6	8.2	7.6
Conventional ratoon	106	19	0.2	4.2	4.0

[a]Land preparation, irrigation, seed, and establishment expenses were considered. Seedbed management, seedling pulling, and weeding expenses were excluded. Exchange rate: US$1 = ₱ 27.

The greater costs of land preparation and transplanting for the main crop vs the cost of lock-lodging in the ratoon, and the lower irrigation costs for the ratoon contributed to the time-adjusted efficiency of the lock-lodge ratoon crop, particularly when water was supplied by pumping.

Future plans. In 1992, research on lock-lodging will directly compare this ratooning option with another transplanted main rice crop in the same season in four farmers' fields in two provinces. If this novel ratooning technique continues to show promise, adaptive research led by NARS will be encouraged to verify the usefulness of this technology in environments where time, water, and land constrain rice production. In some areas, the shorter duration of the lock-lodge ratoon may allow greater flexibility in diversifying with a nonrice crop, but without a large decrease in total rice production of the cropping system.

Water and tillage management

Water-efficient irrigation technique for rice

Water use in most irrigated rice farms is high because continuous flooding is practiced throughout the season. Fields are often flooded to control weeds. With increasing demands and costs to develop water resources, the need to use water-efficient rice production systems is most pressing, especially for DS rice, which cannot compete well with other crops unless water supply is subsidized.

We conducted research in Guimba, Nueva Ecija, Philippines, to identify irrigation techniques that are water-efficient and at the same time do not reduce yields. The study evaluated the following water regimes established in transplanted ricefields: 1) the traditional continuous shallow flooding, 2-7 cm depth (WR1), 2) shallow flooding similar to WR1 up to panicle initiation and then saturated soil (WR2), 3) saturated soil throughout (WR3), and 4) alternate wetting to saturate the soil and drying for a maximum of 1 d after attaining soil saturation, but without allowing the soil to crack (WR4).

The experiment was conducted in two farmers' fields for two dry seasons at each site, from 1988 through the 1991 DS, using a randomized complete block design. The fields have a clay loam soil, an average water table depth of 95 cm, and are irrigated by shallow tubewell pumps.

Farm plots were of 10 × 15 m. Polyethylene sheets were installed at 60-70 cm depths along the center of dikes to prevent seepage between adjacent plots with different water regimes. All plots received 100-30-30 kg NPK/ha. Weed control was uniform across the water regimes, but not the same in all seasons. In 1988 DS, butachlor at 0.6 kg active ingredient/ha was applied 1 d before transplanting. In 1989 and 1990 DS, two passes of a rotary weeder and one hand weeding were done; in 1991 DS, only one hand weeding was done.

In the standard practice (WR1), 20 mm of water was lost daily because of percolation. Only 9 mm/d was lost when saturated soil was maintained (WR3). The average water used in WR3 was therefore 60% of that used in WR1 during the seasons (Table 22). Regime WR3 was adequate to fully meet the crop's evapotranspiration demand for water. During 1988 and 1989, weeds were effectively controlled in all water regimes, hence there was no significant yield

Table 22. Mean rice yields, water use, water productivity, and weed weights under selected water regimes. Guimba, Nueva Ecija, Philippines, 1988-91 DS.

Item	Water regime[a]			
	WR1	WR2	WR3	WR4
Mean yield (kg/ha)				
1988 and 1989	5552 a	5237 a	5153 a	4336 b
1990 and 1991	5102 a	4833 a	4198 b	3757 c
Water use (mm)				
1988 and 1989	1793 a	1168 b	1068 b	728 b
1990 and 1991	2785 a	1804 b	1644 bc	1065 c
Relative water use (%)				
1988 and 1989	100	65	60	41
1990 and 1991	100	65	59	38
Weed weights (g/m²)				
30-45 DT[b]				
1988 and 1989	19.3 a	12.4 a	30.1 a	52.0 a
1990 and 1991	63.1 a	54.4 a	194.2 b	159.1 b

[a]WR1 = continuous flooding (2-7 cm); WR2 = similar to WR1 up to panicle initiation, then saturated soil; WR3 = saturated soil throughout; WR4 = alternate wetting (to saturate the soil) and drying (up to maximum of 1 d after attaining saturation). In a row, values with the same letter are not significantly different at the 5% level by DMRT. [b]Days after transplanting.

difference between WR1 and WR3. This indicates that with normal weed control measures (chemical or mechanical/manual), excessive water need not be used as a tool for weed control. Further, water saving of about 40% can be achieved without yield reduction if a saturated soil regime (WR3) is maintained through the growing season in place of the usual shallow-flooded regime (WR1). In WR3, more than 80% of the savings accrued from reduced percolation because of reduced water head on the field.

During DS of 1990 and 1991, the same degree of water saving was achieved with WR3, but the average yield was significantly reduced because of inadequate weed control (only one hand weeding was done). This resulted in higher weed growth in 1991 and lower mean yield for the two seasons of 1990 and 1991 (Table 22). In 1990, however, water regime WR2 controlled weeds as well as WR1 did because of the weed suppressive effect of shallow flooding during the crop's vegetative period. Therefore, WR2 yield was not significantly different from that of WR1. But because of higher percolation rates during the early part of the season, total water use with WR2 was slightly higher than with WR3, but still significantly less than with WR1. On the average, water use in WR2 was 35% less than in WR1 during the DS of 1990 and 1991. Thus, if weed pressure is high, WR2 is the most appropriate water management regime for substantial water savings without yield sacrifice; however, without high weed pressure, WR3 (saturated soil) is the best water regime. Soil nitrate and ammonium concentrations measured in the experimental plots were similar in WR1 and WR3 regimes, indicating that N losses from the soil do not differ in these two regimes.

When maintaining the saturated water regime (WR3), it is important to prevent soil cracking which increases water loss by percolation. The alternate wetting and drying regime (WR4) saved much water, but at the cost of significant yield reductions.

Future plans. Developing means and techniques for improving water use efficiency in irrigated rice production will be more important as water supplies for agricultural purposes become more costly and/or competitive with other uses. We will continue investigations of practical means by which rice farmers in irrigation systems could increase the productivity of water without having to sacrifice yield potentials or incur significant additional labor or other inputs. In rice farms using groundwater, we will analyze the economic benefits of adopting the water-efficient irrigation methods reported here. We will extrapolate these findings for rice farms with various soil types and determine how the design and operational procedures of large-scale irrigation systems could be modified to implement practically the water-efficient irrigation techniques over wider areas.

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Drought tolerance of direct seeded vs transplanted rice

In recent years, direct seeded rice (DSR) culture has been expanding and replacing transplanted rice (TPR) in several countries in the region. This process is under way in the Upper Pampanga River Integrated Irrigation System (UPRIIS), which is the Philippines' premier irrigation system and serves more than 100,000 ha of rice area in Central Luzon. The implications for water management are important not only for the irrigation system's present capacity to support rice production but also for future system design and operation.

We continued to investigate the performance of DSR and TPR, and the processes and implications of their substitution in irrigated production systems. During the 1990-91 DS, we experimented with DSR and TPR grown on a clay soil (65% clay) farm at Maligaya, Nueva Ecija, under six water regimes. One (W1) represented the common practice of shallow flooding (5-7 cm water depth), and another (W2) a more water-efficient method in which a saturated soil regime was maintained throughout the season. The four water-short regimes are as follows:

W3—mild water stress in vegetative stage;
W4—severe water stress in vegetative stage;
W5—mild water stress in the reproductive stage; and
W6—severe water stress in the reproductive stage.

The mild and severe water stress regimes lasted 10 and 20 d, respectively, starting with saturated soil.

The experiment used a split-plot, randomized complete block design with four replications, with the main plot (20 × 8 m) for water regime and the subplots (10 × 8 m) for crop establishment method. Farmers' practices for input levels were followed. IR64 was grown at seeding rates of 150 kg/ha for DSR and 120 kg/ha for TPR. Fertilizer was 120-40-40 kg NPK/ha for both. The plot was kept weed-free by hand weeding and herbicide use.

DSR yield was significantly higher than TPR except in W1, where the yield was higher but the difference was statistically insignificant (Table 23). DSR yield advantage was higher for the severe levels of water stress at both vegetative and reproductive stages of the crop than at mild levels. Under severe water stress, DSR yielded 772 kg/ha more than TPR in W4 and 1,005 kg/ha more in W6. Water-stressed soils in DSR plots had less cracks than in the plots with TPR. DSR in all water regimes had significantly higher plant populations, more panicles per unit area, and higher percentages of filled grains, which may have contributed to the yield difference.

The farmers of UPRIIS are aware that DSR is more drought-tolerant than TPR. A survey of 30 UPRIIS farmers indicates that about 85% of them considered DSR, once established, more tolerant of water stress than TPR. About 55% said they would grow DSR in areas where shortage of irrigation water is expected following crop establishment.

Future plans. Because of its higher yield potential in farmer field conditions and lower labor require-

Table 23. Effect of water regime on yield and yield components of direct seeded rice (DSR) and transplanted rice (TPR).[a] MRRTC and UPRIIS,[b] 1990-91 DS.

Water regime[c]	Yield (t/ha)			Yield component difference (DSR-TPR)		
	DSR	TPR	Difference (DSR-TPR)	Tillers (no./m²)	Panicles (no./m²)	Unfilled grains (%)
W1	7.6	7.4	0.2 ns	336**	164**	-4.0**
W2	7.3	6.7	0.6**	314**	142**	-3.3**
W3	7.0	6.3	0.7**	267**	167**	-4.3**
W4	6.1	5.3	0.8**	266**	160**	-3.3**
W5	6.4	6.0	0.4*	278**	143**	-1.8 ns
W6	5.2	4.2	1.0**	171**	92**	-9.8**
Mean	6.6	6.0	0.6	272	144	-4.4

[a]In a column, ** = significant at 1% level by DMRT, * = significant at 5% level by DMRT, ns = not significant.
[b]Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines, and Upper Pampanga River Integrated Irrigation System. [c]W1 = continuous shallow flooding (5-7 cm), W2 = saturated soil throughout season, W3 = mild water stress in vegetative stage, W4 = severe water stress in vegetative stage, W5 = mild water stress in reproductive stage, W6 = severe water stress in reproductive stage.

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ment, DSR is economically more attractive to farmers than TPR. Farmers in the UPRIIS, are replacing TPR, but in most other irrigated areas such replacements are either marginal or nonexistent. We plan to 1) determine the relative profitability of DSR; 2) identify land-based and hydrologic requirements that make the shift from TPR to DSR feasible; 3) determine the water-saving that can be achieved with the shift both at the farm and irrigation system levels, and assess its implication for irrigation system productivity; and 4) determine why the shift to DSR is not taking place on a wider scale.

Pest ecology and integrated pest management

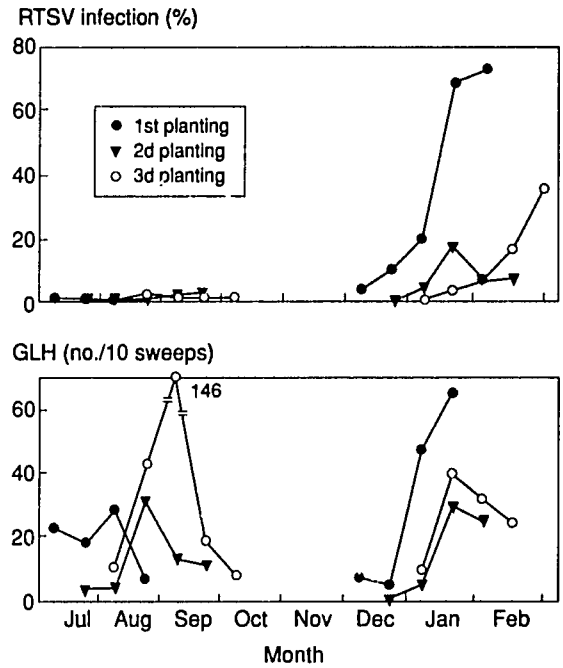
If not managed, the insects, weeds, microorganisms, rodents, and other pests that inhabit the irrigated rice environment may cause significant losses. However, incorrect pest management (such as improperly timed pesticide application) also may cause losses. Knowing when, where, and how to select and deploy pest control practices is essential for farmer profit, yield sustainability, and health and environmental protection. A prerequisite to correct selection and deployment of the pest control methods is an understanding of the actions, reactions, and interactions of components in the crop ecosystem that affect the pests and their natural enemies.

Pest epidemiology, dynamics, and ecological interactions

Tungro virus-insect vector relations. Green leafhopper *Nephotettix virescens* density, RTD incidence, and infection with RTBV and RTSV were monitored once every 2 wk in farmers' fields planted at 3-4 wk intervals in Iloilo and Sultan Kudarat, Philippines. IR74 was planted in WS and IR72 in DS 1990 croppings.

Leafhoppers were collected by sweep net. RTD incidence was assessed visually and infection by the RTD viruses was indexed by ELISA.

Leafhopper density and virus infection differed with cropping season and planting time. In Sultan Kudarat, more leafhoppers were collected in the third planting of WS than in the other plantings. In DS, the first planting had more leafhoppers. In both seasons, however, leafhoppers declined at a later stage of rice growth. Although F. TD symptoms were not observed in either WS or DS, ELISA revealed a



7. RSTV infection and number of GLH/10 sweeps in 3 plantings at 3-4 wk intervals during the Jul-Oct (WS) and Dec-Feb (DS) croppings. Sultan Kudarat, Philippines, 1990.

low level of RTSV infection in WS regardless of planting time. Further, RTSV infection was high in DS and the first planting had higher infection than later plantings. Generally, the increase in RTSV infection corresponded to seasonal increase in leafhopper abundance (Fig. 7). Very few leafhoppers were collected in Iloilo and no RTD was detected.

Volunteer rice plants germinating from seeds spilled after threshing were monitored for GLH, RTBV, and RTSV. Threshing sites used in the 1990 DS crop were surveyed in Magarao and Pili, Camarines Sur; Barotac Nuevo, Iloilo; and Isulan, Sultan Kudarat. RTD vectors were collected by sweep net and 10-20 batches of 10 seedlings from each site were assayed separately using ELISA to detect RTBV and RTSV.

More leafhopper vectors were collected in Sultan Kudarat than in Camarines Sur and Iloilo, although leafhoppers were present at most sampling sites. No RTD virus infection was detected in Camarines Sur. More RTSV infection was present in plants collected from Iloilo and Sultan Kudarat, but only a few sites produced RTBV (Table 24). Low composite infection of RTBV and RTSV was detected even though it is known that testing the seedlings in batches increases the chance of detecting double infection.

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Table 24. Tungro vector density and percentage of RTBV and RTSV infection in volunteer rice plants in 3 Philippine provinces, 1990 DS.

Province	Sampling sites (no.)	Av vector density[a]	Batches tested[b] (no.)	Batches (%) of seedlings infected with		
				RTBV + RTSV	RTBV	RTSV
Camarines Sur	5	4.4	77	0	0	0
Iloilo	12	2.5	239	3.7	0.4	17.5
Sultan Kudarat	16	19.0	317	4.4	1.9	21.3

[a]Leafhopper catches per 10 sweeps. [b]Batches of 10 seedlings assayed separately by ELISA.

Table 25. Developmental time and sex ratio of F_1 progenies of YSB from 6 sites in the Philippines.

Site	Days (no.) from egg hatch to adult emergence[a]	Sex ratio				df	G^b
		Male	Female	Total			
Cagayan	39-47	12	16	28		1	0.58 ns
Ifugao	36-49	59	82	141		1	3.77*
Batangas	42-53	424	468	892		1	2.18 ns
Calauan, Laguna	40-50	79	102	181		1	2.92 ns
IRRI, Laguna	45-60	34	38	72		1	0.22 ns
Nueva Ecija	37-49	93	104	197		1	0.62 ns
					Total	7	10.27 ns
	Total	701	810	1511	Pooled	1	7.87**
					Heterogeneity	6	2.40 ns

[a]*F* value = 570.23 P > 0.001. [b]*G* statistics (Sokal and Rohlf 1969). The null hypothesis is a 1:1 sex ratio.

The data confirmed the prevalence of RTSV infection in the field even in volunteer crops.

Results show that volunteer rice plants may be infected with RTD viruses and may harbor the RTD vectors. These plants may serve as direct sources of infection and vectors for the succeeding crop, especially in asynchronously planted fields.

Genetic variability in yellow stem borer. Understanding variability in insect pest populations is important in rice plant improvement efforts aimed at exploiting varietal resistance to control insects. The information can be used to predict levels of expected difference in a species' response to a particular cultivar and to monitor change in response over time.

A number of parameters are being measured to quantify genetic variation in YSB *Scirpophaga incertulas* populations from six discrete geographical locations in the Philippines—Cagayan, Ifugao, Batangas, and Nueva Ecija Provinces, and at Calauan and IRRI in Laguna Province.

F_1 progenies of each population were cultured on IR62 rice plants. We recorded developmental time and sex ratios. Survival and weight of larvae representing different genotypes (egg masses) also were recorded after 18 d of feeding on 9 rice genotypes.

The developmental time of the YSB populations varied widely (Table 25). The *G*-test of sex ratio data showed that only the Ifugao population differed significantly from the expected 1:1 sex ratio although all the populations had a higher proportion of females. This was borne out by the pooled *G*. The large pooled sample indicated significantly more females than males. However, the populations did not show significant heterogeneity in sex ratio (Table 25). Therefore, the progeny deviations were, as expected, not significantly different from each other.

Rice genotype had a significant effect on larval survival and weight (Table 26). Larval weight varied with the YSB strain (population), but survival did not. There was no variety × population interaction in either weight or survival data. The data suggest that

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Table 26. Analysis of variance of survival and larval weight of YSB after 18 d feeding on 9 rice genotypes.

Source	Survival				Larval weight		
	df	Type III MS	*F* value	P > F	Type III MS	*F* value	P > F
YSB strain[a]	3	.0902112	1.698	0.1780	1.30207845	4.367	0.0102
YSB genotype (egg mass/strain)	76	.0486687	2.860	0.0001	0.28203274	1.259	0.0868
Rice variety	8	.6928647	32.252	0.0001	0.82503005	3.177	0.0126
YSB strain × rice variety	24	.0214829	1.262	0.1815	0.26055065	1.163	0.2727

[a]Populations from Zaragoza, Nueva Ecija, and Calauan and IRRI, Laguna.

Table 27. ShB severity on IR58 planted in soils collected from IRRI ricefields.

Field no.	Relative lesion height (%)		
	Crop 1	Crop 2	Crop 3
528	44 fg	21 abc	2 ab
B-13	15 a	10 a	4 ab
503	30 a-g	16 abc	4 ab
1002	22 a-d	22 abc	6 ab
M-13	30 a-g	17 abc	2 ab
116	20 abc	19 abc	8 ab
UR4	26 a-f	20 abc	11 abc
424	45 g	22 abc	6 ab
428	22 a-d	20 abc	13 abc
226	20 abc	14 abc	9 abc
M9	20 abc	23 abc	19 abc
229	19 abc	21 abc	10 abc
306	28 a-g	20 abc	8 abc
624	30 a-g	22 abc	2 a
422	22 a-d	27 c	12 abc
B-42-A	42 efg	18 abc	0 a
Check	60 g	45 d	38 d

if a variety is more resistant than other varieties to one YSB strain, it also will be more resistant to other YSB strains.

In summary, YSB populations do not appear to have varied responses to rice. However, genetic differences may be observed in response to other variables. The variation in response of YSB populations to *Bacillus thuringiensis* (*B.t.*) is being investigated (see right column).

Soil suppressive to sheath blight. Field testing of bacterial isolates for biocontrol of rice diseases gave varied results. To determine whether the variability was field specific, soil samples were collected from 40 field plots at IRRI and assayed for suppressiveness and conduciveness to the sheath blight (ShB) *Rhizoctonia solani* pathogen. Soil samples were air-dried, sieved through a 2-mm screen, and then placed on plastic plates. Sclerotia germination and mycelial growth on the samples were evaluated.

To test for suppression of ShB lesion development, IR58, a rice variety susceptible to ShB, was directly seeded in soil mixed with the *R. solani* inoculum at a ratio of 1:20 (wt/wt). The rice plants were evaluated for ShB 40 d after sowing (DAS). Results showed that ShB was well developed in sterilized soil with pathogen inoculum at 21 DAS. Of 40 soil samples from different field plots, 14 were suppressive to ShB development and 8 were conducive (level of disease development was comparable with that of the check). In three consecutive rice plantings, several soil samples consistently reduced ShB severity (Table 27). Different bacteria were isolated from these soils. Some were Gram-negative with either yellow or creamy colony forms; others were Gram-positive with white colonies (Table 28). Both groups of bacteria inhibited sclerotia germination in *R. solani*. We will evaluate and characterize further their role in soil suppression of ShB development.

Pest control tactics

***Bacillus thuringiensis* effects on yellow stem borer.** Laboratory bioassays determined the toxicity of seven purified CryI and one CryII endotoxins of *B.t.* to YSB. The endotoxins were mixed into an artificial insect diet in a liquefied state (temperature below 60 °C). The diet-endotoxin mixture was poured into 20-ml scintillation vials without lids and dried overnight under a fume hood. Before infesting the vials with YSB (six 1-d-old larvae/vial), the diet's surface was split with a small spatula (5 slits/vial) to ease larval entry. The vials with larvae were inverted and incubated at 27 °C for 4 d, then mortality was recorded. Data were processed by Probit analysis.

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Table 28. Association of bacteria in suppressive and conducive soils.

Field no.	Soil type[a]	Bacteria colony description	CFU (10^7/g soil)	Germination (%)
B-42-A	C	Yellow, Gram-negative	5	40
		Bacillus, Gram-positive	12	0
		White, Gram-negative	320	90
B-13	S	Bacillus, Gram-positive	16	50
		White, Gram-negative	44	0
C-35	S	Bacillus, Gram-positive	47	10
		Yellow, Gram-negative	90	35
827	S	Bacillus, Gram-positive	5	0
		Fluorescent, Gram-negative	7	0
226	S	Bacillus, Gram-positive	52	20
		White, Gram-negative	3	30
L-2	S	Bacillus, Gram-positive	95	30
B-14	C	Bacillus, Gram-positive	28	35

[a]C = conducive, S = suppressive.

Table 29. Effect of *B.t.* purified endotoxins on the yellow stem borer.

Endotoxin	LC_{50} (ng/ml)	Slope
CryIA (a)	19,739	1.27
CryIA (b)	164	1.28
CryIA (c)	799	1.48
CryIB	11,548	0.75
CryIC	10,644	3.55
CryID	18,050	0.55
CryIE	515,094	1.56
CryIIA	1,406	3.92

CryIA(b) and CryIA(c) were the most effective against YSB, giving LC_{50} values of 164 and 799 ng/ml, respectively, followed by CryIIA with 1,406 ng/ml (Table 29). The results indicate that genes of CryIA(b), CryIA(c), or CryIIA should be the first choices in efforts to engineer *B.t.* endotoxin genes in transgenic rice deployment systems to control YSB.

Effect of green manure on nematodes. The rice-root nematodes *Hirschmanniella oryzae* and *H. mucronata* infest most of Asia's irrigated ricefields. Green manure (GM) crops *Aeschynomene afraspera* and *Sesbania rostrata* have potential to control rice-root nematodes. We measured the effects of planting and/or incorporating *S. rostrata* and *A. afraspera* on the nematodes and rice yields under the following experimental conditions: 1) rice grown continuously, 2) incorporation of *S. rostrata* and *A. afraspera* shoots after the first rice crop, 3) removal of *S. rostrata* and *A. afraspera* shoots following their growth as a first crop, and 4) incorporation of *S. rostrata* and *A. afraspera* shoots following their growth as a first crop.

Table 30 gives nematode soil populations after each crop and yields of the second crop (rice) in four experiments using *S. rostrata*. After the first crop, rice-root nematode population densities were lower in plots where *S. rostrata* was grown than in plots where rice was the first crop. These results indicate that growing *S. rostrata* effectively reduced rice-root nematode population densities. In addition, nematode population densities in experiments 2, 3, and 4 were reduced by the incorporation of *S. rostrata* shoots. Except for one treatment in experiment 4, the yield of the second rice crop was higher in plots with continuous rice when *S. rostrata* was incorporated than in the control plots. These results indicate a fertilizer effect of GM. Yields obtained in plots where *S. rostrata* had been grown as a first crop but not incorporated as GM were always higher than in the control plots. In all four experiments, the yield was highest when *S. rostrata* was grown as a first crop and incorporated. Results were similar when *A. afraspera* was used.

The experiments indicate that 1) rice-root nematodes may be controlled by crop rotation with *S. rostrata* and *A. afraspera* and to a lesser extent by incorporation of these legumes as GM, 2) the rice yield increase obtained after a rotation with *S. rostrata* and *A. afraspera* did not arise solely from a fertilizer effect of the GM, and 3) rice-root nematodes may cause significant yield losses in irrigated rice.

Table 30. Effects of *Sesbania rostrata* growth and incorporation of shoots on second crop (rice) yields and *Hirschmanniella mucronata* and *H. oryzae* population densities per dm^3 of soil.[a]

Treatments[b]			Initial nematode population (no./liter of soil)	Final nematode population (no./liter of soil)		Rice yield (t/ha)
Crop 1	Crop 2	Green manure incorporation		Crop 1	Crop 2	
			H. mucronata, experiment 1, rainy season			
R	R	–	860 a	766 b	783 b	2.2 c
R	R	+	1024 a	1055 b	621 ab	3.2 b
S	R	–	775 a	9 a	446 ab	2.9 b
S	R	+	750 a	12 a	352 a	4.0 a
			H. oryzae, experiment 2, rainy season			
R	R	–	771 a	708 b	465 b	1.2 b
R	R	+	500 a	705 b	40 a	3.0 a
S	R	–	494 a	1 a	0 a	2.8 a
S	R	+	472 a	4 a	24 a	3.2 a
			H. mucronata, experiment 3, dry season			
R	R	–	513 a	394 bc	390 b	3.8 c
R	R	+	827 a	628 c	123 a	4.6 b
S	R	–	181 a	204 ab	64 a	4.9 ab
S	R	+	474 a	38 a	26 a	5.4 a
			H. oryzae, experiment 4, dry season			
R	R	–	17 a	258 b	160 b	3.4 b
R	R	+	51 a	207 b	39 a	3.7 b
S	R	–	110 a	35 a	23 a	4.4 a
S	R	+	147 a	24 a	15 a	4.6 a

[a]Values are mean of five replications. For each experiment, means in each column followed by the same letter do not differ at $P < 0.05$ according to Duncan's multiple range test. [b]R = rice, S = *S. rostrata*, – = no incorporation of *S. rostrata* shoots, + = incorporation of *S. rostrata* shoots.

Integrated pest management implementation

Simulation analysis of insecticide spray efficacies. We used a simulation model to determine the effectiveness of insecticides to control BPH *Nilaparvata lugens*. The model assumes that the population is driven by an initial cohort of adults from neighboring crops or from long distance displacement. Biological processes (sex ratio, oviposition rates, and the age-specific daily survival rates of the various stages) are included as subroutines. Calculation of the life span of each stage assumes that the stage has a constant daily survival rate. If the probability of an adult surviving and remaining in the population to age j is Saj, it is viewed as the proportion of the adult cohort surviving to age j. Therefore, the number of adults surviving to time t from the initial cohort of a_0 will be $A_t = Sa_t \cdot a_0$. The total number of live adults at time t is then

Table 31. Developmental periods of BPH used in the simulations.

Parameter	Developmental period (d)		
	Adult females	Egg	Nymph
Mean (x)	18.87	12.82	9.19
Standard deviation (s)	7.98	5.38	1.40
Maximum duration (d)	32.00	15.00	13.00

$$A_t = \sum_{j=0}^{\alpha} S\,Saj \cdot a_{t-j}$$

where a is the potential adult longevity. Length of the egg and nymph stages are computed in the same way.

The model runs on daily survival rates generated from the mean and standard deviation and maximum

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stage development periods. Table 31 gives the parameters used. Test BPH populations were generated using a cohort of 5 BPH adults/hill per d and spray efficacy was computed as

$$\text{Spray efficacy} = \frac{K - J}{K} \times 100$$

where K = total adult-days with no spray, and J = total adult-days with spray.

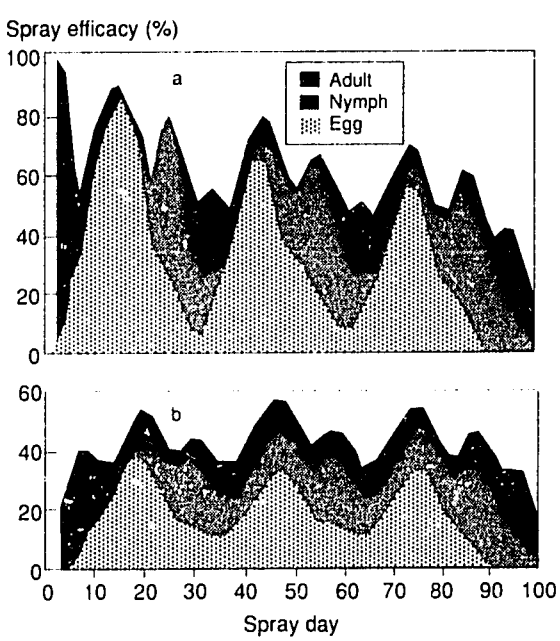
The effects of one spray on any day were simulated for two immigration patterns: 1) immigration by a single cohort, and 2) immigration at a constant daily rate. The simulations for an insecticide causing 100% mortality at all BPH stages showed that spray efficacy is reduced when immigration is daily (Fig. 8). The results imply that in the tropics where immigration is often daily, sprays would be much less effective than in temperate regions. Moreover, field sprays would likely be less efficient than assumed in the model.

For BPH control, most insecticides have little or no effect on the egg stage. Simulations without egg efficacy showed marked periods where sprays have virtually no impact (Fig. 9).

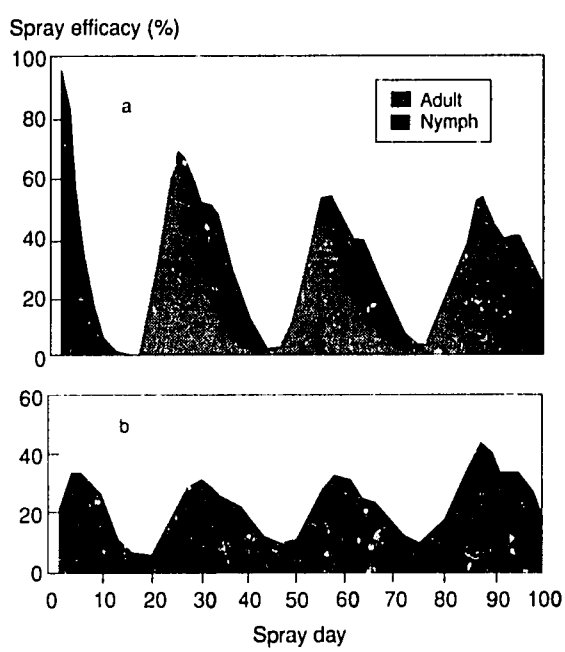
Where daily immigration occurs, spray efficacies are further reduced. Use of an insecticide with perfect kill gave only about 30% efficacy. In practice, even less efficacy would be expected. Since an insecticide would kill natural enemies as well in the tropics, significant payoffs from insecticide use against a pest such as BPH seem unlikely.

Ultralow-volume compressed air sprayer. The ULV compressed air sprayer is a new concept in low-volume hand-held spraying. It comprises a lever-operated air pump, power booster, and compression chamber, which supplies compressed air through a series of microtubes to a standard spray nozzle. In the spray nozzle, air is mixed with a very low volume of pesticide before being discharged. Air volume and pressure are accurately regulated to provide an optimum ratio of air and pesticide mix. Volume outputs range from 5 to 15 liters/ha, compared with more than 200 liters/ha with a conventional knapsack sprayer. Tests showed that most droplets were emitted as fine spray (100-200 μm) and the droplet size spectrum appears very narrow, an ideal situation for general insecticide and fungicide application.

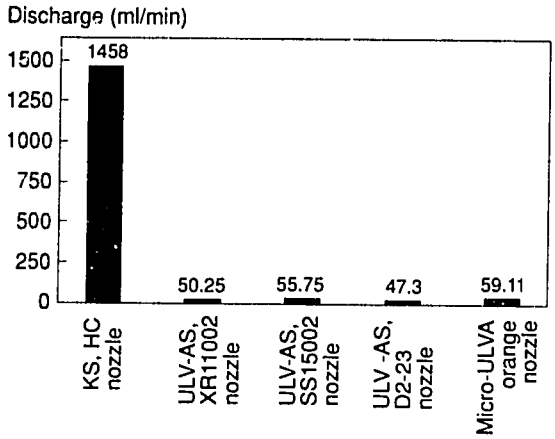
Figure 10 highlights the ULV aspects of the sprayer and compares it with a commercially available ULV sprayer, and a conventional knapsack sprayer. The discharge from the IRRI air sprayer is 4% of that of the knapsack sprayer.



8. Relative spray efficacy of a perfect insecticide on egg, nymph, and adult when adult recruitment occurs 1) on day 1 and 2) daily.



9. Relative spray efficacy of an insecticide with perfect efficacy on adults and nymphs with 1) recruitment on day 1 and 2) daily recruitment.



10. Discharge of liquid using various sprayers and nozzles. KS = Tung Ho knapsack sprayer with hollow cone nozzle, ULV-AS = ultralow-volume air sprayer.

Next steps

Research leading toward integrated pest management (IPM) implementation in selected irrigated environments will be stepped up in 1992. Comprehensive guidelines will be developed for implementing IPM for all major pests of irrigated rice in Central Luzon, Philippines. Then, a large-scale farmer participatory experiment will be organized to evaluate the impact of IPM at the village level. Pest management specialists, economists, trainers, communication specialists, and extension personnel will collaborate in designing, implementing, and evaluating the experiment. The objective will be to determine the costs and benefits of IPM at the farm and community levels and to identify constraints to and requirements for adoption.

Understanding pest epidemiology, dynamics, ecological interactions, and genetic variability is paramount to the design and implementation of IPM. This work will be continued and the knowledge gained will be used in developing the IPM guidelines.

Increasing the range and determining the impact of pest control tactics are other essential aspects of IPM. The project will continue to seek and evaluate biological, cultural, physical, and chemical tactics.

Subprogram III: Livelihood and production environments

Systems productivity and sustainable rice systems

In 1991, project goals were changed from an emphasis on systems productivity to a specific focus on identifying quantifiable indices of sustainability of rice systems that govern the short- and long-term viability of rice-based cropping systems. This report covers the transition. We present final reports concerning crop diversification and survey studies of farmer practices with regard to sources and processing of rice seed under former project activities, and the new project concept including the rationale and objectives for the change of emphasis.

Integration of forage legumes and food crops

Forage crops can be grown as a sole crop or intercropped with an upland cereal planted after rice in lowland soils during DS. Such a cropping pattern increases the diversity of the rotation and can result in greater total productivity than continuous double-cropping of rice.

Sorghum *Sorghum bicolor* was intercropped with forage legumes to evaluate the performance of the crop combinations as a source of human and animal food in rice-based cropping systems. We experimented in an IRRI field with the following soil characteristics: silty clay, pH 6.2, 1.0% organic C, 0.13% total N , 20 mg extractable P (Olsen)/kg, and 13.4 cmol(+) exchangeable K/kg. The forage legumes *Clitoria ternatea*, *Desmanthus virgatus*, and *Stylosanthes guianensis* were planted simultaneously with sorghum in alternate rows after minimum tillage. Monocrop treatments for all species and fallowed plots were included as checks. Supplemental irrigation was given three times. Sorghum was fertilized with 100-60-60 kg NPK/ha.

Forage was first harvested 60-90 d after seeding with subsequent cuttings at 3-wk intervals. The last herbage regrowth was incorporated as GM to the following rice crop (IR74). Sorghum was ratooned after the first harvest and allowed to produce forage. Fertilizer inputs of 30-30-30 kg NPK/ha were applied to the subsequent rice crop. Plots that were fallowed before rice were fertilized with 30-30-30, 60-30-30, or 90-30-30 kg NPK/ha for comparison with the GM treatments.

Sorghum grain and fodder dry matter (DM) yields were not affected by intercropping (av 4.01 t grain/ha and 4.27 t fodder/ha). Sorghum ratoon was likewise not significantly affected, with mean yield of 4.06 t DM/ha. However, ratoon DM yield was slightly lower with the presence of intercrops because of shading by the rapid regrowth of the fully established forage legumes. In monocrop systems, the highest

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total forage DM yield (13.9 t/ha) was obtained from desmanthus in 7 mo (Dec-Jun). Stylo gave forage yields of 10.2 t/ha and clitoria gave 9.3 t/ha. When intercropped with sorghum, forage yielded 46% regardless of species, although total fodder production was significantly higher with intercropping (av 14.14 t DM/ha) than with monocropping.

Rice yield was highest (4.8 t grain/ha, 5.4 t straw/ha) following clitoria and desmanthus monocrops. Rice following sorghum + desmanthus or clitoria treatments yielded 4.0 t/ha, which was similar to rice yields on fallowed plots that received 90 kg N/ha. Yields were lowest in plots planted previously to monocrop sorghum (2.4 t/ha) and fallowed plots that received 30 kg N/ha (2.9 t/ha). The results suggest that food and fodder production in rice-based farming systems can be increased through integration of cereal-forage legume crop mixtures. Furthermore, plow-down of the forage legume appears to contribute N to the subsequent rice crop, thus reducing the total fertilizer inputs required.

Farmers' seed selection and processing: practices and perceptions

Rice seed is easily contaminated by seeds of weed species of similar maturity, particularly when weed seeds are similar in size to the rice grain. Rice seed selection and cleaning methods used by farmers may reflect their awareness of the potential for weed seed contamination. A study conducted in Guimba, Nueva Ecija, Philippines, 1) examined farmer practices regarding seed selection and processing; 2) determined whether the degree of weed seed contamination was influenced by rice seed source, threshing method, and water source; and 3) surveyed farmer perceptions about the causes of weed problems in their ricefields.

Of 70 rice seed samples, 76% were obtained from seed saved by the farmer from his own field and 22% were obtained from a neighbor's field. Farmers chose seed in selected patches in their own or in a neighbor's field that appeared to have high-yielding, uniform plant types. Most seed was machine-threshed. Farmers passed a portion of the selected sheaves through the thresher before threshing the seed they would save. This reduced contamination from residual seeds of weeds or other rice varieties that may have lodged in the machine. To further eliminate weed seed, more than half of the samples were winnowed. In a few cases, threshed samples were placed in water to remove lighter seed that floated. Only 17% of the samples were manually threshed.

Ninety-seven percent of the samples were contaminated with weed seed. Major contaminants were *Echinochloa glabrescens* (contaminated 79% of the samples, at a mean of 56 *E. glabrescens* seeds per contaminated 1 kg rice seed sample), *Ischaemum rugosum* (71% of samples, 52 seeds/kg), *Echinochloa crus-galli* (30% of samples, 73 seeds/kg), and *Fimbristylis miliacea* (26% of samples, 8.2 mg seeds/kg rice seed or approximately 110 seeds/kg). Grouping the major weeds by similar species, *Echinochloa* spp. contaminated 87% of the samples, or 87 seeds/kg; other grasses (excluding *I. rugosum*) contaminated 10% of samples, with a mean of 15 seeds/kg; and sedges were found in 34% of the samples, with a mean of 10 mg weed seed/kg rice seed.

Seed from farmers' own fields had less weed seed than that from neighbors' fields. Although farmers obtaining seed from neighbors usually selected the patches to be used for seed, farmers processing seed for their own use were apparently more careful than farmers processing seed for others. Manually threshed seed was less contaminated with *Echinochloa* spp. and *I. rugosum* than machine-threshed seed.

Although more weeds would be expected in rainfed areas because of poor water control, only the seeds of sedges were found in significantly higher amounts than in areas served by shallow well or small communal and large irrigation systems. Other weeds did not differ with respect to water source.

Most farmers (60-75%) thought that the *Echinochloa* spp. were disseminated via contaminated seed rather than in the soil. However, 91% thought that *I. rugosum* was soil- rather than seed-borne. Although farmer reasons for these perceptions were not determined, lack of awareness that *I. rugosum* was a seed contaminant may reduce farmers' care in selecting patches for seed harvest.

Researchers are studying the relationship between farmers' practices and their perceptions concerning N fertilizer management and pesticide use against defoliators in the early season. Comparing the results with recommended practices would help in identifying production constraints that are unknown to or underemphasized by rice researchers.

Indices of sustainability of rice systems

Intensified rice cropping in irrigated systems resulted from the introduction of modern, short-dura-

tion varieties and small-scale mechanization of threshing and tillage operations that reduced the turnaround time between crop cycles. Continuous, irrigated rice systems with two and sometimes three yearly rice crops are now common throughout Asia. The intensification of rice cropping may have contributed as much to the increase in global rice supplies from the green revolution as has the increased yield potential of modern varieties.

From a historical perspective, intensive rice systems are in their infancy. Although they have existed for less than 30 yr, food security for billions of rice consumers depends on the ability to sustain productivity of these agroecosystems. With loss of prime irrigated land to urbanization and industrialization, further intensification on existing irrigated land and increased yield per unit area will be required to meet the future needs of an expanding population. A crucial issue is whether intensive, irrigated rice systems maintain the resource base on which future productivity depends, or whether the structure and function of such agroecosystems cause changes in the resource base that lead to greater input requirements or undesirable externalities.

Recent evidence from long-term field studies of continuous rice systems indicates disturbing trends. All of these experiments follow a similar concept in which management practices are optimized to include the best varieties, complete water control with irrigation, recommended nutrient inputs, and modern pest management strategies. In one experiment at IRRI with three rice crops per year, yields of the highest yielding varieties have declined linearly by 35-40% since 1968 ($r = -0.82$, DS). At a research site in Nueva Ecija, Philippines, yields in WS have declined by nearly 100 kg/ha per yr since 1968 ($r = -0.68$) in a continuous double-crop rice system. In a similar double-crop system in Hyderabad, India, DS rice yields have also declined by about 40% in a 12-yr period. At best, yields have remained constant in several other long-term studies, but even these results arouse concern because rice yields in Asia on irrigated land must increase to meet future demand.

Sobering production trends are also evident from aggregate data of some Asian countries and survey data in which yields and input use were monitored for the same farmers over 8-10 yr. In Indonesia, the Philippines, and Thailand, for example, rice yield per unit of fertilizer applied has decreased substantially in the past 10 yr.

With a growing body of evidence that rice yields stagnate or decline under intensive rice cropping with present management practices, it is urgent that we understand the fundamental basis for sustained productivity and output/input efficiency of these systems.

Next steps

A new set of project objectives specifically targets the issues of sustained productivity in intensive irrigated rice systems. Beginning in mid-1991, project goals have emphasized 1) identifying the factors responsible for the yield decline in some continuous rice systems, and developing management strategies that reverse or prevent such declines; 2) quantifying system output/input efficiencies as indices of change in the resource base, with emphasis on the relationship between productivity and specific soil properties that are crucial to soil quality in irrigated rice systems; and 3) understanding farmer knowledge and perceptions of soil quality, changes in output/input efficiencies, and short- vs long-term trade-offs in management strategies to sustain productivity of intensive rice systems.

Rice-wheat systems

The IRRI Program report for 1990 previewed the inception of an international collaboration in rice-wheat research. The initial activities of that collaboration are described here. The importance of on-farm diagnosis of constraints to rice-wheat productivity and profitability in helping guide research priorities was emphasized in the program reports for 1989 and 1990. This year we feature a new initiative in long-term monitoring of farm practices and farm resources (including land) as an indicator of system sustainability. We also report national, state, and district statistics for the trends in rice and wheat production in relation to human population and describe continuing work addressing the constraint of inadequate wheat establishment following rice.

International collaboration in rice-wheat research

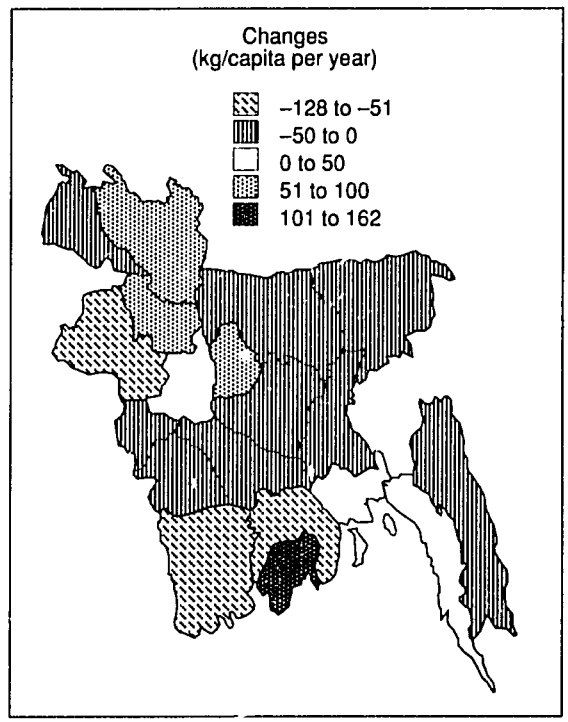
About one-half of the world's 20-25 million ha planted to a rice-wheat system is in Bangladesh, India, Nepal, and Pakistan. In May 1991, their agricultural research systems, together with IRRI and the International Maize and Wheat Improvement Center

(CIMMYT), defined a consortium-model research agenda (and budgets). Through nine lead centers (key sites) the collaboration aims to address the constraints to rice-wheat productivity and profitability that have been provisionally identified for each country's major rice-wheat production zones. The agenda also prominently features an expanded diagnosis for system constraints and interactions, and includes professional development programs and international travelling workshops.

Production trends. Geographic information systems and district-level statistics of rice and wheat production and productivity are being used to determine current levels and historic trends in area and productivity of the rice-wheat system. New estimates for the area practicing the rice-wheat sequence are 0.6 million ha in Bangladesh, 9 million ha in India, 0.5 million ha in Nepal, and 1.5 million ha in Pakistan. China has 10.3 million ha of rice-wheat or rice-rice-wheat. Productivity data indicate that yields of rice and wheat continue to increase in most regions of South Asia, but with much higher farm inputs. Moreover, rice yields in Haryana, India, which increased steadily to 1978, have since then been static, probably because rice-wheat has been extended to inferior lands with poor quality water. In other regions, combining rice and wheat productivity data with census data on human populations helps determine whether rice and wheat in individual districts and countries is keeping pace with population growth. For each administrative district of Bangladesh, the change from 1961 to 1987 in production of rice-wheat has been quantified in relation to population. Many districts show lower production per resident person in 1987 than in 1961 (Fig. 11). For Bangladesh as a whole, the 146 kg/capita per year in 1987 was 17 kg (or 10%) less than in 1961.

Diagnostic and monitoring surveys. Diagnostic surveys of farmer practices and inputs and of constraints and opportunities in the rice-wheat system have been concluded for rice and wheat phases for the regions surrounding Bhairawa (Nepal terai), Faizabad (rainfed Uttar Pradesh, India), and Pantnagar (irrigated terai, Uttar Pradesh). Common constraints specific to or important for the rice-wheat system were

- delayed and suboptimal establishment of rice and wheat (sometimes exacerbated by poor compatibility of rice and wheat cultivars),
- excess water use for wheat and occasionally rice,



11. Changes in rice-wheat availability per person in Bangladesh between 1962 and 1987.

- weeds and rats,
- lack of rice threshers and rice and wheat reapers, and
- labor scarcity at rice transplanting and at rice and wheat harvests.

Sustainability of productivity is a major concern for rice-wheat systems, as is sustainable profitability for farms where production is maintained only by large increases of inputs. The international collaboration is therefore seeking to quantify sustainability through ongoing and new long-term experiments on crop and resource management, and also through a new program for regular, long-term monitoring of farmers' practices, inputs, productivity, and resource (including land) quality. The first monitoring was initiated during the 1991 wheat season for 170 farm fields in the region surrounding Bhairawa (Nepal). CIMMYT designed and conducted the sampling, and IRRI participated in the analysis using a model that relates estimates for short- and long-term sustainability to a measured index of land quality—an index that is influenced by present and past farm management practices such as application of farmyard manure (FYM). Short-term sustainability (which can be affected by present management) is repre-

sented here by the ratio of actual farm yield to an estimate of the maximum possible when using the farmer's resource inputs. This ratio is analyzed for its dependence on eight agronomic/management factors (choice of wheat cultivar, quality of land preparation, ratio of N:P fertilization, promptness of seeding, plant-population density at and after seeding, and incidence of diseases and rats) and on nine socioeconomic factors: farm size, number of landholdings, farm accessibility, irrigation, mechanization, farm-family size, availability of off-farm employment, labor status (indigenous or immigrant), and tenure. Long-term sustainability (influenced by consistent management) is assessed using the effects of short-term sustainability, land quality, and farm practices in an economic model for wheat yield. The model—the translog production function, which can estimate elasticities, interactions, and effects of input substitutions—related wheat yield to soil type, irrigation (reflecting access to tubewell water), waterlogging (natural drainage), crop rotation (allowing for the effect of break crops), inorganic and FYM fertilizers, and weeding.

Results for short-term sustainability indicate that wheat yields were 25% less than optimal in fields on which neither farmyard manuring nor intercropping with mustard was practiced. This effect was more pronounced on poor quality, marginal lands. The short-term (wheat) sustainability was lessened equally by farm management features (inappropriate choice of cultivar other than NL297, poor land preparation and wheat establishment, diseases, and rats) and socioeconomic factors (inaccessibility, owner management, and off-farm work opportunities).

Long-term sustainability was enhanced by farmyard manuring and crop rotation on nearly all land types. Effects could be detected within a period as short as 3 yr. Each year, for every animal/ha, 0.5 t FYM/ha was made available for wheat; but one additional farm-family adult/ha diverted manure and lessened its availability by 0.15 t/ha. The lack of fuelwood further lessened manure availability by 0.6 t/ha per yr.

Interaction terms indicate that deep clay soils are more responsive to fertilization than coarser soils. One additional irrigation for wheat on clay soils in a well-weeded rice - mustard - rice - wheat sequence produced an incremental 90 kg of wheat grain/ha in naturally drained soil but only 36 kg/ha in waterlogging-prone land. Corresponding values for incremental gains from 1 kg of inorganic fertilizer/ha were 10 and 2.6 kg/ha; for 1.0 t FYM/ha, the gains were 41 and 10 kg grain/ha. Averaged over all environments and farm practices and crop rotations, a decrease of 1.0 t FYM/ha requires the substitution of 9.5 kg of inorganic nutrients/ha to maintain wheat productivity.

Field studies within the International Rice-Wheat Collaboration. During 1991, programs of field experimentation have been implemented to varying extents at the nine lead centers within the four cooperating South Asian countries. Because of the many interactions in the rice-wheat system, these programs carry out multifactorial, multidisciplinary production and investigational studies. The main features of these interactive programs are summarized here for each center. Some preliminary findings are given, although these activities were initiated only in the later part of 1991.

- In Kala Shah Kaku (Punjab, Pakistan), issues of tillage and seeding for rice and wheat are being studied interactively with concerns of weed management and wheat duration. Findings from the rice phase indicate that the benefit of controlling weeds (predominantly broadleaved species) is proportionately higher for rice grown on puddled than on nonpuddled soil.
- In Dokri/Larkhana (Sind, Pakistan), the field program addresses rice and wheat fertilization, tillage, irrigation, and seeding for wheat (including tests of a New Zealand seeder and of relay seeding), and the options of rice - legume - wheat rotations. Preliminary results show that for experiments on-station and in a farmer's field rice yields were 7% higher when 8 t FYM/ha was added to the recommended applications of inorganic fertilizer.
- In Joydebpur (Bangladesh, simulating Chuadanga conditions), activities examine the effects and interactions of puddling and nonpuddling land management for rice with tillage alternatives for wheat and with system fertilization.
- In Dinajpur (Bangladesh), an integrative program examines rice-wheat rotations that involve jute or GM together with major nutrient and micronutrient fertilization and wheat establishment.
- In Bhairawa (Nepal), experiments are evaluating proven Chinese technologies for wheat tillage and seeding, options for relay seeding of wheat

and of deep tillage for both rice and wheat, long-term fertility (including effects of Zn and B), pathogens, and nematodes.

- In Naldung (Nepal), experiments at elevations of 500, 1,000, and 1,500 m on terraced riceland study the effects of wheat fertilization and cultivars.
- In Faizabad (India), effects and interactions are sought among land management for rice, tillage or seeding for wheat, duration of rice growth, and organic fertilization. In 1991, when the monsoon arrived very late, rice yield averaged 2.2 t/ha across three puddling treatments compared with 1.6 t/ha for two nonpuddling preparations.
- In Nainital (Pantnagar, India), integrative research measures the effects and interactions for rice-phase tillage, wheat establishment, pest management, and NPK fertilization. Preliminary data show that the wheat population established in previously puddled soil was initially 24% higher with direct drilling than with conventional tillage; but by 47 DAS, increasing tillering in cultivated soil lessened this advantage to 10%, and the aboveground DM of wheat was 5% higher and the root fresh matter 80% higher in cultivated soil.
- In Kaul (Haryana, India), effects and interactions are sought among 1) irrigation regimes for the rice-wheat sequence (conventional regime compared with a regime using 30% less water), 2) three combinations of rice and wheat establishment, and 3) three levels of fertilization applied to both rice and wheat (recommended rates of NPKZn, recommended rates of NPKZn + 10 t FYM/ha, and 1.5 × recommended rates of NPKZn). Initial measurements show that the wheat population was 18% higher from seeds drilled into thoroughly harrowed seedbeds than from seeds broadcast into less harrowed soil.

Rice-soil structural management for postrice wheat

Emergence and growth of postrice wheat were investigated in field trials at IRRI to determine effects and interactions of three methods of postrice tillage for wheat seed zones in eight combinations involving three methods of wheat seeding, two seed rates, and wheat seed zone structural amendment applied with 5 t gypsum/ha to fieldwater during the preceding rice crop. The eight treatments were each applied at three delayed wheat seedings with respect to rice harvest, resulting in different regimes of seed zone moisture and strength. The preceding irrigated rice was grown in rows spaced alternately at 7 and 28 cm. The 28-cm spacing allowed easy access of postrice implements that tilled the soil and sowed the wheat without impediment from rice roots and stubbles.

Six of the eight treatments involved a prototype slit seeder (S). This design (improved since the 1990 Program report) sows two rows of wheat 10 cm apart within the 28-cm interstubble spaces. The seeder was used in nontilled (T0) soil, in soil rototilled between stubbles (T1), in soil previously treated (G1) or not treated (G0) with gypsum, and with wheat seed rates of either 60 or 120 kg/ha. The six selected combinations were S-T0-G0-60, S-T0-G0-120, S-T1-G0-60, S-T1-G0-120, S-T0-G1-60, and S-T1-G1-60. Gypsum was thus evaluated in both tilled and nontilled soil, but only at the lower seed rate, where its prospective benefit in enhancing emergence would be more beneficial. A seventh treatment, M-T1-G0-120, provided manual seeding (M) against which to evaluate the prototype seeder. The eighth treatment, PBH-G0-120, involved the traditional farmers' method of plowing, broadcasting wheat seed (at 120 kg/ha), then harrowing the seed zone.

Seed zone moistures (vol/vol) at the three wheat seeding dates (following rice harvest on 14 Dec 1990) were 0.46 on 3 Jan 1991, 0.46 on 5 Jan, and 0.38 on 13 Jan. For the seeder, tillage promoted higher rates of emergence at each seeding rate and each seeding delay (especially for the longest delay), but emergence from the seeder was less than from manual sowing or from the traditional plowing, broadcasting, and harrowing, although the two latter treatments had higher seed zone strength. Gypsum also enhanced emergence by about 5%. (Emergence rates for the 13 Jan sowing were influenced by rainfalls of 7 and 8 mm on 14 and 15 Jan.)

For all treatments, average values for plant-population density at emergence were adequate for wheat production, but with mechanized seeding, more than 30% of the seeded area had unseeded sections (gaps along seed rows) of 10 cm or more. After emergence, all treatments were irrigated to return the soil to field-capacity moisture whenever one-half of the plant-available soil water in the root zone was calculated to have been depleted. This irrigation allowed subsequent wheat tillering and culm survival to achieve more than 6 million culms/ha (MC/ha) at maximum tillering and about 4 MC/ha at harvest on all treatments. Tillering was somewhat less without tillage,

and was highly variable—only a small part of the variation related to variation in emerged plant population. (The relations of wheat population density at harvest to those at plant emergence and at maximum tillering were consistent with those determined at the same site in 1990.) Irrigation also helped maintain soil strength below 0.3 MPa throughout the season in the 0- to 0.2-m depth. Root-length density (for all treatments and seeding delays) was 0.2-1.5 cm/cm^3 in the 0- to 0.2-m depth and 0.02-0.3 cm/cm^3 in 0.2 to 0.7 m.

Grain yields averaged over all tillage, seeding, and gypsum treatments were about 1.7 t/ha for the earlier sowings and 1.3 t/ha for the later ones. Because of late-December rains, the first sowing (3 Jan) was later than intended and was so close to the second sowing in timing, seed zone moisture, and wheat growth that yields of the first and second sowings in each treatment were combined. For earlier sowings, and for mechanized seeding only, yield from 120 kg seed/ha was 2.06 ± 0.07 t/ha—18% higher than the 1.74 ± 0.05 t/ha achieved with 60 kg seed/ha.

For the third sowing (13 Jan), the higher seed rate again produced 18% more grain: 1.45 ± 0.08 t/ha compared with 1.23 ± 0.08 t/ha for the lower rate. At the higher rate, and averaged over all seeding delays, shallow rototillage (T1) increased yield over T0 by only 3 ± 5%, but T1 increased yield by 13 ± 5% at the lower seed rate.

Yields were not affected by gypsum. In contrast to findings at the same site in 1990, traditional plowing, broadcasting, and harrowing (PBH) produced the least grain among the 120 kg seed/ha treatments: 1.63 ± 0.22 t/ha for early sowings and 1.26 ± 0.11 t/ha for later ones. T1 with manual sowing of 120 kg seed/ha yielded less (1.75 ± 0.05 t/ha) than mechanized seeding in earlier sowings, but was comparable (1.49 ± 0.12 t/ha) in later ones. Mechanized seeding achieved yields in excess of 2.0 t/ha despite the gaps along rows of emerged seedlings.

Wheat duration was not constant for all treatments with the same sowing date because heavy March rains caused lodging and enforced a premature harvest for some plots. However, the varying duration allowed us to analyze wheat grain production for each day of plant duration (sowing to harvest) in the field. The production rate was highest for durations of 76-80 d, which were 10-14 d less than the nominal 90-d duration for the wheat cultivar we used, and was 10% less than maximal at 67- and 88-d duration.

Effects of tillage, gypsum, and delayed sowing on seedling and plant growth (as separated from effects on seeding emergence) can be determined more effectively through analyses of yield/million emerged plants (Y/MEP) or of yield/million harvested culms (Y/MHC) than through yield/ha. For all sowing delays, Y/MEP was highly variable among treatments, and was substantially higher for 60 than for 120 kg seed/ha. For early sowings, PBH gave higher Y/MEP than other treatments with a seed rate of 120 kg/ha, except during the third sowing (into drier soil). Gypsum gave a slight increase in Y/MEP for the third sowing, but not for the earlier ones.

Y/MHC was much less variable than Y/MEP, reflecting the influence of compensatory tillering. Y/MHC was not affected by tillage at either seeding rate, but was increased by gypsum at the lower seed rate.

Next steps

During 1992, the International Collaboration in Rice-Wheat Research shall pursue its program in diagnostics and monitoring—including diagnostic surveys in Bangladesh (Chuadanga and Dinajpur), India (Haryana), and Nepal (Naldung). It will hold an advanced workshop (Kathmandu) to define and standardize procedures for on-farm monitoring and analysis in relation to sustainability, and to analyze (by the standardized procedures) two extensive data sets recently gathered in monitoring programs in Sind and Punjab (Pakistan). We shall conclude ongoing analyses for India and Nepal with analysis, synthesis, and interpretation of national and district statistics for rice-wheat production and productivity. We will then compile data bases for Pakistan.

Findings from the diagnostic and monitoring activities shall continue to guide the objectives and activities of the several multifactor field studies. The studies are conducted in the nine lead centers and are addressing in an integrative manner the various constraints to rice-wheat productivity and sustainability. The 12 million ha of roughly contiguous rice- and wheat-growing areas of South Asia represented by the lead centers comprise a major ecoregional system—this ecoregional perspective will be recognized and featured in future planning (both scientific and administrative) of the Collaboration.

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Global climate change and rice

Policymakers and scientists have become increasingly concerned with global environmental issues. As a result of stratospheric ozone depletion, greater penetration of ultraviolet-B (UV-B) radiation has increased CO_2 and CH_4 concentrations in the atmosphere, which may cause temperatures to rise through the greenhouse effect.

This project addresses two major questions: how will global changes affect rice production and how does rice production affect global climate change? Last year's report included initial results of research on the effects on rice of ambient UV-B radiation and high temperature stress. This report will focus on CH_4 emissions from flooded rice soils and rice ecosystem modeling activities.

Methane emissions from flooded rice soils

Atmospheric CH_4 concentration has increased about 1% annually to 1.7 ppmv during the last three decades. About 500 million t of CH_4 is emitted annually into the atmosphere. Global CH_4 emission has to be reduced because CH_4 contributes significantly to the greenhouse effect, it is an important sink for the atmosphere's cleaning agent (OH radicals), and oxidation of CH_4 in the stratosphere provides a pathway for enriching the stratosphere with H_2O and resulting ice crystals, which catalyze O_3 destruction.

Flooded ricelands are a major source of atmospheric CH_4. CH_4-producing bacteria thrive in flooded soils, and rice plants conduct CH_4 from the soil to the atmosphere. CH_4 emissions increase whenever rice growth increases. The challenge is to develop technologies that increase rice yield and reduce CH_4 emission at the same time. Before mitigation options can be developed, we have to identify the mechanisms that control CH_4 fluxes in ricefields and we have to reduce uncertainties about the strength of CH_4 sources.

Ricefields are estimated to emit 40 million to 100 million t of CH_4 into the atmosphere each year. This is 10-20% of the total annual CH_4 emission from all sources. Estimates of C cycling indicate that Asian ricefields may emit up to 63 million t of CH_4/yr. The estimate is reduced to 47 million t (Table 32) if different CH_4 production potentials for various soil types are taken into consideration. These estimates do not include ebullition of CH_4 through disturbance of rice soil during cultivation practices.

IRRI and the U.S. Environmental Protection Agency started a collaborative research project on

Table 32. Estimated methane emission from Asian wetland ricefields based on C inputs and modifying soil properties.

Country	Harvested rice area (km^2)	Rough rice production (million t/yr)	Annual C input[a] (million t)	Annual methane emission (million t)	Annual methane emission modified by soil properties (million t)
Bangladesh	97,216	22.7	10.3	4.1	3.96
China	321,499	174.7	53.3	21.3	14.71
India	426,545	92.4	46.4	18.5	14.54
Indonesia	79,439	40.5	11.3	4.5	3.54
Japan	13,707	13.4	2.5	1.0	0.80
Kampuchea	10,113	2.0	0.9	0.4	0.35
Democratic People's Republic of Korea	10,403	8.0	1.9	0.8	0.56
Republic of Korea	6,644	6.2	1.3	0.5	0.43
Laos	3,525	1.2	0.4	0.1	0.08
Malaysia	5,895	1.7	0.7	0.3	0.17
Myanmar	40,048	14.0	4.9	2.0	1.39
Nepal	6,589	2.7	0.7	0.3	0.18
Pakistan	18,513	4.9	2.1	0.8	0.41
Philippines	25,464	8.9	3.0	1.2	0.82
Sri Lanka	7,331	2.4	0.9	0.4	0.25
Taiwan	6,358	2.3	1.1	0.4	0.42
Thailand	92,366	19.2	9.5	3.8	2.24
Vietnam	58,219	15.4	6.7	2.7	1.84
Total	1,231,874	432.6	157.9	63.1	46.69

[a]15% of straw, 100% of roots, 100% of aquatic biomass (algae and aquatic weeds), and 50% of weeds are returned. Organic amendments are not included. 30% of returned C is transformed to CH_4.

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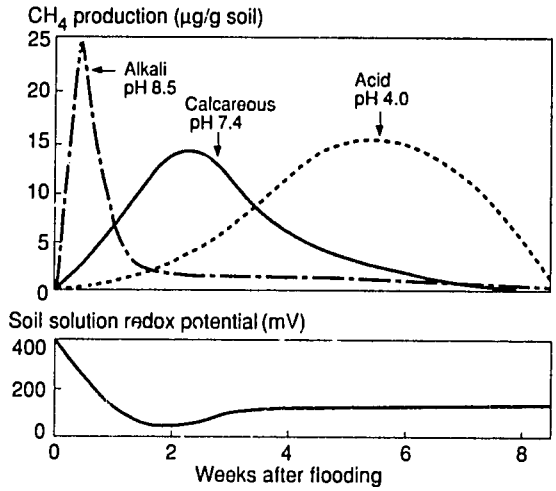
CH_4 from ricefields with the Fraunhofer Institute of Atmospheric Environmental Research, Louisiana State University, and the Agricultural University of Wageningen. In a greenhouse experiment to determine the effect of soil properties on CH_4 production, seven soils from different rice-growing areas were collected, set in greenhouse pots, planted to IR36, and kept flooded to 5 cm. Soil solution was anoxically drawn by gravity to monitor chemical and electrochemical changes. CH_4 production from undisturbed soil cores was determined by a gas chromatograph with a flame ionization detector using a Porapak N column.

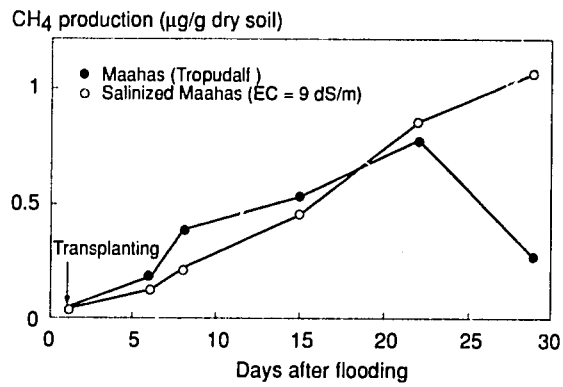
The pattern of CH_4 production is influenced by initial soil pH, organic matter, and anoxic soil conditions. High pH favors CH_4 production. Alkali and neutral calcareous soils produced CH_4 shortly after flooding although the Eh of the soil solution was greater than -200 mV. In acid soils, CH_4 production began later but lasted longer. Peak CH_4 production in the calcareous and acid soils was attained at a soil solution Eh less than 100 mV and pH near neutral (Fig. 12).

In another greenhouse study, the effect of electric conductivity on CH_4 production in a Tropudalf soil (Maahas clay) planted to IR72 was determined. The addition of NaCl salt slightly delayed CH_4 production, but the effect did not persist (Fig. 13). CH_4 production in naturally saline soils may be suppressed by related sulfate concentrations rather than by electric conductivity.

We commenced baseline measurements of CH_4 in an irrigated wetland soil (Maahas clay, pH 6.4, 1.57% organic C, CEC 37.3 meq/100 g) using a 24-h closed chamber measuring system. Treatments were four modes of urea fertilizer application: T1 = broadcast at transplanting, T2 = broadcast and incorporation at final harrowing, T3 = broadcast 10 d after transplanting, T4 = deep placement of urea supergranule at transplanting; no N fertilizer at later growth stages. CH_4 emission rates (10-50 mg /m^2 per d) were low because of prolonged presubmergence and low rice growth—straw yields inside the chambers were equivalent to 1.8-2.8 t/ha. Soil pH was constant at about 7, soil redox potential varied from 0 to 100 mV, and soil temperature in all treatments ranged from 29 °C during early growth stages to 26 °C after flowering. The mode of emission was similar under all treatments. Emission rates were lowest in T1, which also gave the lowest rice yields.



12. Methane formation in alkaline, calcareous, and acid soils.



13. Kinetics of soil-entrapped methane in NaCl-salinized soil.

Future plans. Research will continue to investigate the effects of N fertilizer application methods on CH_4 emission in irrigated fields. Effects of organic amendments, water regimes, and cultivars will also be studied.

Environmental conditions in the Philippines represent only a small spectrum of rice ecosystems. Therefore, in national research systems representing major rice ecosystems and subecosystems, additional activities will be established with funding from the United Nations Development Programme.

Rice ecosystem modeling—insects

Global climate change can affect rice pests and diseases. Rice ecosystem modeling activities have combined experimental and simulation approaches to assess the effect of increased temperatures on the distribution of BPH.

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Phytotron experiments showed no significant differences in mean longevity in the 25-35 °C temperature range (Table 33). At 40 °C and above, however, longevity was reduced dramatically. No BPH survived more than 24 h at 45 °C. High temperatures also reduced oviposition, with 30 °C appearing to be optimum (Fig. 14).

We compared the abilities of different BPH populations to survive high temperatures. The time required to kill 50% of a population exposed to a constant lethal temperature was the same for all BPH populations reared on different rice cultivars (Table 34). The macropterous female was most tolerant of high temperatures.

Pest data collected in the Republic of Korea from 1980 to 1989 were used to construct a data base in the Spatial Analysis System. Topographical base map layers were constructed based on 250- × 250-m interval readings of elevation. Polygons of county and provincial borders were constructed separately (Fig. 15). Polygons were reclassified and categorized according to climatic conditions, cultural practices, and regional environments.

The 10-yr data of daily trap catches and pest occurrences in rice from 138 pest surveillance stations were used to build thematic map layers. The layers were overlaid and analyzed using climatic and topographical map layers to identify zones where pest problems were greatest.

Both spatial and temporal BPH patterns were displayed using the geographic information system. Contingency analysis of map layers showed that areas with greater BPH densities were closely related to zones of early season immigration (Fig. 16). High temperatures after immigration also favored BPH outbreaks. Annual spatial distributions were analyzed for striped rice borer and rice water weevil. Spread of the weevil, which recently invaded the Republic of Korea, was related to wind speed and direction and to topography. High risk zones for the rice water weevil were identified by overlaying related map layers. The finding awaits validation from pest surveillance.

Future plans. Research will investigate other insect pests and the extrapolation of the geographical information system to larger areas, and will link pest incidence maps with predictions of rice crop yield loss.

Table 33. Mean longevities of brachypterous BPH adults at different temperatures.

Temperature (°C)	Sex	Mean longevity ± SE[a] (d)	Maximum
25	M	10.06 ± 1.76	22
	F	14.10 ± 2.08	27
30	M	7.72 ± 1.06	18
	F	15.12 ± 1.97	35
35	M	8.46 ± 1.33	17
	F	12.72 ± 1.69	23
40	M	2.58 ± 0.64	7
	F	2.32 ± 0.56	9

[a]SE at 95% CL.

Table 34. LT_{50} values of BPH from 3 rice cultivars.

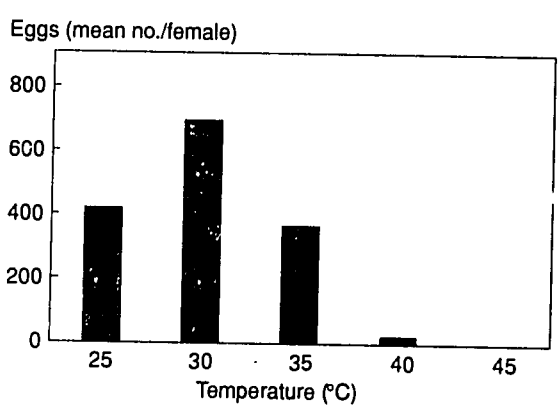
Insect, cultivar	LT_{50}[a] (h)	Fiducial limits	Slope
3d instar			
TN1	22.8	17.9 - 31.8	2.5
Mudgo	24.1	18.6 - 35.9	2.4
ASD7	24.6	18.1 - 42.1	2.0
5th instar			
TN1	27.3	25.1 - 30.2	4.6
Mudgo	32.2	29.4 - 36.8	4.8
ASD7	34.2	30.6 - 40.5	4.2
Brachypterous female			
TN1	19.4	10.8 - 27.8	5.4
Mudgo	13.7	10.9 - 16.6	6.1
ASD7	14.5	11.6 - 17.5	6.1
Macropterous female			
TN1	55.5	44.9 -107.1	3.5

[a]Time required to kill 50% of a population exoosed to a constant lethal temperature.

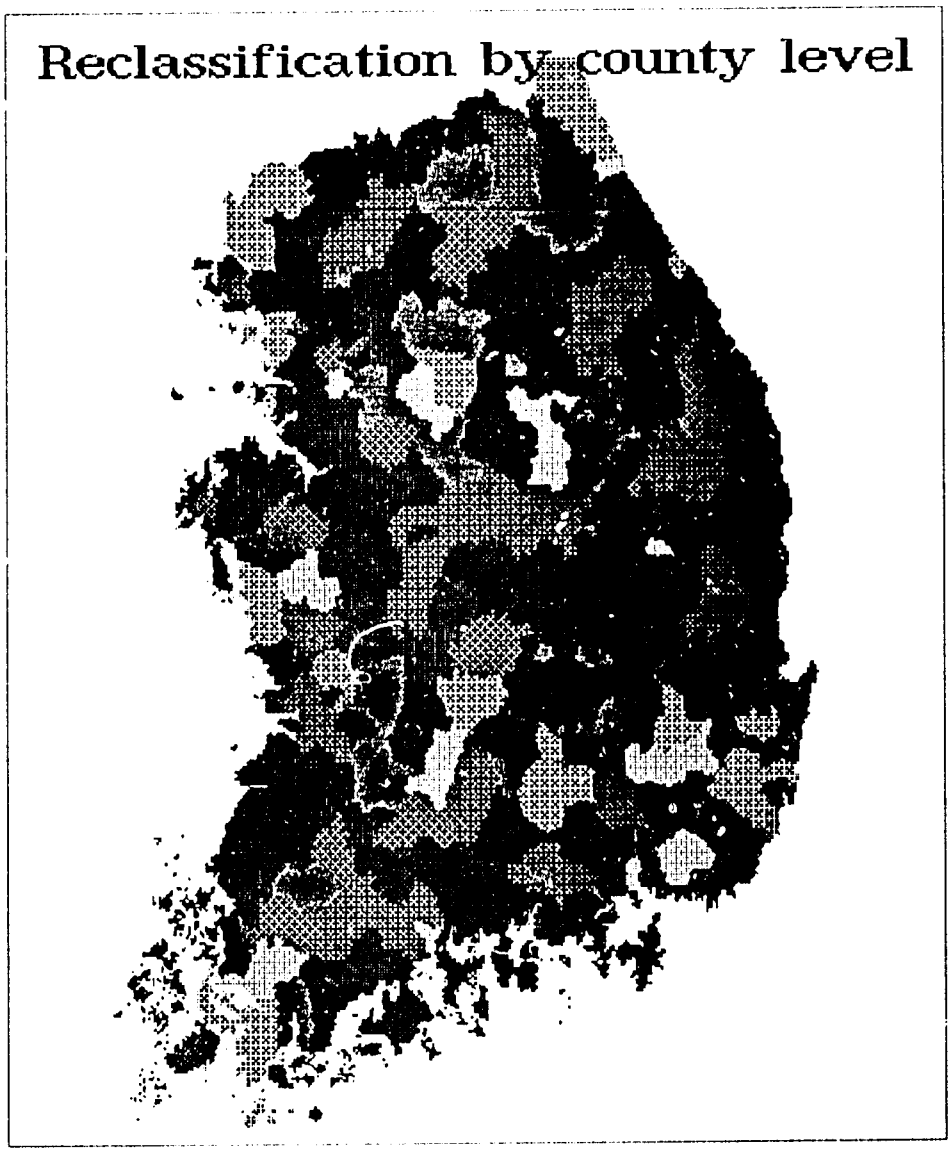
Technology-environment interactions

Health impact of pesticide use

For a comprehensive assessment of the impact of pesticide use in the Philippines, environmental and health data from selected pesticide-exposed farms and farmers in Laguna and Nueva Ecija and from control farms and farmers in Lucban, Quezon, were



14. Effect of temperature on BPH oviposition.



15. Topographical base map of pest data in the Republic of Korea.

intensively and extensively monitored from 1989 to 1991. Twelve biological, medical, and social scientists worked together on the same sample of 56 Laguna farms or farmers, 57 Nueva Ecija farmers, and 39 Lucban farms or farmers.

Results of environmental impact analysis showed no detectable residues in the soil, surface water, or grains from the Laguna or Lucban field samples. However, results indicated leaching of monocrotophos, endosulfan, and chlorpyrifos into the groundwater, and residues of at least one of these insecticides were detected in six of the seven artesian wells monitored in Laguna. We detected monocrotophos residues ranging from 0.1 to 1.84 μg/ml in one well. That amount exceeded the acceptable daily intake of 3×10^{-4} mg/kg of body weight. Well water is used as drinking water.

Health impact results showed that eye, dermal, neurologic, hematologic, pulmonary, and gastrointestinal problems are associated significantly with long-term pesticide exposure (Table 35). We suspect that cardiovascular problems are also associated

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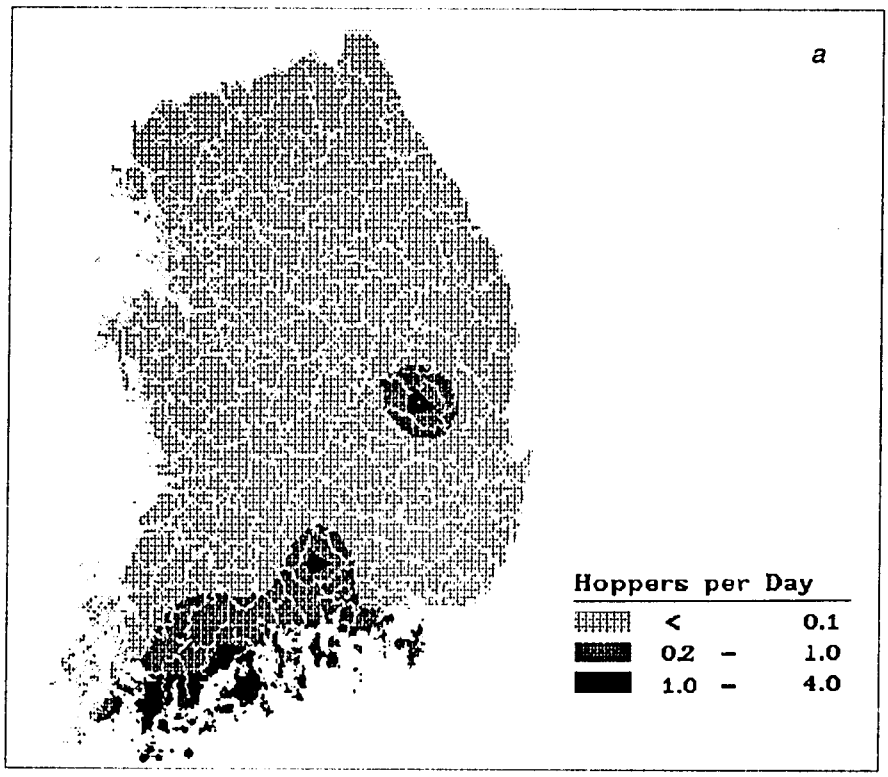

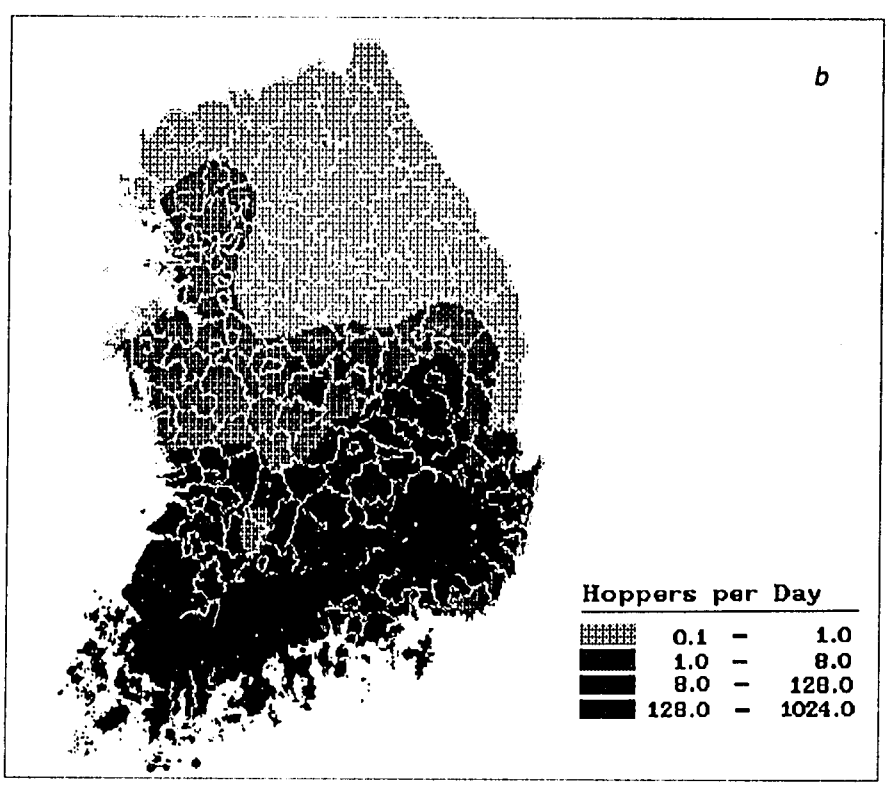

16. Early immigration zones of the brown planthopper in the Republic of Korea.

with long-term pesticide exposure but evidence for this remains inconclusive because of the small sample size in the younger age group of the control (Table 36). The percentages of abnormal findings in the Nueva Ecija and Laguna (exposed) samples was significantly higher than in the Lucban (unexposed) samples, particularly for pterygium, nail pitting, eczema, polyneuropathy, bronchial asthma, anemia, and chronic gastritis. Health costs were statistically the same for the pesticide-exposed groups ($110 for Laguna and $113 for Nueva Ecija) but significantly higher than those of the control group ($69 for Lucban).

The incidence of pterygium eye problem was much higher in the exposed group (67% in Nueva Ecija and 25% in Laguna) than in the control group (10% in Lucban). This is especially significant as the control is a relatively aged group and, if other factors were equal, could be expected to show a higher incidence. For at least 5 yr, the exposed farmers have been using phenoxy herbicides and acetamide, herbicides known to be moderately irritating to the eye. Age-group analysis showed that none of the three farmers younger than 40 in the control group had pterygium, while 7.14% of the Laguna farmers and 44.44% of the Nueva Ecija farmers were affected.

Table 35. Prevalence of health impairments by organ system among sampled Lucban (Quezon), Laguna, and Nueva Ecija farmers.[a]

Health indicator	Prevalence					
	Control		Exposed			
	Lucban		Laguna		Nueva Ecija	
	no.	%	no.	%	no.	%
Eye	4	10.53 a	14	25.00 b	38	66.67 c
Pterygium	4	10.53 a	14	25.00 b	38	66.67 c
Dermatologic system	0	0.00 a	8	14.29 b	26	45.61 c
Nail destruction	0	0.00 a	0	0.00 a	21	36.84 b
Eczema	0	0.00 a	8	14.29 b	7	12.28 b
Respiratory system	9	23.08 a	27	48.21 b	26	45.61 b
Bronchial asthma	0	0.00 a	9	16.07 b	4	7.02 a
Abnormal findings:	9	23.08 a	23	41.07 b	23	40.35 b
Decreased breath sounds	4	10.26 a	20	35.71 b	8	14.04 a
Harsh breath sounds	0	0.00 a	3	5.36 a	5	8.77 a
Coarse rales	4	10.26 ab	2	3.57 a	11	19.30 b
Decreased chest expansion	1	2.56 a	6	10.71 b	0	0.00 a
Decreased percussion	0	0.00 a	1	1.79 a	0	0.00 a
Rhonchi, base	1	2.56 a	0	0.00 a	0	0.00 a
Chest tenderness	0	0.00 a	0	0.00 a	1	1.75 a
Cardiovascular system	18	46.15 a	28	50.00 a	28	49.12 a
Elevated blood pressure	9	23.08 a	14	25.00 a	12	21.05 a
Abnormal electro-cardiograph	13	33.33 a	19	33.93 a	21	36.84 a
Gastrointestinal tract	0	0.00 a	32	57.14 b	5	8.77 a
Chronic gastritis	0	0.00 a	32	57.14 b	5	8.77 a
Kidney	1	2.56 a	24	42.86 c	15	26.32 b
Elevated blood urea nitrogen	0	0.00 a	1	1.79 a	1	1.75 a
Elevated creatinine	0	0.00 a	7	12.50 b	4	7.02 ab
Albuminuria	0	0.00 a	6	11.11 b	7	12.28 b
Hematuria	1	2.56 a	18	33.33 b	6	10.53 a
Neurologic system	10	25.64 a	16	28.57 a	20	35.09 a
Polyneuropathy	0	0.00 a	3	5.36 ab	6	10.53 b
Isolated hypo/hyper/ areflexia	10	26.32 a	13	23.21 a	14	24.56 a

[a]In a row, percentages with a common letter are not significantly different at $\alpha = .05$ using χ^2 test or Fisher's exact test.

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Table 36. Percentage by age group of ECG impairment in subjects exposed to pesticides (Laguna and Nueva Ecija) and in a control group.[a]

Age (yr)	Laguna (exposed)			Lucban (control)			Nueva Ecija (exposed)		
	no.	With impairment		no.	With impairment		no.	With impairment	
		no.	%		no.	%		no.	%
< 40	28	8	28.57	3	0	0.00	18	7	38.39
40-49	8	3	37.50	13	4	30.77	13	5	38.46
> 50	20	8	40.00	23	9	39.13	26	9	34.62
Total or average	56	19	33.93	39	13	33.33	57	21	36.84

[a]Relative risk: Laguna/Lucban = 1.15 ns, Nueva Ecija/Lucban = 1.09 ns. ns = not significant by Mantel Haenszel chi-square test at 0.05.

The relative risks of 3.48 (Laguna) and 7.10 (Nueva Ecija) showed a strong causal association between pesticide use and the development of pterygium.

Almost half (45%) of the Nueva Ecija sample showed dermal impairments compared with 14.29% of the Laguna farmers and none in the Lucban group. None in the Laguna or Lucban samples exhibited nail destruction which was evident in 36.84% of the Nueva Ecija group. Nail destruction may be due to the organotine used as molluscicide. Snails are more abundant in Nueva Ecija. In Laguna and Lucban, snails are removed manually.

None of the control group had polyneuropathy while 5% of the Laguna and 10.5% of the Nueva Ecija samples suffered from it. There is a significant difference between the results for Lucban and Nueva Ecija. Taking alcohol consumption into account reduces the Nueva Ecija percentage to 7.69.

Thirty percent of the Laguna sample had significantly low hemoglobin levels compared with 10% of the Nueva Ecija sample and 8% of the Lucban sample. Only the Laguna farmers used lindane, an organochlorine, which is suspected to be hematotoxic. Stratification controlling for intestinal parasites showed a relative risk of 4.75 for Laguna over Lucban—this is statistically significant at the 0.05 level. Farmers who used at least one item of protective gear (clothing, mask, or gloves) had significantly higher hemoglobin levels than those who used none.

Of the Laguna sample, 4% had lower baseline cholinesterase levels than those of Lucban and Nueva Ecija. A total of 56% of the Laguna sample showed cholinesterase depression in the first monitoring period and 61% in the second. Farmers who had 30% or greater depression showed that drinkers and nondrinkers in the second monitoring showed diminishing patellar tendon reflexes, nausea, vomiting, and sluggish pupillary reflexes—all are symptoms of acute pesticide poisoning. Stratification for alcohol consumption showed that drinkers and nondrinkers exhibited similar trends of cholinesterase depression.

There were no significant differences in the electrocardiograph (ECG) tests among the farmers of the three sites (Table 36). None of the under-40 age group in Lucban had abnormal ECG findings, while 38% in Nueva Ecija and 29% in Laguna did. Young males generally handle the task of pesticide application and our results show that they face an abnormally higher risk of cardiac problems. However, this finding is inconclusive because the sample is small.

Bronchial asthma affected 16% of the Laguna sample, 7% of that in Nueva Ecija, and none in the Lucban sample. After adjustments for tobacco smoking, the figures are 21% for Laguna, and zero for Nueva Ecija and Lucban. Considering other pulmonary impairments, the relative risk was 2, which indicates a 100% increase in risk for pesticide users.

More than one-half (57%) of the Laguna sample had chronic gastritis. This is significantly higher than the 9% for the Nueva Ecija sample. Kidney disturbances were reported for 43% of the Laguna sample, 26% of the Nueva Ecija sample, and 15% of the Lucban sample.

Endosulfan and 2,4-D are used by the Laguna and Nueva Ecija groups. That Laguna farmers employ

Table 37. Summary of soil properties[a] measured in Laguna and Lucban ricefields.

	Laguna[b]						Lucban[c]					
	C	N	P	pH	Fe	H_2O	C	N	P	pH	Fe	H_2O
Mean	2.3	0.23	30	6.3	1.1	105	2.5	0.28	9	5.2	3.6	162
Max	3.8	0.33	81	7.5	2.3	183	3.2	0.62	74	7.2	5.9	383
Min	1.5	0.15	2	5.4	0.3	51	1.8	0.18	2	4.5	0.8	98

[a]C = % organic C, N = % organic N, P = available Olsen P, Fe = active Fe (ppm), H_2O = soil moisture % on a dry weight basis. [b]Sampling was conducted at the end of the 1989 DS and the beginning of the 1989 WS. Available Fe was analyzed only in WS. [c]Sampling was conducted at the beginning and end of the 1991 DS.

greater amounts of these chemicals may explain their higher rate of renal impairment.

Conclusions and future plans. Health externalities caused by pesticide use dominate the environmental effects. Pesticides that might be linked with health impairments include certain organophosphates, organochlorine, organotine, and phenoxy herbicides, which the exposed farmers have used for an average of 5 yr.

Previous results showed that the net impact of pesticides on farm productivity is negative when health effects are explicitly accounted for. The addition of the Nueva Ecija sample in the study confirmed this finding and thereby showed that the rate of return to general rice research will be overestimated if health effects are not considered, while the returns to research that reduces pesticide use will be underestimated.

A study was designed to determine the cost effectiveness of training in overcoming pesticide-related health problems. It is hypothesized that trained farmers would practice safety precautions, have fewer illnesses, incur lower health expenses, and consequently have better farm productivity than those without training. An 18-h, 3-d experiential training program was conducted for 57 farmers and laborers from Nueva Ecija. Before and after the training, baseline cholinesterase and physical examinations were done. The training program focused on pesticide toxicity, necessary health measures and safety precautions, and first aid measures specific to pesticide poisoning. Training modules and materials generated will be transferred to PhilRice for future farmer training.

Aquatic oligochaete populations in rice soils from two areas of the Philippines

Aquatic oligochaetes are involved in the nutrient cycling processes of ricefields through translocation and mineralization, yet field studies concerning these organisms are scarce. Little is known about the densities, distributions, dynamics, and composition of their field populations. To assess the environmental and health impacts of pesticide use in rice production, aquatic oligochaetes were investigated in selected ricefields of Laguna (32 fields) and Lucban (30 fields). The multidisciplinary study was carried out under a scientific agreement between IRRI, the Natural Resources Institute (UK), and ORSTOM.

The investigation aimed to determine population densities and compositions in ricefields of the two areas, and to identify the effects of agricultural practices and soil properties (Table 37). Agricultural practices were monitored by IRRI's Social Sciences Division through interviews with rice farmers.

In Laguna, agrochemical regimes varied considerably between farms. In Lucban, fertilizer use was generally low and the only pesticides applied were rodenticides.

Although species compositions differed between areas and among farms, the Tubificidae *Limnodrilus hoffmeisteri* and/or *Branchiura sowerbyi* were typically dominant in both areas (Fig. 17). The highest aquatic oligochaete population density (44,000/m^2) was recorded in a field in Lucban; however, population densities were considerably higher in Laguna. A population density of 44,000/m^2 was estimated to represent an oligochaete biomass of 780 kg fresh weight/ha.

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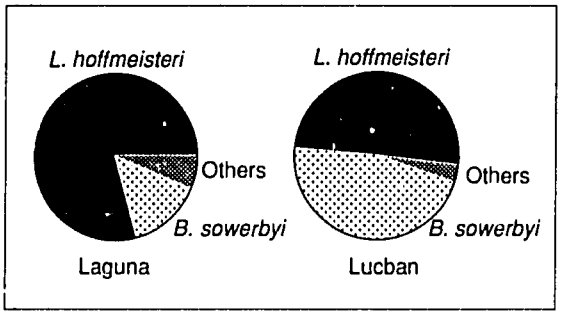

17. Composition of aquatic oligochaete species in rice soils sampled in Laguna and Lucban.

At the Laguna sites, aquatic oligochaete populations were positively correlated with soil organic C ($p<0.001$), soil moisture content ($p<0.001$), and quantity of N fertilizer applied ($p<0.005$). Soil organic C below 1.75% and soil moisture below 80% at the time of sampling were apparently limiting. No relationships were found between pesticide use (frequency, quantity, or type) and oligochaete population density. No relationships were found between soil texture and aquatic oligochaete populations at the Laguna sites.

At the Lucban sites, no correlations were found between soil properties measured or agrochemical use and oligochaete population densities. Population densities higher than 2,000/m^2 developed only in soils with a pH greater than 6. All soil organic C and soil moisture content values in Lucban were above the critical levels identified in Laguna. Soil texture was not determined on the Lucban farms.

Significantly different aquatic oligochaete populations and agroecological conditions were encountered within and between the two areas. Evidence suggests that populations can be limited by soil organic matter, moisture content, and pH but that they could be promoted, probably indirectly, by the application of N fertilizer. In ricefields where the parameters discussed are not limiting factors, aquatic oligochaetes can develop dense populations and they probably contribute significantly to the translocation and mineralization of nutrients.

To verify the findings, we will extend the study to an area in Central Luzon where pesticide usage is higher.

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Rainfed lowland rice ecosystem

More than 75% of the 40 million ha of rainfed lowland rice area is in South and Southeast Asia. Unlike irrigated areas, rainfed lowlands are characterized by hydrologic complexity and variability. Only about one-fifth of rainfed lowlands in South Asia and one-third in Southeast Asia have favorable crop growing conditions, the rest being prone to varying degrees of drought, flood, or drought and flood. These hydrologic characteristics have a profound impact on land use and productivity. Poor soil fertility and low farmer resource base also contribute to the low yields prevailing in rainfed lowland areas. However, recent research suggests that riceland productivity can be increased substantially in these areas.

The adequate understanding of the physical and socioeconomic parameters and processes that condition the farmers' use of ricelands and production inputs, and the identification of the major constraints that limit productivity are at the core of research planning in this ecosystem. Research to develop technologies for relieving the constraints will have to be directed not only toward economically attractive alternatives for the generally resource-poor farmers, but also at environmental sustainability. Clearly, a multidisciplinary approach with a systems perspective is needed for addressing such problems. The rainfed lowland rice ecosystem program is organized to enhance the multidisciplinary approach in its research.

In 1991, the program's six projects were consolidated into four. Two projects are now under subprogram I and two under subprogram II.

The Rainfed Lowland Rice Consortium became operational during 1991, with seven key sites in five countries: Bangladesh, India (2 sites), Indonesia, Philippines (2 sites), and Thailand. One season of planned research has been completed at all key sites.

Subprogram I: Sustainable resource management

Resource management for enhanced productivity

Dry seeding technique for rainfed lowlands

The farming practices of 31 randomly selected farm samples in a large contiguous rainfed area in Urbiztondo, Pangasinan Province, Philippines, were studied for 2 yr to analyze the technologies used for rice and other crops. The site has a unimodal rainfall pattern with a yearly rainfall total of about 2,000 mm, more than 90% of which falls from May to October.

About 40% of the farmers grow only wet season (WS) rice. Approximately one-third of the rest grow rice - mungbean; one-third, maize - rice; and one-third, maize - rice - mungbean. Maize is usually grown before rice on most of the farm. Mungbean is grown in the well-drained, higher topographic half of the farmland.

Dry seeding of rice in dry-plowed fields is the most promising new technology for improving riceland productivity. About one-third of the farmers dry seed rice. They dry-plow during May or June. Dry plowing is accomplished faster with custom tractor service, but this service is not necessary for the new technology. About half the farms are plowed by custom-hired tractors, while the rest use animal draft

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power. Animal draft is a slightly cheaper power source, but takes 4-5 d longer per hectare.

In 1991, dry seeded rice (DSR) was established 7-8 wk before transplanted rice (TPR). This allowed DSR to use about 360 mm of premonsoon rains before TPR was established on the field, resulting in higher water use efficiency in DSR. On the average, DSR was harvested about 20 d before TPR. Consequently, a more favorable hydrologic environment was created for a postrice mungbean crop at this site. In 1991, these farms had about 140 mm more rainfall in the postrice season than did the transplanted farms. Almost all farmers who grow rice - mungbean dry seeded their rice, which indicates their understanding of the advantage of dry seeding to facilitate intensified cropping.

Weed control is the biggest challenge for DSR. Until recently, use of DSR technology was unattractive and yields were low because of difficulty in weed control. However, it has become evident that herbicides can effectively control weeds in DSR. In 1991, about 70% of the dry seeded farms used herbicides, applied higher amounts of fertilizer inputs than the no-herbicides farms, and achieved an average yield higher by about 1.5 t/ha.

For comparable fertilizer inputs, DSR is producing 0.6 t/ha higher average yields and higher income (about $95/ha higher net returns) than TPR at the site (Table 1).

DSR technology shows high potential for increasing productivity in terms of both rice qyield and cropping intensity in rainfed lowlands where drought is a major limiting factor. Future research will focus on

Table 1. Comparative costs and returns of dry seeded rice (DSR) vs transplanted rice (TPR). Urbiztondo, Pangasinan, Philippines, 1991 wet season (WS).

Item	Dry seeded (n = 11)	Transplanted (n = 15)	Difference[a]
Rice yield (t/ha)	3.4	2.8	0.6
Total value of output[b] ($/ha)	501	422	79 ns
Total paid-out costs ($/ha)	164	201	(37)*
Total variable costs ($/ha)	395	412	(16) ns
RAPC[c] ($/ha)	337	221	116**
Gross margin ($/ha)	106	11	95

[a]Significant at 5% (**) and 10% (*) levels by *t*-test. ns = not significant. [b]US$1 = ₱26.00. [c]Returns above paid-out costs.

- assessing the risks and rewards of the different cropping systems,
- determining the specific factors responsible for higher yields of DSR, and
- evaluating the constraints to wide-scale adoption of the promising component technologies that allow higher farm productivity and income.

Benefits of crop management by *beusani*

In crop management under the *beusani* system, which is widely practiced in eastern India, fields are wet-plowed at 30-50 d after emergence (DE) when 5-10 cm of water has accumulated in the field. Fields are then planked. Seedlings are redistributed, and fields are hand weeded. Beusani is reported to control weeds, improve root growth, aerate and loosen soil, improve crop nutrition, reduce water loss, and increase resistance of rice to insects and environmental stresses. We investigated these claims, and found that the soil-loosening effect of wet plowing through seedlings was temporary, as evidenced by lower soil penetration resistance in recently plowed than in previously plowed plots. Soil strength tended to revert gradually to its preplowing level. Surprisingly, the soil-loosening effect of beusani was not confined to the layers plowed, but extended to 35-cm depth. Wet plowing temporarily reduced root length density—probably a direct effect of root pruning—but stimulated root regrowth so that root length density in plowed plots exceeded that in unplowed treatments. Rice roots recovered and benefited from the loosening of soil brought about by plowing up to 40 DE, but wet plowing may be detrimental if it is done too late.

The reduction of soil strength to 35-cm depth and the resultant improved root elongation may increase the drought tolerance of beusani over nonbeusani rice. In this experiment, however, fields were kept flooded after wet plowing so any such advantage could not be observed. This question will be the subject of future research.

Percolation barriers in well-drained soils

Increasing rainwater utilization efficiency is a key factor in improving rice yields in well-drained soils. The possibility of improving water shortage by installing subsurface percolation barriers using polyethylene sheets was evaluated at the Ubon Rice Research Institute, Thailand. The soil was an Aeric

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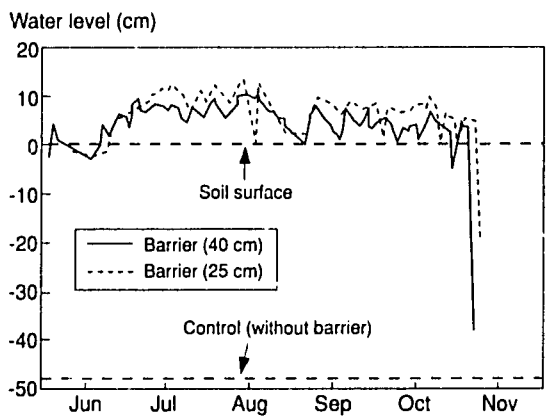
Paleaquult with pH 4.4; sandy (78.8% sand, 16.4% silt, and 4.8% clay), with bulk density of 1.57-1.67 g/cc; infiltration rate 66.6 cm/d; 0.08% organic C; CEC 1.46 meq/100 g of dried soil; 0.02% total N; 1.0 ppm available P; and 0.02 ppm K.

Five treatments were tested: percolation barriers installed at 25-cm (T1) and 40-cm (T2) depths, seepage barrier on bunds installed only up to 40-cm depth (T3), undisturbed control without bund (T4), and undisturbed control with bund (T5). The ends of percolation barriers installed in T1 and T2 were at the top of the bunds to eliminate seepage flow through the plot boundaries. Three rice crops were grown successively from 1989 to 1990. The plots were subdivided to compare two alternative crop establishment methods: dibbling and transplanting. Applied fertilizers were 3 t farmyard manure/ha and 50-22-42 kg NPK/ha.



1. Water levels in plots with and without subsurface percolation barriers. Ubon Rice Research Institute, Thailand, 1989 wet season (WS).

Total rainfall during the growing season was 1,430 mm in 1989 and 1,605 mm in 1990. Throughout the season, water accumulated on the soil surface in the plots with barriers, but never in the plots without barriers (Fig. 1). In 1989, treatments with barriers produced nearly four times the total dry matter (TDM) of those without barriers (Table 2). Both dibbling and transplanting gave superior TDM and grain yields in the presence of the percolation barrier. On the average, a single rainfed crop in 1989 yielded about 1.8 t/ha and two crops in 1990 yielded a total of 2.7 t/ha from plots with percolation barriers. The grain yield was virtually zero in plots without barriers due to severe drought stress in both years (Table 2). The barriers increased cropping intensity, allowing two rainfed rice crops to be grown in 1990.

These results have stimulated subsequent research at the site to develop percolation barriers using more practical materials and techniques, and appropriate economic analysis. If the technology can be made cost-effective, percolation barriers may provide a significant advance in rainfed rice farming in highly percolating soils.

Table 2. Grain and total dry matter yields of DSR and TPR as affected by barriers to percolation and seepage.[a] Ubon Rice Research Center, Thailand, 1989 and 1990 WS.

Treatment no.	Soil treatment	1989 total dry matter (t/ha)			Grain yield (t/ha)					
					1989			1990[b]		
		DSR	TPR	Average	DSR	TPR	Average	TPR1	TPR2	Average
T1	With plastic barrier at 25-cm depth	6.88	5.15	6.02	1.8	1.8	1.8	1.5	1.4	3.0
T2	With plastic barrier at 40-cm depth	7.72	4.86	6.29	1.9	1.6	1.8	0.8	1.6	2.4
T3	With plastic barrier on sides only, 40-cm depth	1.61	1.46	1.54	0	0	0	0	0	0
T4	Undisturbed control, without bund	1.00	1.41	1.20	0	0	0	0.1	0	0.1
T5	Undisturbed control, with bund	1.43	1.07	1.25	0	0	0	0	0	0

[a]Average of 3 replications. [b]No data for DSR (T1 and T2 were damaged by flood, and T3-T5 by drought). Two successive TPR crops were planted.

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Intercropping green manure with dry seeded rice

Farmers who grow DSR generally broadcast rice seed and either cannot afford fertilizer inputs or consider their use to be risky even though DSR responds positively to added nutrients. Green manure (GM) has been shown to increase rice yields as it improves N availability and soil organic matter. However, since farmers do not generally consider production of a separate GM crop, a new system of GM intercropped with row-sown DSR was designed.

Field experiments were conducted at IRRI; in Muñoz, Nueva Ecija, in cooperation with PhilRice; and in Raipur, Madhya Pradesh State, India, with the Indira Gandhi Agricultural University. Stands were adequate in all treatments and locations (Table 3,4,5). Rice grown in paired rows (33-cm spacing between pairs of rice rows 7 cm apart) with GM incorporated 40 DE yielded more grain and took up more N than urea application treatments. Although broadcast DSR with beusani and urea application yielded less than paired row DSR with GM, there was little difference between broadcast and paired row DSR when GM was intercropped and incorporated (Table 5).

A major constraint DSR farmers experience is the short time for land preparation and sowing of rice before the onset of heavy monsoon rains. The paired row DSR with GM intercrop took 60-100% more time for land preparation and sowing than broadcast DSR (Table 5). On the other hand, postemergence tillage (beusani) took less time in paired row DSR so that total labor requirements were less than for broadcast DSR. Future research will emphasize development of simple farm implements that will speed the initial establishment of the paired row DSR with GM intercrop at Rainfed Lowland Consortium sites.

Table 3. Effect of rice establishment, nutrition, and postemergence tillage on stand density, tillers at harvest, grain yield, and N uptake. IRRI, 1991 dry season (DS).

Treatment	Seedling density 20 DAS[a] (no./m²)	Tillers at harvest (no./m²)	Grain yield (t/ha)	N uptake at harvest (kg/ha)
Paired row, GM[b]	341	443	4.3	70.1
Paired row, urea	330	427	3.4	60.5
Paired row, urea and trampling	336	429	3.8	64.2
Broadcast, urea and beusani	330	328	2.5	49.7
LSD (0.05)	ns	23	0.2	6.3

[a]Days after seeding. [b]Green manure.

Table 4. Effect of rice establishment, nutrition, and postemergence tillage on stand density, tillers at harvest, grain yield, and N uptake. IRRI-PhilRice, Muñoz, Nueva Ecija, Philippines, 1991 WS.

Treatment[a]	Seedling density 15 DE[b] (no./m²)	Tillers at harvest (no./m²)	Grain yield (t/ha)	N uptake at harvest (kg/ha)
Paired row, GM	330	430	4.5	88
Paired row, GM and herbicide	352	442	4.4	84
Paired row, GM and urea	338	427	4.5	92
Paired row, urea and cono weeding	330	434	4.2	79
Paired row, urea and herbicide	355	426	4.2	84
Paired row, urea, cono weeding, and additional urea	317	430	4.4	87
Broadcast, urea and beusani	324	353	3.6	64
Broadcast, urea, herbicide, and beusani	281	345	3.6	69
Pooled standard error of mean	22	15	0.1	

[a]Cono weeding = weeding done with a push-type rotary weeder with a cone-shaped rotor. [b]Days after emergence.

Table 5. Effect of rice establishment, nutrition, and postemergence tillage on stand density, grain yield, and labor expense in seeding and postemergence tillage/weeding.[a] IRRI-Indira Gandhi Agricultural University (Indian Council of Agricultural Research), Raipur, India, 1991 WS.

Treatment	Seedling density 20 DAS (no./m²)	Grain yield (t/ha)	Labor expense			
			Seeding		Postemergence tillage/weeding	
			Labor-d/ha[b]	Bullock (paid-d/ha)	Labor-d/ha	Bullock (paid-d/ha)
Paired row, GM	173	3.6	10.8	5.4	36.2	3.3
Broadcast, GM	159	3.6	6.4	4.7	75.4	7.6
Row (20 cm), urea, between-row plowing	172	3.3	11.4	5.7	43.7	6.1
Broadcast, urea, beusani	153	3.3	5.0	4.2	56.0	6.6
Row (20 cm), urea, hand weeding	177	3.3	11.4	5.7	46.3	-
Broadcast, urea, hand weeding	170	2.7	5.2	4.4	64.1	-
Pooled standard error of mean	12	0.2	0.5	0.5	3.0	0.3

[a]Does not include common weeding. [b]Includes human labor involved in plowing and manual seeding.

Weed population in relation to hydrology and weed management

As part of the Thai-IRRI collaborative research effort, weed density was determined in five transects in Northeast Thailand: north, middle, and south of Ban Khu Khat; Ban Non Yai; and Ubon Rice Research Center. Each transect consisted of three toposequence positions: upper, middle, and lower. Transects were sampled before transplanting, and 30 and 60 d after transplanting (DT).

Before transplanting, grassy weeds (in descending order *Paspalum distichum* L., *Cynodon dactylon* Pers., and *Digitaria elongata* Spreng) had the greatest population densities. The major broadleaf weeds were *Hedyotis tetrangularic* Walp., *Hedyotis diffusa* Willd., *Glinus oppositifolius* (L.) A.Dc., and *Hyptis suaveolens* (L.) Poit. At this time the soil was acidic (pH 4.3-5.9) and relatively fertile with respect to P and K.

At 30 DT, broadleaf weeds dominated in all toposequence positions. In addition to those listed above, *Lindernia anagallis* Pennell, *Ludwigia hyssopifolia* Exell., *Monochoria vaginalis* Presl., and *Blyxa japonica* Maxim. appeared.

At 60 DT, broadleaf weeds continued to dominate and some succulent weeds appeared: (e.g., *Ludwigia adscendens* Hara, *Utricularia aurea* Lour., *Ottelia alismoides* Pers., and *Najas graminea* Del). Thus, numbers of weed species increased through time.

Water depth correlated negatively with both weed number ($r = 0.30$) and weed weight ($r = 0.48$). Thus weed number and weight were greatest in the upper terrace positions in all locations.

In Ban Non Po, Ubon, the effects of land preparation and weed control methods on weed numbers and productivity of DSR were investigated. The major DSR weed was *Cynodon dactylon* L. Hand drilling of DSR led to significantly more tillers, less weed weight, and greater grain yield than planting DSR with a rolling injection planter (Table 6). The highest yields and best weed control were achieved with a combination of herbicide plus interrow cultivation, or herbicide plus interrow cultivation and spot weeding. Overall, yields of DSR were low, but were about equal to yields of TPR in nearby farmers' fields.

Considering these findings, future research will emphasize development of integrated weed management practices.

Establishing upland crops following lowland rice in saturated soils

Vast areas of riceland in South and Southeast Asia remain fallow after rice is harvested. Saturated soil conditions limit the immediate establishment of upland crops, since conventional seeding methods can be practiced only on drained soils with adequate bearing capacity for tillage or seeding implements. Saturated soils limit oxygen exchange and are chemically reduced, constraining seed germination and growth. When seeding is delayed until the soil has dried to an optimum moisture content, the soil strength of puddled ricefields greatly increases, limiting

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Table 6. Effect of weed control and planting method on rice height and tillering of KDML 105, and weed weight and grain yield in DSR. Ban Non Po, Ubon, Thailand, 1991 WS.

Weed control method	Height (cm)			Tillers (no./m^2)			Weed wt (g/m^2)			Grain yield (t/ha)		
	RIP[a]	HD[b]	Mean	RIP	HD	Mean	RIP	HD	Mean	RIP	HD	Mean
Chemical + interrow	109	108	109 ab	150	193	172 a	3.0	5.4	4.2 a	1.5	1.7	1.6 a
Chemical + interrow + spot	118	112	115 b	161	186	174 a	11.4	17.9	14.7 ab	1.7	1.6	1.6 a
Interrow	107	108	108 ab	128	153	140 b	32.7	21.5	27.1 b	1.2	1.2	1.2 b
No weeding	105	104	104 a	115	147	131 b	45.9	14.5	30.0 b	1.1	1.2	1.2 b
Average	110	108		139	169		23.3	14.8		1.4	1.4	

[a]Rolling injection planter. [b]Hand drilling.

vertical root growth, and ultimately resulting in severe crop water deficits.

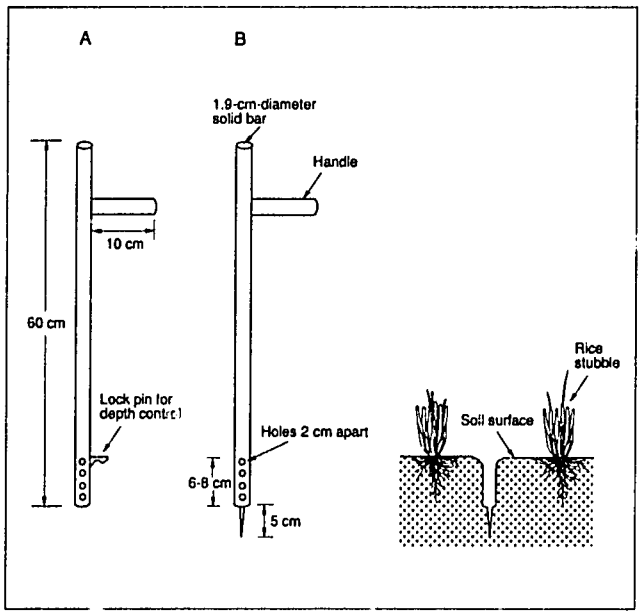
A novel technique for establishing upland crops was tested in saturated ricefield soils, based on the observation that deep planting in wet soil is feasible in open holes because of an adequate gaseous exchange pathway to the soil surface. Three field experiments to compare the performance of mungbean *Vigna radiata* (L.) Wilczek used the "plunger planter" method of crop establishment and alternative methods on silty clay Tropaquept in a postrice rainfed environment at IRRI during the 1990 and 1991 dry seasons (DS).

An initial experiment in 1990 DS evaluated the effect of seeding depth on seedling emergence and plant productivity. Mungbean seeds were planted at seven depths (2, 4, 6, 8, 10, 12, and 14 cm) in open 1.9-cm-diam holes, using two types of plunger planter implement. One implement made a regular cylindrical hole and the other had a sharp 5-cm point attachment (Fig. 2) which provided a root penetration channel in the soil immediately below the seed.

Planting depth did not have a statistically significant effect on seedling emergence—emergence was high over a wide range of plunger planting depths, but the optimum depth was 6-8 cm (90-96% emergence). The shallowest planting depth (2 cm) tended to have the lowest seedling emergence (88-90%) because of greater exposure to higher temperatures from direct sunlight, and greater soil desiccation and soil strength in the near-surface layer. The point attachment on the plunger had no significant effect on seedling emergence. Deep planting did not adversely affect seedling emergence or plant productivity, but produced more etiolated plants.

Grain yields and TDM were not significantly affected by planting depth or the presence of the point attachment. Yields varied from less than 1 t/ha with the shallowest planting depth (2 cm) to 1.2-1.7 at the deeper depths. The 6-cm depth with the point attachment gave the highest yields (1.7 t/ha). TDM yields conformed closely to those for grain.

A second experiment in the 1990 DS compared the plunger planter technique with five other planting methods for mungbean following WS rice (Table 7). The treatments were applied as soon as the soil moisture content sufficed for implementation of each method. Therefore, the seeding date varied with method. Plunger planting was done immediately after field surface drainage when the soil was satu-



2. Plunger planter without (A) and with (B) point attachment, and cross section of soil showing hole made with point attachment (B) in between 2 rice rows or hills. IRRI. 1990 dry season (DS).

Table 7. Grain yield, total dry matter, yield components, and other agronomic traits of mungbean as influenced by method of crop establishment. IRRI, 1990 and 1991 DS.

Planting method		Grain yield (t/ha)	Total dry matter (t/ha)	Emergence (%) 10 DE[a]	Plant count at harvest (no./10 m²)	Soil moisture (%) at planting at ODW[b] (0-10 cm)
			1990 DS (Mar-May 1990)			
T1	Plunger	1.6	3.7	82.5	337	49.6
T2	Furrow-hand drill	0.5	1.4	23.5	66	34.8
T3	Conventional	0.8	2.3	23.5	82	33.5
T4	Furrow-plunger	1.3	2.8	89.0	260	33.5
T5	Slit seeder	0.6	1.6	67.0	188	34.1
T6	Inverted-T seeder	0.4	1.5	33.5	109	-
	F-value	**	**	**	**	**
	CV (%)	26.5	24.3	37.4	29.9	7.2
	SE	0.3	0.4	13.9	36.7	1.9
			1991 DS (Jan-Apr 1991)			
T1	Plunger	2.2	4.7	96.6	351	45.3
T2	Furrow-hand drill	1.8	5.1	95.2	360	43.9
T3	Conventional	1.5	5.0	95.2	345	43.6
	F-value	*	ns	ns	ns	ns
	CV (%)	12.8	7.1	4.5	6.4	7.2
	SE	0.2	0.3	3.0	15.9	2.2

[a]Average 5-m row. [b]Oven-dry weight.

rated. The other seeding treatments were applied 4 d later when the soil consistency and bearing capacity became adequate.

Seedling emergence measured at 10 DE and actual plant count at harvest were consistently and significantly higher in the plunger-planted treatments (82.5-89.0%) than with the other methods of crop establishment (23.5-67.0%) (Table 7). At sowing time with the plunger planter, the presence of water on saturated soil hastened germination and emergence. The lowest emergence occurred in the furrow-hand drill and conventional tillage treatments at

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10 DE and at harvest, which indicates the importance of water availability for germination and emergence at the seed zone, especially during emergence.

Grain yields with the plunger planting methods (T1 and T3) were significantly higher than those with all other crop establishment methods. The TDM yields followed a similar trend. The highest TDM yield was obtained from plunger-planted mungbean on saturated soil. The contribution of yield components to grain yield varied among the methods of crop establishment.

On the basis of 1990 results, three treatments (T1, T2, and T3) were selected for further testing in the 1991 DS. The methodology and cultural management practices were the same as in the 1990 DS experiment. Grain yields in all treatments were substantially higher than in the 1990 trial, apparently due to more favorable weather conditions (cooler temperatures, lower evapotranspiration requirements) which enabled the crop to utilize the stored soil moisture more effectively. In 1991, grain yields of the plunger-planted mungbean were significantly higher than those from the two other methods of crop establishment. The TDM and the components of yield were not significantly affected by planting method.

Seeding with the plunger planter demonstrated superior potential for establishing mungbean on saturated soils immediately after the harvest of the WS rice crop. Plant emergence was substantially better than with conventional seeding methods and recently developed mechanical seeders. Grain yields increased 18-220% with plunger planting, depending on the soil and atmospheric conditions. The yield advantage of the plunger planting technique comes partially from seeding the crop when the soil is fully saturated, gaining time for germination and root growth before soil strength becomes resistant to root penetration.

Tillage and weeding levels in a rice - cowpea crop rotation

An experiment was conducted to determine the effects of crop establishment method (zero tillage and conventional tillage) and weeding treatments on weed growth and crop performance in a rice - cowpea rotation. For the conventional-tillage treatment in rice, land was prepared by one plowing and two harrowings with an animal. Glyphosate at 1.5 kg ai/ha was applied 3 d before planting in the zero-tillage plots. Presoaked IR66 seed was sown with a drum seeder at 72 kg/ha in 20-cm rows in the conventionally tilled plots and dibbled at a 20- × 20-cm spacing in the zero-tillage plots. A strip-plot design with four replications was used.

In the zero-tillage cowpea plots, weeds and rice stubble were cut and removed before planting. The conventional-tillage plots were rototilled twice with a hand tractor. Cowpea IT82D-889 was dibbled at 40- × 20-cm spacing with four to five seeds per hill. Cowpea seedlings were thinned to three per hill after establishment.

Tillage treatments for rice did not affect the dominant weed species, their biomass at 8 wk after planting, or rice yield, but weeding treatments did (Table 8). Reduction in weed growth caused by 2,4-D application (0.6 kg ai/ha 19 d after planting) alone was insufficient to cause appreciable yield increase. One or two hand weedings following 2,4-D application resulted in greater yield increases. Rice yields, which were low because of bird damage, increased as weeding intensity increased.

Good weed control in rice resulted in less weed growth in zero-tillage cowpea at 1 wk after crop emergence (Table 9). Tillage for cowpea and the subsequent drying reduced crop stand and decreased weed emergence and growth. The tilled plots had 23% less cowpea plants than the zero-tillage plots.

Hand weeding further reduced weed growth, but two hand weedings were required to increase yields significantly. Cowpea yields were higher with zero tillage than with conventional tillage.

The results indicated the feasibility of using zero tillage in a rice - cowpea crop rotation with adequate weed control, particularly in rice. Future research will emphasize weed problems encountered in DSR in both rice - fallow and rice - upland crop systems.

Integrated nutrient management

Integrated nutrient management research for the irrigated rice ecosystem was continued jointly with the Rainfed Lowland Rice Ecosystem Program. Soil, water, and crop residue management between rice crops can greatly influence availability of soil nutrients to rice, particularly in the rainfed lowlands where long fallow or upland cropping periods occur between rice crops. The major research thrust of the integrated nutrient management project is to understand how fallows, water deficits, soil drying and

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Table 8. Effect of tillage and weeding treatments on weed weight and yield of wet seeded rice in a rice - cowpea rotation.[a] IRRI, 1990 WS.

Weeding treatment	Tillage treatment			
	Conventional[b]	Conventional[c]	Zero	Mean
	Weed weight (g/m²) 8 WE			
2,4-D + 2 HW	11	9	16	12 a
2,4-D + 1 HW	34	24	89	49 a
2,4-D	130	164	172	155 b
Unweeded	253	217	240	237 c
Mean	107 a	103 a	129 a	
	Rice yield (t/ha)			
2,4-D + 2 HW	1.9	1.8	1.5	1.7 a
2,4-D + 1 HW	1.7	1.4	1.2	1.4 b
2,4-D	0.8	0.8	0.4	0.7 c
Unweeded	0.3	0.3	0.1	0.2 d
Mean	1.2 a	1.1 a	0.8 a	

[a]In a column or row within a parameter, means followed by a common letter are not significantly different at the 5% level by DMRT. WE = weeks after emergence, HW = hand weeding. [b]The subsequent cowpea received conventional tillage. [c]The subsequent cowpea had zero tillage.

Table 9. Effect of tillage and weeding treatments in rice - cowpea on weed density, weed weight, and cowpea yield.[a] IRRI, 1990-91.

Weeding treatment in rice - cowpea	Tillage treatment			
	CT - CT	CT - ZT	ZT - ZT	Mean
	Weeds (no./m²) 1 WE			
2,4-D + 2 HW – 2 HW	-	113	193	153 a
2,4-D + 1 HW – 1 HW	-	195	222	209 a
2,4-D – 1 HW	-	300	375	338 b
Unweeded - unweeded	-	355	391	373 b
Mean	-	241 a	295 a	
	Weed weight (g/m²) 5 WE			
2,4-D + 2 HW – 2 HW	3 a	1 a	2 a	2 a
2,4-D + 1 HW – 1 HW	7 ab	17 b	16 ab	14 b
2,4-D – 1 HW	18 bc	17 b	21 b	19 b
Unweeded - unweeded	28 c	103 c	98 c	77 c
Mean	14 a	35 b	34 b	
	Cowpea yield (t/ha)			
2,4-D + 2 HW – 2 HW	0.75	0.95	1.09	0.93 a
2,4-D + 1 HW – 1 HW	0.55	0.90	0.78	0.74 b
2,4-D – 1 HW	0.38	0.98	0.98	0.78 b
Unweeded - unweeded	0.51	0.83	0.74	0.69 b
Mean	0.55 b	0.92 a	0.90 a	

[a]In a column or row within a parameter, means followed by a common letter are not significantly different at the 5% level by DMRT. CT = conventional tillage, ZT = zero tillage, HW = hand weeding, WE = weeks after emergence.

wetting, and crop sequences influence soil fertility and nutrient availability for rice.

Nitrogen mineralization potentials of wetland soils

Soil N constitutes about 60% of the total N uptake of rice whereas fertilizer N constitutes only about 40%. A deeper understanding of the release pattern of N in various rice soils is needed to manage the N input more efficiently. The study assessed the N mineralization potentials and effect of temperature on mineralization, and developed models to predict the availability of soil N to rice under lowland conditions.

The experiment used 16 soil series, in four soil orders: Vertisol (four soil series), Mollisol (two), Inceptisol (four), and Entisol (three). Three soil

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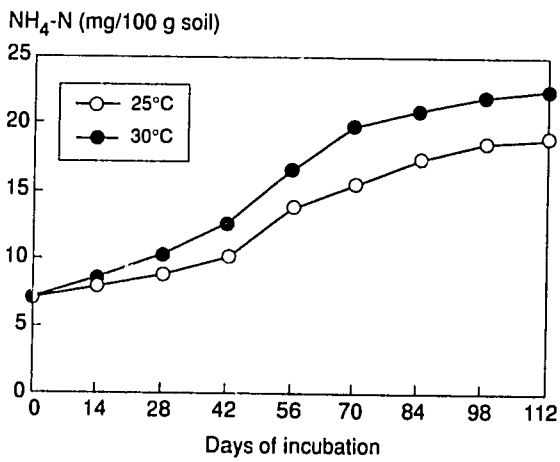
series were unclassified. Except for these three, all soil series have been used under the INSURF network of IRRI.

Incubation studies were conducted in the phytotron at 25 and 30 °C. Wet soil samples equivalent to about 20 g of oven-dried soil were placed inside each test tube (25 × 195 mm). Deionized distilled water was added into each test tube and the test tubes were shaken and tapped manually to allow the soil particles to settle at the bottom. The test tubes were filled to capacity with deionized water and covered with screw caps. The setup was incubated in the phytotron. Samples were taken at 14-d intervals. At each sampling period, NH_4^+-N was extracted from the soil with 2N KCl solution and the exchangeable NH_4^+ was determined by steam distillation with MgO. The mineralization pattern of organic N for each soil was determined and compared with the pattern derived from predictive models. The mineralization parameters such as mineralization potential (N_p), active N fraction (N_p/N_{total}), and mineralization rate constant (k) were estimated.



3. Effect of temperature on mineralization of organic N in Casiguran series.

Results showed that in flooded soils, much higher amounts of available NH_4^+-N were released at 30 °C than at 25 °C. Figure 3 is a typical illustration of the influence of temperature on mineralization of organic N in wetland soils. The N release pattern could be described by either the logistic or exponential model. The logistic model is based on the following relationship:

$$N = \frac{N_p}{1 + \left(\frac{N_p}{N_o} - 1\right)^{*} e^{-kt}}$$

where:

T = time, days
N = mineralized N, mg/100 g soil
N_p = mineralization potential, mg/100 g
N_o = initial mineralized N, mg/100 g
k = rate constant, per day

Table 10. Mineralization parameters for various wetland soils at 30 °C.

Soil series	Logistic model				Exponential model			
	N_o	N_p	k	Active N	N_o	N_p	k	Active N
Binangonan	1.754	6.693	0.040	7.04	1.491	6.574	0.014	6.92
Maahas (IRRI)	3.951	16.420	0.011	9.28	3.982	14.887	0.003	8.41
Calumpang	2.878	11.195	0.025	4.74	2.840	31.656	0.002	13.41
Casiguran	6.143	25.544	0.031	9.12	6.057	39.687	0.005	14.71
Tupi	2.610	6.356	0.022	7.48	2.576	5.403	0.008	6.36
Bantog	0.929	4.545	0.032	3.39	0.811	7.318	0.006	5.46
Luisita	3.208	10.428	0.024	10.03	3.162	14.872	0.005	14.30
Luisiana	6.824	28.977	0.007	16.94	6.882	17.576	0.002	10.28
Alimodian	4.424	10.228	0.017	5.27	4.383	9.727	0.005	5.01
Pili	4.884	14.091	0.016	7.42	4.800	24.772	0.002	13.04
Maahas (Victoria)	6.924	16.468	0.018	6.78	6.833	15.268	0.006	6.28
Maligaya	8.440	17.074	0.011	9.38	8.388	13.930	0.004	7.65
Langa	7.050	12.509	0.020	4.98	6.989	6.452	0.011	2.57
San Dionisio	3.825	9.004	0.011	10.00	3.814	15.587	0.002	17.32
Santa Rita	3.507	8.616	0.017	6.68	3.456	8.696	0.005	6.74
Tagulod	1.034	3.830	0.053	4.40	1.011	3.196	0.021	3.67

The exponential model assumes the following form:

$$N = N_p (1 - e^{-kT}) + N_o$$

where T, N, N_p, N_o, and k are the same as in the logistic model. Therefore, given N_p, N_o, and k, the amount of mineralized N at any time T can be predicted. Based on the experimental data on N release pattern for each soil, mineralization parameters, e.g., N_o, N_p, and k, can be estimated (Table 10). In general, the mineralization rate constants (k) were higher in the logistic model than in the exponential model. The Casiguran series showed a consistently high N_p while the Tagulod series gave a consistently low N_p.

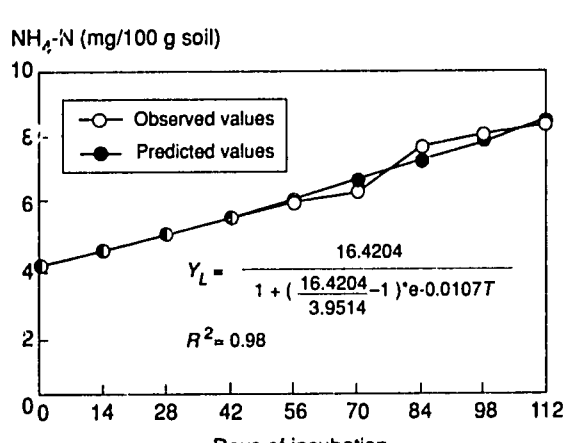
There was very close agreement ($R^2 = 0.98$) between observed and predicted values of mineralized N in the Maahas (IRRI) series (Fig. 4). However, two soils of the same soil order may have different mineralization parameters, depending on their physicochemical properties. For soils of similar total N content, active N fraction could be a good indicator of potentially available soil N. Studies are being carried out to calibrate the obtained phytotron incubation results with field data.

Effective use of nitrogen in lowland rice-based cropping systems

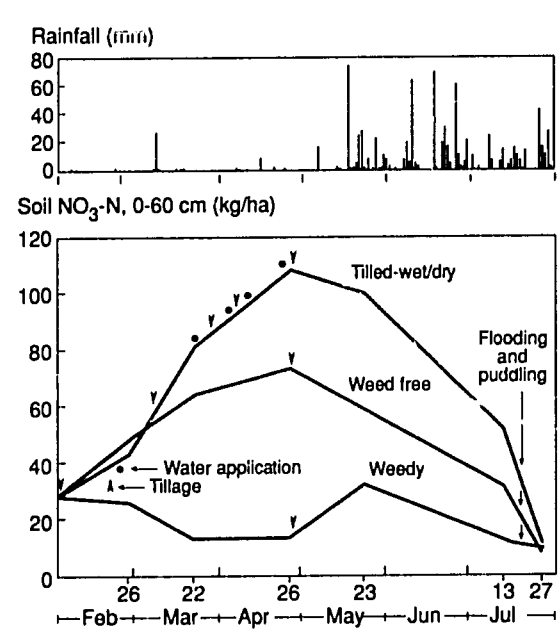
Lowland rice soils typically undergo cycles of drying and flooding. On drying, organic N mineralizes to ammonium, which is rapidly converted to nitrate. The nitrate accumulates in soil and is prone to loss through denitrification and leaching during flooding. In rainfed lowlands, the transition from dry to flooded soil conditions occurs over a 45- to 60-d period. IRRI, the Nitrogen Fixation by Tropical Agricultural Legumes Project, the University of Hawaii, and the International Fertilizer Development Center (IFDC) are jointly conducting research to better understand N dynamics and N balance of the rainfed lowland rice ecosystem and to identify soil and crop management practices that minimize nitrate loss.

In an experiment at IRRI, three fallow treatments—weedy, weed-free, and tilled under dry/wet cycle—were established at the start of the 1990 DS. During the subsequent dry-to-wet transition (DWT) period, sesbania and mungbean crops and weedy and weed-free fallows were imposed as subplots in the DS main plots. After the harvest of mungbean pods, the soil was flooded and puddled, plant residues incorporated, and rice transplanted. Soil nitrate accumulation and loss, soil and atmospheric N captured in plants, and plant residue N effects on rice yield were examined.

Depending on plant growth and tillage, 14 to 108 kg nitrate-N/ha (0- to 60-cm depth) was measured during a 3-mo dry period ending in April (Fig. 5). Nitrate buildup was lowest in plots maintained weedy and highest when nitrification was promoted by tillage



4. Observed and predicted values of mineralized N in Maahas (IRRI) series at 30 °C in the logistic model.



5. Rainfall and nitrate in the top 60-cm soil layer before rice, 1990 experiment.

and water application in the tilled wet/dry plots. During the subsequent 2-mo DWT period, rains were frequent and most of the nitrate was lost unless it was assimilated by plants. On the average, less than 10 kg nitrate-N/ha was measured 1 wk after soil flooding. Plants presumably assimilated soil nitrate and thus rendered less nitrate to be lost during DWT (Table 11).

Less nitrate was lost when weeds or crop plants were present during DWT. Legumes with higher N requirement than weeds most effectively reduced N loss when nitrate was present in large quantities or when planted during the DS in weed-free and tilled wet/dry fallows. Sesbania in tilled wet/dry fallows assimilated 97 kg N/ha from soil compared with only 46 kg N/ha in weedy fallow. A conservative N balance estimate indicates nitrate loss of up to 98 kg N/ha in tilled wet/dry plots when soil was bare during DWT. In contrast, positive change of up to 172 kg N/ha was observed when sesbania was the DWT crop.

Despite some nitrate loss, legumes contributed positively to N balance because of additional N input from biological nitrogen fixation (BNF). Legume BNF, however, decreased with increased assimilation of soil N; BNF-N in mungbean decreased from 63 to 47 kg N/ha and in sesbania from 154 to 125 kg N/ha when the preceding DS fallow was tilled wet/dry rather than weedy.

The large differences in soil nitrate did not substantially influence the total amount of N accumulated by weeds or crop plants. The amounts of N that were available for recycling ranged from 31 to 35 kg/ha in weed residue, 65 to 77 kg/ha in mungbean, and 200 to 222 kg/ha in sesbania. Thirty to 37 kg/ha was removed from the land in harvested mungbean pods. Rice yield was lowest (2.7 t/ha) when rice was grown in fallows that were kept weed-free throughout the DS and DWT periods. Rice yield increased to 3.2 t/ha when weeds, which were allowed to grow during DWT in preceding DS weed-free plots, were incorporated. Weed N might have contributed to this yield increase. Yield of rice further increased to 3.8 t/ha when the DWT weedy fallow was preceded by DS weedy fallow although weed N applied to rice did not increase. Regardless of the DS fallow treatments or nitrate levels, rice yield averaged 4.3 and 4.9 t/ha when mungbean and sesbania residues, respectively, were produced and incorporated in situ during DWT.

The data show that nitrate loss is likely when more is accumulated than the plant biomass can capture. Legumes, because of their high N requirements, may reduce nitrate loss more than weeds when nitrate production is large. In addition, legumes can compensate for nitrate loss and may increase the total usable N by accrual of BNF-N. The traditional practice of leaving fields weedy during DS conserves N but usable N accumulation and rice yield are likely to be low compared with those in systems with legumes. Further work on the effectiveness of native and BNF-N recycled to rice is in progress.

Table 11. N dynamics during the dry-to-wet transition (DWT) period in a lowland rice-based cropping system.

Management		Soil nitrate (kg N/ha) (0-60 cm)			Soil N captured in plant (kg N/ha)	Minimum nitrate loss (kg N/ha)	BNF-N[a] in plant (kg N/ha)	Change in N (kg N/ha)
DS	DWT	Maximum during DS or DWT	1 wk after flooding	Difference (A)	(B)		(C)	(A+B+C)
Weedy	Sesbania	37[b]	9	-28	46	0	154	+172
	Mungbean	32	10	-22	33	0	63	+74
	Weeds	27	8	-19	34	0	0	+15
	Weed free	32	9	-23	0	23	0	-23
Weed free	Sesbania	73[c]	8	-65	59	6	154	+148
	Mungbean	73	8	-65	46	19	52	+33
	Weeds	73	7	-66	31	35	0	-35
	Weed free	73	9	-64	0	64	0	-64
Tilled-wet/dry	Sesbania	108[c]	8	-100	97	3	125	+122
	Mungbean	108	9	-99	66	33	47	+14
	Weeds	108	9	-99	35	64	0	-64
	Weed free	108	10	-98	0	98	0	-98

[a]N from biological nitrogen fixation. [b]Obtained on 23 May. [c]Obtained on 26 April. Plots tilled before initiation of DWT treatments.

Effect of crop establishment practice on phosphorus and nitrogen fertilizer efficiency

Rainfed lowland soil is normally aerated (aerobic) between rice crops and saturated or flooded (anaerobic) during much or all of the rice cropping period. Direct seeded rice crop can be established by either wet or dry seeding. In wet seeded rice (WSR), germinated rice seeds are broadcast onto puddled, saturated soil. In DSR, seeds are broadcast and incorporated in unsaturated, nonpuddled soil.

Because of differences in aeration status of soil at the time of wet and dry seeding, the availability of soil P and hence the requirements for P and N fertilizer may differ between WSR and DSR. In collaboration with the IFDC, a 2-yr field experiment was conducted in Oton, Iloilo, Philippines, to determine the effects of crop establishment method on rice response to P and N fertilization.

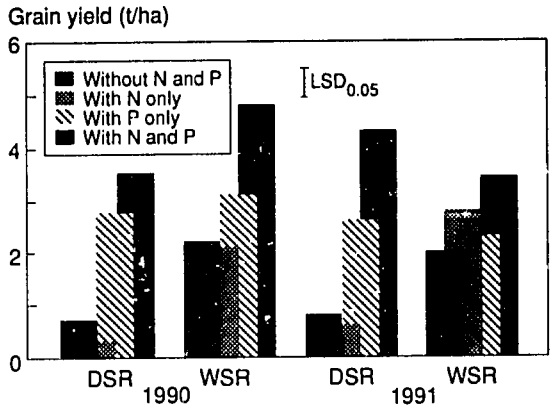
The experimental design was a randomized complete block with two crop establishment methods (WSR and DSR) in factorial combination with four fertilizer treatments (no applied N or P, 15 kg P/ha, 90 kg N/ha, and 15 kg P/ha plus 90 kg N/ha). The top 20 cm of soil had air-dried pH (1:1 wt/vol water) 6.4, 15 g organic C/kg, 1.1 g total N/kg, CEC 57 cmol/kg, and 3 mg Bray P/kg.

With no N and P fertilizers, rice yield was consistently higher with WSR than DSR, suggesting that soil flooding and puddling before the establishment of rice increased the availability of soil N and P (Fig. 6). On this P-deficient soil, application of N alone consistently failed to increase yield; but application of P alone increased yield. Yields were lower for DSR than WSR without P fertilizer, but were statistically similar for DSR and WSR when P was applied. Combined use of P and N fertilizers increased yields more than did P fertilizer alone.

Thus, P is a relatively more important fertilizer input for rice sown on dry soil before soil flooding than for rice sown after flooding and puddling soil.

Management of fertilizer potassium and crop residue with rice and soybean in rotation

Appropriate fertilizer management practices are essential for each crop in rotation in highly intensive and diversified systems of food production, especially when crops are grown on different soil moisture regimes. An experiment in Jakenan Experiment Station in Central Java, Indonesia, seeks to determine 1) which crop in the rotation benefits most from fertilizer K application, 2) the residual effect of applied K on the growth and yield of subsequent crops, and 3) the effect of returning crop residue to subsequent crops in rotation.



6. Effect of rice establishment method and fertilizers on yield of rainfed lowland rice. Oton, Iloilo, Philippines. DSR = dry seeded rice, WSR = wet seeded rice.

The cropping sequence adopted consists of direct seeded rice *gogo rancah* during WS, and *walik jerami* TPR on minimum-tilled land during DS followed by soybean. Figure 7 shows cropping period and rainfall pattern.

The soil of the experimental site has been classified as fine mixed isohyperthermic Aeric Tropaqualf with pH 5.3 in the top 20 cm of soil, 0.358% organic C, 16 ppm available P (Bray 2), CEC 4.10 meq/100 g, 0.07 meq exchangeable K/100 g, 2.74 meq Ca/100 g, and 0.33 meq Mg/100 g, and 0.27 ppm available Zn.

Fertilizer treatments for each crop in the sequence are given in Table 12. All plots received N and P. Urea at the rate of 75 kg N/ha was applied in three splits for both rice crops and 25 kg N/ha for the soybean crop. Triple superphosphate at the rate of 13 kg P/ha was applied to all crops. The full rate of K was 50 kg/ha for all crops. P and K were applied 10 d after germination for the direct seeded rice and soybean and at planting for TPR.

Grain and straw yields of the direct seeded rice crop were higher than those of TPR (Table 12) because the direct seeded rice had favorable moisture while TPR had drought stress during the reproductive stage.

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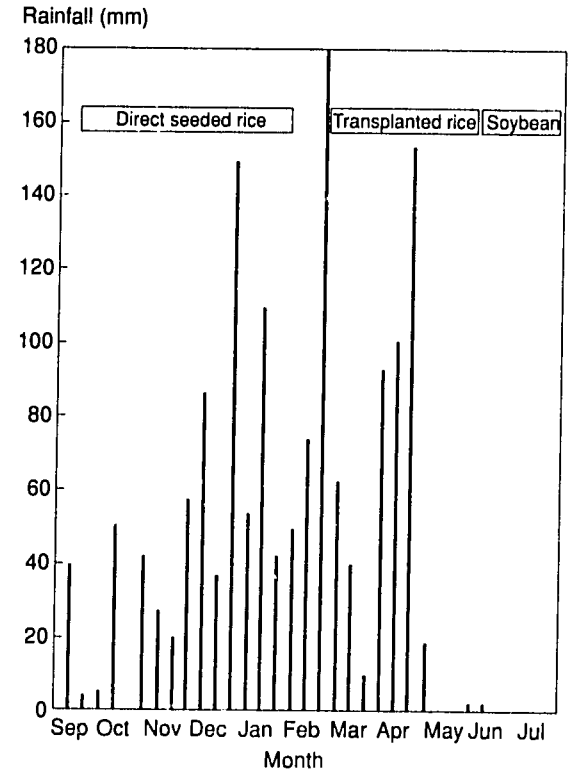


7. Rainfall pattern during the growth of the *gogo rancah* and *walik jerami* rice crops. Jakenan, Central Java, Indonesia.

Differences in grain yield among direct seeded rice treatments were significant, especially between crop residue returned and crop residue removed. The differences were more pronounced when K fertilizer was not applied. Even with a full rate of K application, K response was not very apparent probably because the roots of direct seeded rice were able to penetrate and exploit the soil before it was completely and continuously saturated. Differences in straw yield among direct seeded rice treatments were not significant.

Differences in grain and straw yields of TPR were significant. Grain yields were highest when the full 50 kg K/ha was applied to the crop. The increase over the control plot was significant with and without crop residue returned. The benefit from returning the residue of the preceding crop was marked, especially when K was not applied to the crop, because the biomass of the previous crop contributed K to the soil.

Total direct seeded crop uptake of K, N, and Zn did not vary significantly among the treatments. K uptake ranged from 55.2 to 143.0 kg/ha, N uptake from 95.6 to 119 kg/ha, and Zn uptake from 238 to 374 g/ha. Table 13 shows the average and total uptakes of K, N, and Zn in TPR. The values are half

Table 12. Effect of K application and crop residue management on grain and straw yield of IR64 direct seeded and transplanted in Jakenan, Central Java, Indonesia, 1990-91.

Treatment[a]			Yield (t/ha)			
			Direct seeded		Transplanted	
Direct seeded	Transplanted	Soybean	Grain	Straw	Grain	Straw
1/2 K + CRR	No K + CRR	1/2 K + CRR	5.66 ab	7.70	2.28 abc	3.5 abc
1/2 K	No K	1/2 K	5.30 a-d	7.22	1.61 ef	2.4 cd
1/2 K + CRR	1/2 K + CRR	No K + CRR	5.4 a-d	7.13	2.44 ab	3.5 abc
1/2 K	1/2 K	No K	5.04 bcd	5.81	2.03 bcd	2.7 bcd
No K + CRR	1/2 K + CRR	1/2 K + CRR	6.13 a	8.10	2.68 a	4.0 ab
No K	1/2 K	1/2 K	4.61 cd	6.47	1.78 de	2.7 bcd
No K + CRR	C + CRR	No K + CRR	5.34 a-d	6.35	2.66 a	3.6 abc
No K	K	No K	4.36 d	6.21	1.99 cde	3.1 a-d
K + CRR	K + CRR	K + CRR	5.93 ab	7.35	2.61 a	4.3 a
K	K	K	5.10 a-d	7.72	2.17 bcd	3.7 abc
No K + CRR	No K + CRR	No K + CRR	5.48 abc	6.11	2.10 bcd	2.7 bcd
No K	No K	No K	4.47 cd	5.80	1.36 f	1.9 d
		CV (%)	10.1	23.8	10.6	22.1
		LSD 0.01	1.2	ns	0.52	1.6
		0.05	0.9	ns	0.39	1.2

[a]CRR = crop residue returned. Full dose of K is 50 kg/ha.

Table 13. Effects of K application and crop residue management on total K, N, and Zn uptake of transplanted IR64 in Jakenan, Central Java, Indonesia, 1990-91.

Treatment			Total uptake		
Direct seeded	Transplanted	Soybean	K (kg/ha)	N (kg/ha)	Zn (g/ha)
1/2 K + CRR	No K + CRR	1/2 K + CRR	48.8 bcd	56.0 ab	127.0 ab
1/2 K	No K	1/2 K	14.5 e	38.6 de	88.8 bc
1/2 K + CRR	1/2 K + CRR	No K + CRR	46.7 cd	58.2 a	114.6 abc
1/2 K	1/2 K	No K	30.0 de	40.3 cde	78.7 c
No K + CRR	1/2 K + CRR	1/2 K + CRR	68.5 bc	56.9 ab	150.9 a
No K	1/2 K	1/2 K	26.3 de	41.2 cde	89.4 bc
No K + CRR	K + CRR	No K + CRR	75.6 b	56.5 ab	114.9 abc
No K	K	No K	49.5 bcd	50.5 a-d	118.8 abc
K + CRR	K + CRR	K + CRR	101.6 a	56.5 ab	130.5 ab
K	K	K	67.8 bc	52.5 abc	110.0 abc
No K + CRR	No K + CRR	No K + CRR	25.5 de	44.2 b-e	104.8 bc
No K	No K	No K	14.9 e	33.4 e	75.6 c
Average			47.5	48.7	108.7
		CV (%)	31.0	14.7	20.5
		LSD 0.1	33.9	16.5	51.2
		0.5	24.9	12.2	37.6

those of the direct seeded crop. K uptake was highest when the full rate of K was applied to every crop in the rotation. The gap in total K uptake between with and without residue returned was less when the full rate of K was applied to the TPR than when a half rate of K or no K was applied. On the total N uptake of TPR, the effect of crop residue management was more evident when K fertilizer was applied to the other crops in rotation. Crop residue management markedly affected total Zn uptake, especially when no K or a half rate of K was applied.

The study is being continued to determine the effects of long-term K application with and without crop residues on the productivity of the rice - rice - soybean system.

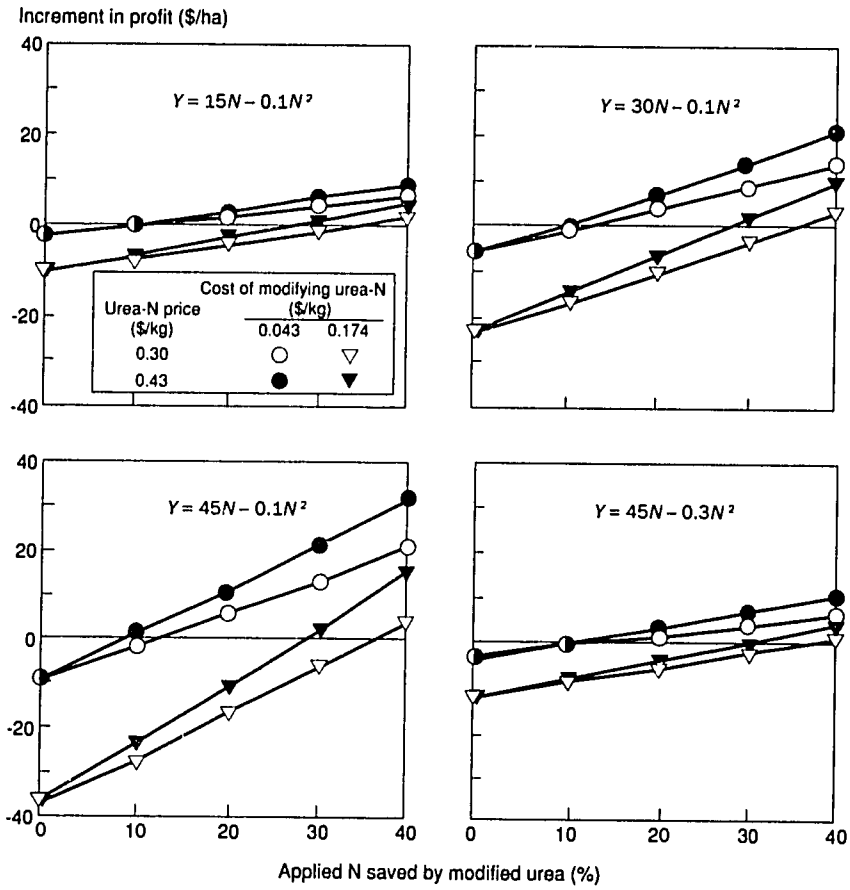
Potential benefits of urea modifications

About one-third of the N applied as urea can be lost, primarily through volatilization of ammonia. N can also be lost by nitrification-denitrification and in runoff when water flows across ricefields. Many modifications to urea such as amendment with urease inhibitors, nitrification inhibitors, algicides, soluble salts, and acidifying agents have been proposed to overcome N loss. However, little is known about the economic benefits and acceptable farm-level costs for urea modified with such amendments.

IFDC and IRRI collaborated in developing a methodology to predict the increased rice yield associated with use of urea modifications. The methodology aimed to 1) estimate the potential economic benefits of using urea modifications that reduce N loss and enhance rice yield, and 2) identify combinations of crop response to N, N losses, and urea prices required to make the use of modified urea economically effective.

Because information is lacking on the urea-N that can be saved by modification and on the cost of modifying urea, the evaluation of potential economic benefits was conducted as a sensitivity analysis. Combinations of four quadratic response functions for urea (Yield = $\beta N - qN^2$), two prices of conventional urea-N ($0.30 and $0.43/kg), five levels of saving in applied urea-N as a result of modification (0, 10, 20, 30, and 40%), and two costs of modifying urea-N ($0.043 and $0.174/kg) were used in the analysis. The price of grain was held constant at $0.16/kg. The increment in farmers' profit with the use of modified urea was the difference in net benefit between modified urea and conventional urea when these fertilizers were used at rates that maximize profit.

The increment in profit with modified urea consistently increased linearly with increasing saving of N by modified urea (Fig. 8). The increment in profit became more sensitive to saving of N as crop response to urea increased (i.e., β increased while q remained constant in the response functions for



8. Increment in farmers' profit as affected by price of urea N, cost of modifying urea per kg N, and yield response to urea. Grain price = $0.16/kg.

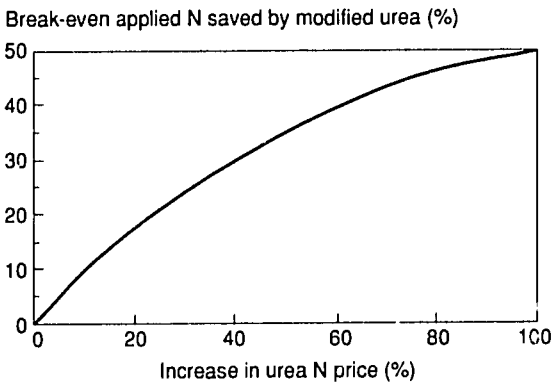
conventional urea). With all four urea response functions, the increment in profit decreased dramatically with increased cost of modifying urea, and increased slightly with increased urea price. The increased cost of modifying urea must be low to provide a positive increment in profit and an incentive to adopt modified urea. At a given price of N from urea and cost of modifying urea, the applied N saved by modified urea at conditions of zero increment in profit (break-even N saved) was not affected by the response functions.

The applied urea-N that must be saved for maximum profit of modified and conventional urea to be equal (the break-even N saved) increased with increasing cost of modifying urea. The increase in break-even N saved with increasing cost of modifying urea, expressed as a percent increase in urea-N price, was independent of the urea-N price. For example, a 33% increase in urea-N price as a result of modification corresponded to a break-even N savings of 25% (Fig. 9).

The results suggest that modified urea would provide highest increments in profit and, therefore, highest incentives for adoption in environments with high rice response to urea-N, high-priced conventional urea, and high urea-N losses that can be reduced or eliminated (saved) by urea modification. In regions with two cropping seasons per year, modified urea would be more economical in the season with the higher response to N, assuming that savings of applied N and prices of fertilizer were similar for both seasons.

Long-term fertility experiments (LTFE)

The LTFE in irrigated rice are conducted at four sites in the Philippines: IRRI, Los Baños; the Philippine Rice Research Institute (PRRI) Central Experiment Station in Muñoz, Nueva Ecija; the Bicol Regional



9. Effect of increased price of urea N, resulting from modification, on the applied N that must be saved through modification of urea to make the profit from conventional urea equal that from modified urea.

Integrated Agricultural Research Center (BRIARC) in Pili, Camarines Sur; and the Visayas Experiment Station (VES) in Jaro, Iloilo City. The IRRI experiment began in 1964, with the 56th and 57th consecutive rice crops harvested in the 1991 DS and WS, respectively. The 47th and 48th crops were harvested at the other sites except at the Visayan station, where the 1991 DS crop was aborted for lack of irrigation water.

In previous years, grain yields and changes in soil fertility were monitored, but total nutrient uptake and nutrient removal in harvested grain and straw were not. Thus, historical nutrient input/output balances were not quantified in these studies. Such balances are needed to interpret trends in the yield response to nutrient inputs and changes in soil properties that govern nutrient availability.

In the 1991 DS, whole plants in each fertilizer treatment were sampled from 12 hills at physiological maturity and total NPK content was determined in grain and straw. Grain yields were measured from a 5-m^2 harvest area within each plot. Straw yields were estimated by the measured harvest index from the 12-hill, whole plant sample after oven drying, and the grain yield obtained from the 5-m^2 harvest area. Rice stubble (cut 30 cm from the ground) that remained in the field after harvest was sampled from 12 hills to determine the quantity and nutrient content of rice straw returned to soil. These measurements allow estimation of the nutrient input/output balance. The same procedures were followed in WS at each site, but analyses are not yet available.

Initial DS results indicate several consistent features across locations: 1) highest yields were achieved in the full NPK treatments at each site; 2) grain yield, total uptake, and net removal of both N and P in control plots without fertilizer inputs were remarkably similar at all sites although the initial soil properties differed, and remain different; 3) although yield levels at the three sites ranged from 5.4 to 7.0 t/ha in treatments with complete NPK inputs, total N uptake in these treatments was comparable, ranging from 105 to 109 kg N/ha.

These similarities suggest a homeostasis for the run-out levels of N and P supply under exhaustive farming without exogenous nutrient inputs, and equivalent plant N assimilation with complete NPK inputs when the same rate of N is applied each season at each location in the same manner (i.e., 2/3 basally incorporated and 1/3 broadcast at panicle initiation). At issue is whether similar N supply characteristics at these three sites represent a common process of evolution in soil properties that govern N release from organic matter and the efficiency of N fertilizer utilization.

Uptake of P in treatments with both N and P inputs differed across sites (Table 14), but all such regimes showed a large surplus in net P input after accounting for P removal with harvest. The difference in P uptake may reflect differences in P sorption characteristics of the soils.

N application increased K uptake at each site regardless of K input level (Table 14). Addition of both N and P further increased K uptake. Two sites showed a net K removal in treatments that received the full NPK treatment. The lack of a response to K in the +NPK vs +NP treatments at each site indicates that K supply is not yet a limiting factor. Previous analyses have shown that K input from irrigation water at IRRI and BRIARC contributes to the maintenance of soil K levels.

The monitoring of nutrient balance at the LTFE sites will continue in the 1992 WS and DS. Although biomass and grain yields differed because of fertilizer input levels, the N and P concentration of grain and straw varied little in these treatments, and the harvest index was nearly identical across treatments within sites. It should therefore be possible to estimate the historical nutrient balances at each site on the basis of grain yield and estimates of straw and grain nutrient concentration.

In 1992 the activity aims to interpret changes in soil fertility and rice response to added nutrients in relation to the historical nutrient balance and the

Table 14. Grain yield and NPK balances[a] in three long-term fertility experiments at IRRI, Philippine Rice Research Institute (PRRI), and Bicol Regional Integrated Agricultural Research Center (BRIARC), 1991 DS.

NPK treatment (elemental basis) (kg/ha)	Grain yield (t/ha)	Nitrogen balance (kg/ha)					Phosphorus balance (kg/ha)					Potassium balance (kg/ha)				
		Total uptake	Harvest removal	Recycled in stubble	Net		Total uptake	Harvest removal	Recycled in stubble	Net		Total uptake	Harvest removal	Recycled in stubble	Net	
					Input (+)	Output (–)				Input (+)	Output (–)				Input (+)	Output (–)
								IRRI[b]								
0-0-0	2.68 d	45 c	33 c	12 c		33	4.8 d	2.9 d	1.8 b		2.9	66 c	20 d	46 c		20
140-0-0	4.82 c	85 b	63 b	22 b	77		9.3 ab	7.3 a	2.1 b		7.3	138 b	53 abc	85 b		53
140-13-0	5.65 ab	97 ab	69 b	28 a	71		10.6 a	6.6 ab	4.0 a	6.4		154 ab	58 abc	96 ab		58
140-0-25	5.10 bc	91 b	59 b	32 a	31		6.4 cd	3.1 cd	3.3 a		3.1	153 ab	47 bc	106 a		22
140-13-25	5.82 a	109 a	83 a	26 ab	57		8.7 a	5.0 bc	3.7 a	8.0		168 a	69 a	100 a		44
								PRRI[c]								
0-0-0	2.89 c	43 c	32 c	11 d		32	4.5 b	2.9 c	1.6 b		2.9	53 d	20 c	33 c		20
140-0-0	4.64 b	81 b	60 b	21 bc	80		5.6 b	4.3 b	1.3 b		4.3	76 c	33 b	43 bc		33
140-26-0	6.70 a	108 a	78 a	30 a	62		14.0 a	8.0 a	6.0 a	18.0		105 b	42 a	63 b		52
140-0-50	4.21 b	73 b	53 c	20 c	87		5.5 b	4.3 b	1.1 b		4.3	85 c	30 b	55 b	20	
140-26-50	7.02 a	105 a	78 a	27 ab	62		14.2 a	8.5 a	5.7 a	17.5		134 a	53 a	82 a		3
								BRIARC								
0-0-0	3.11 c	52 c	38 b	14 b		38		4.5 c	2.8 b	1.7 b		–2.8	77 c	27 b	50 b	
140-0-0	4.94 a	107 a	78 a	29 a	62			7.0 b	5.2 a	1.8 b		–5.2	138 ab	42 a	96 a	
140-26-0	5.02 a	109 a	74 a	35 a	66		10.4 a	5.2 a	5.2 a	21.8		150 a	51 a	99 a		51
140-0-50	4.37 b	94 ab	67 a	27 a	73		5.7 bc	3.9 ab	1.8 b		3.9	124 b	32 ab	91 a	18	
140-26-50	5.39 a	109 a	72 a	37 a	68		10.3 a	4.8 a	5.5 a	21.2		160 a	37 a	123 a	13	

[a]For each site, means in a column that are followed by a common letter are not significantly different at the 5% level by DMRT. [b]At IRRI, grain yield differed significantly among the three cultivars. Treatment means represent those of the highest yielding cultivar. [c]Treatment means are means of the three test cultivars because grain yields did not differ significantly.

initial soil properties at each site. This information is needed to determine the degree to which balanced nutrient inputs contribute to the sustainability of productivity in continuous irrigated rice systems.

LONG-TERM EFFECTS OF AZOLLA AND SESBANIA

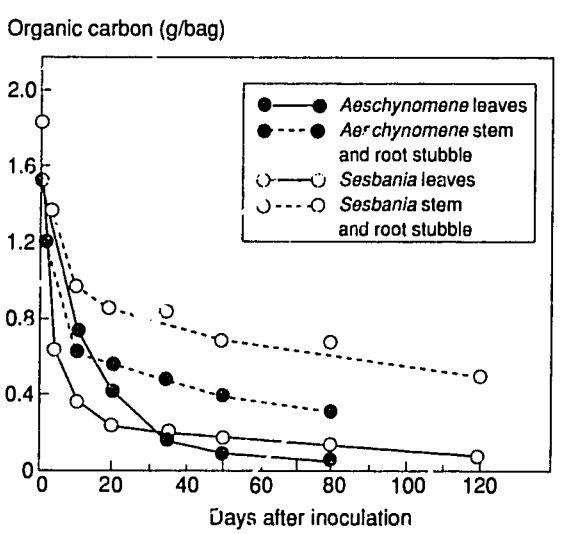
Interest in N_2-fixing GM is growing because of the increasing cost of inorganic fertilizers and concern about long-term soil fertility and productivity. The application of GM to flooded soil is followed by a chain of microbiological activities that are not found when inorganic fertilizer is used. This study aims to determine how organic manure affects the lowland rice-soil system. This long-term biofertilizer experiment started in 1985, measuring in every cropping the growth and N production of GM, and its effects on rice yields and soil fertility.

Decomposition of aquatic green manure and availability of its nitrogen. *Sesbania rostrata* and *Aeschynomene afraspera* decomposed rapidly in lowland rice soil during the first 10 d, after which time more than 50% of the leaves and 30-45% of the stem-root stubble were decomposed (Fig. 10). The half-life of organic matter decay, with the amount of undecomposed material at 10 d as the initial point, was shorter (3-5 wk) for leaves than for stem and root stubble (more than 3 mo). *S. rostrata* decomposed more slowly than *A. afraspera*. Stem bark decomposed first, so that after 2-3 wk only the woody portion remained. Woody residue decomposed very slowly, and persisted in soil 1 yr after incorporation.

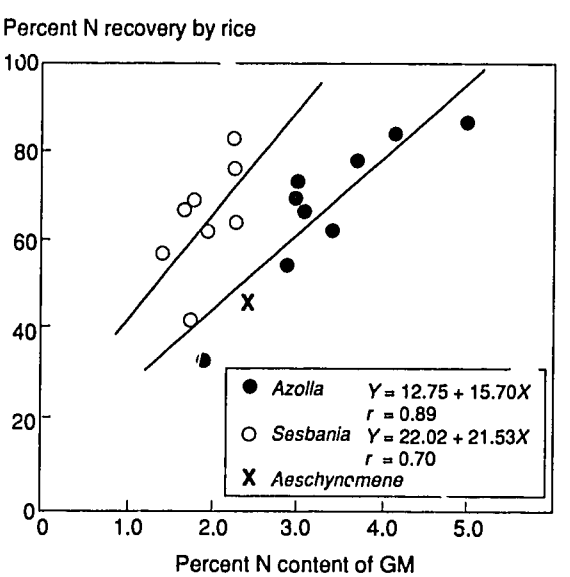
The percent N content of GM is directly related to the amount of N recovered by rice (Fig. 11). Sesbania needed a lower percent N concentration than azolla for the same N recovery by the rice crop. Average N recovery in urea-treated plots was 51%. The N content needed for this recovery was 2.6% for azolla and 1.5% for sesbania. This may be partly because the lignin content of GM is about 10% in 42- to 56-d-old sesbania and 18-30% in azolla.

Effects of green manure on rice yields and soil fertility. Green manuring of nine rice crops resulted in average yield increases of 1.8-3.9 t/ha. This is similar to or higher than increases achieved from application of 60 kg N/ha as urea fertilizer. Plant N uptake decreased with the number of croppings without addition of fertilizer N, was maintained with urea and sesbania incorporation, and increased with azolla incorporation. Grain yield increase was proportional to N applied. Grain yield in DS was higher (32 kg grain/kg of N) than that in WS (12 kg grain/kg of N).

A comparison of soil analysis before the first rice crop (March 1985) and after the seventh crop in the control plots (November 1988) does not show measurable change in the N content. Continuous application of GM increased the percentage of organic N content, but not on an area basis because GM application decreased bulk density. After seven rice crops, GM addition did not affect pH, electrical conductiv-



10. Decomposition of *Aeschynomene afraspera* (in DS) and *Sesbania rostrata* (in WS) in lowland rice soil. IRRI, 1989.



11. Relationship between N of azolla and sesbania and N recovery by rice. IRRI long-term experiment, 1985-90.

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ity, organic C content (% and kg/ha), or exchangeable cations. More P was available in the azolla plots because of water-soluble P addition for azolla growth.

Azolla added a total of 550 kg N/ha in seven rice crops. Of this amount, 384 kg/ha was absorbed by the rice grain and straw, 45.7 kg N/ha was lost (based from ^{15}N estimation), and 120.3 kg/ha (or 17.2 kg N/ha per crop) should have remained in the soil. The total N (kg/ha) in the whole puddled soil layer was not statistically different in the azolla and control plots after seven rice crops because the estimated accumulation from azolla was too small to be detected by soil analysis.

In the tenth rice crop (1990 DS), no fertilizer was applied to any plot. Grain yields from the azolla and sesbania plots were 0.5 t/ha higher than in the control and urea plots. Also, N uptake from GM plots was 11 kg/ha higher than from the urea and control plots, indicating positive residual effects of GM. Grain yield and N uptake were the same in urea and control plots, indicating no residual effect from urea application after nine rice crops. This experiment will be continued to assess the sustainability of irrigated rice - rice systems with inorganic and biofertilizer sources of N inputs.

Mineralization of green manure nitrogen as influenced by plant chemical composition

To minimize N losses and improve a low harvest index, which often results from an unbalanced early N supply, the N mineralization from a GM should match the N uptake pattern of rice.

In collaboration with the University of Giessen, an experiment was conducted in the phytotron to determine the influence of plant chemical composition on the mineralization rate in two flooded soils. Eight legume species, three legume-rice straw combinations, and azolla were incorporated at a rate of 100 mg N/kg of dry soil into 250-g pots filled with Maahas clay and a sandy soil from Floridablanca, Pampanga, Central Luzon. Samples were analyzed weekly for exchangeable ammonium. Plants were analyzed for moisture, N, C, polyphenols, and lignin content.

Correlation of N release with plant chemical parameters (Table 15) indicates that moisture, N, and polyphenol content or C:N ratio are not suitable parameters to predict N release in flooded soils. C:N may be an appropriate indicator for decomposition speed of organic matter if the lignin content of the GM is less than 9%. This feature, however, is encountered only in a few, relatively young, field-grown legume species (e.g., *S. rostrata* and *A. nilotica*). The (polyphenol+lignin):N ratio, usually considered most appropriate to predict mineralization in upland soils, was significantly related to N release only in the clay soil. Net mineralization in all cases was correlated significantly with the lignin:N ratio. Three patterns of net mineralization emerged during the 6-wk incubation (Fig. 12). Pattern 1 exhibited a fast initial N release and was observed in material with lignin:N ratios <2.5. Pattern 3, with a relatively slow initial N release, was representative of material with lignin:N ratios >4. Pattern 2 represents an intermediate type. These patterns were consistent for the sandy soil, but at a considerably lower rate. From material with high lignin:N ratio (e.g., *S. emerus*, *A. afraspera*, and azolla), N release matched best the rice N uptake dynamics in Maahas clay, whereas material with low lignin:N ratio (e.g., *S. rostrata* and *A. nilotica*) was better suited to sandy soil. The lignin:N ratio seemed to be a suitable parameter to predict N release from GM in flooded soils.

Green manure seed production for small farms

The availability of adequate amounts of good quality seed is the most severe agronomic constraint limiting GM usage, but little has been done to overcome the practical problems farmers face in producing their own seed.

Table 15. Correlation of plant chemical parameters and decomposition of organic materials, expressed as number of days until 25 and 50% of the added N are mineralized.

Parameter[a]	Maahas clay		Floridablanca sand	
	25%	50%	25%	50%
Moisture (%)	0.27	0.26	0.51	0.14
Nitrogen (%)	0.09	0.36	0.56	0.17
C:N ratio[b]	0.07	0.45	0.68*	0.13
C:N ratio[c]	0.93**	0.98**	0.86**	0.57
Polyphenol (%)	0.55	0.56	0.02	0.31
Lignin (%)	0.81**	0.58	0.02	0.19
L:N ratio	0.83**	0.76**	0.69*	0.60*
(P+L):N ratio	0.76*	0.84**	0.58	0.45

[a]L = lignin, P = polyphenol. [b]Including all 12 spp. studied. [c]Excluding 5 spp. with more than 9% lignin.

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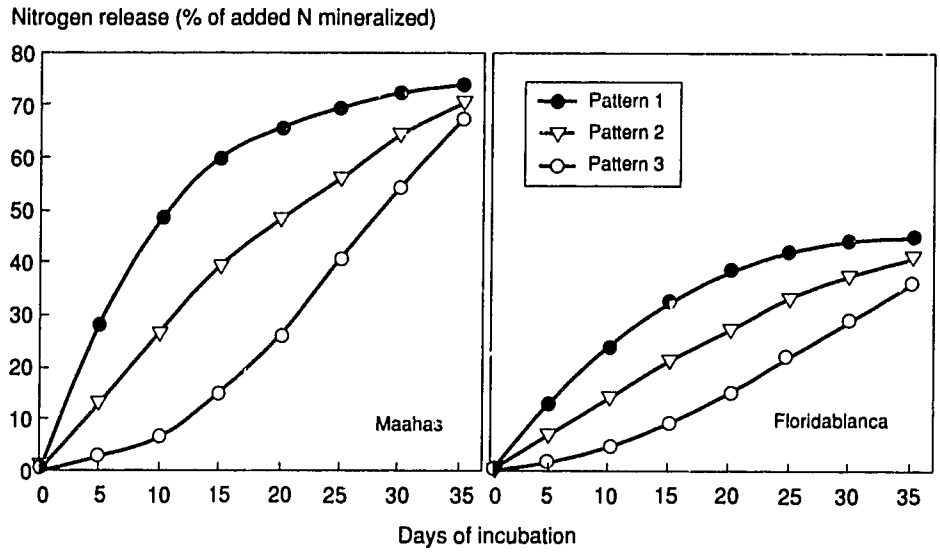

12. N-release patterns of different green manure in two flooded soils.

Table 16. Grain yields when *Sesbania rostrata* and *Aeschynomene afraspera* were intercropped for seed production with rice, IRRI and Ubon Rice Research Center (URRC), 1989 WS.

Treatment		GM yield (kg/ha)			Rice yield (t/ha)		
Planting material	GM population (plants/ha)	Sesbania	Aeschynomene		With Sesbania	With Aeschynomene	
		IRRI	URRC	IRRI	IRRI	URRC	IRRI
GM							
Whole plant	5000	902	35	1117	1.8	1.6	2.9
Whole plant	2500	801	16	678	2.6	1.8	3.1
Whole plant	1250	1004	*	877	2.7	*	3.2
Top cutting	5000	1435	14	814	2.2	1.8	2.8
Top cutting	2500	828	7	596	2.8	1.7	3.4
Top cutting	1250	758	*	388	3.0	*	3.6
Basal cutting	5000	900	30	639	2.3	1.7	3.2
Basal cutting	2500	607	15	426	3.0	1.7	3.1
Basal cutting	1250	869	*	680	3.0	*	3.2
Control (rice alone)					3.0	1.8	3.0
Standard error		194	5	194	0.4	0.2	0.4

*Not tested.

Research at IRRI and at a key on-farm research site in Ubon Province, Northeast Thailand, was conducted to address the issue of developing low-cost, farm-level seed production methods, and to quantify the seed production potential of sesbania. The use of whole seedlings and stem cuttings was evaluated for both Sesbania and Aeschynomene spp. transplanted at a density of one plant per 2, 4, or 8 m^2 of ricefield area (Table 16). Even at high densities, intercropped Aeschynomene was less competitive than Sesbania, with an average seed yield of 857 kg/ha. To avoid significant competition with rice the Sesbania population must be kept low (less than 1 plant/2 m^2 rice area). Sesbania seed yields below this density averaged 811 kg/ha, regardless of the type of planting. Sesbania grew less vigorously in the infertile soils of Northeast Thailand and generally did not affect rice yield even at the higher population (Table 16). Harvested seed yields of Sesbania were about 30 kg/ha in the rice + Sesbania

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intercrop, which is approximately the recommended GM seeding rate per hectare.

We observed the following problems that may make intercropping of GM with rice impractical: 1) rice may be damaged by Sesbania lodged by strong winds and intense rains; 2) intercropping Sesbania may hamper some maintenance operations for the rice, e.g., spraying; 3) after rice canopy closure, the field may be difficult to enter for periodic GM seed priming, especially in heavy soils; 4) the GM seed plants are scattered over a large area, which increases travel time for harvest operations; and 5) the woody root stumps of the GM plants may interfere with subsequent land preparation operations.

Transplanting or seeding along the bunds. The GM is seeded or transplanted in a single row along the bunds and allowed to mature with TPR for seed production. Alternatively, GM plants growing adjacent to the bunds at the time of soil incorporation are left intact and allowed to mature with the rice.

Sesbania branches were clipped to reduce competition for radiation with the adjacent rice and the number of plants along the bund was varied. The GM transplanting was delayed to avoid early competition with the rice.

The GM plants along the bunds shaded the adjacent rice, but row by row sampling showed no strong yield-depressing effect on rice. Whole seedlings at high population, with no clipping, or with clipping of Sesbania but not Aeschynomene, gave the best seed yields (220 g and 159 g/m of bund, respectively) without significant effects on rice (Table 17). Thus, to produce the 30 kg and 50 kg, respectively, of seeds recommended for establishing a satisfactory GM crop stand, 136 m total bund length is needed for Sesbania and 300 m for Aeschynomene.

In Northeast Thailand, the highest Sesbania seed yield was only 10 g/m of bund (Table 18). Seed yields were low because of severe insect damage to flowers, pods, and leaves, and to bund compaction and low soil nutrient status. The Thai farmer would thus require 3,000 m bund length to produce the needed 30 kg GM seed/ha. Regardless of location, transplanting along the bunds is more practical than intercropping with rice and may be a more attractive strategy to farmers when the field area for seed production is limited.

Our comparison indicated that while Aeschynomene was more succulent and had less biomass, and therefore is easier to incorporate into the soil as a GM, Sesbania was easier to manage for seed production. We are now engaged in whole-farm tests of the sustainability of GM production systems that integrate both biomass production and seed production.

Aquatic legumes germplasm collection

The use of the stem-nodulating aquatic legume *S. rostrata* as GM for lowland rice offers potential for resource-poor farmers to grow their own N instead of depending on mineral fertilizers. However, overdependence on a single genotype risks pest and disease outbreaks. Furthermore, use of *S. rostrata* is successful only in a narrow range of environmental conditions.

In 1990, in collaboration with the University of Giessen, 37 new accessions were added to the aquatic

Table 17. Grain yields when *S. rostrata* and *A. afraspera* were grown for seed along bunds. IRRI, 1989 WS.

Treatment		GM plant density (no./linear m)	GM yield (g/linear m)		Rice yield (t/ha)	
Planting material	GM canopy management		Sesbania	Aeschynomene	With Sesbania	With Aeschynomene
GM						
Whole plant	Clipped	1	57.5	84.5	2.3	2.9
Whole plant	Clipped	3	220.2	122.5	2.3	3.1
Whole plant	Unclipped	1	116.5	88.8	2.6	2.6
Whole plant	Unclipped	3	137.2	159.2	2.1	2.4
Basal cutting	Clipped	1	117.2	81.5	2.8	2.5
Basal cutting	Clipped	3	98.8	74.8	2.6	2.9
Basal cutting	Unclipped	1	123.8	85.0	2.7	2.6
Basal cutting	Unclipped	3	151.0	98.0	1.7	2.8
Control (rice alone)					2.7	2.8
Standard error			25.0		0.5	

Table 18. Grain yields when *S. rostrata* was grown for seed along bunds. URRC, Thailand. 1989 WS.

Treatment			
Sesbania planting material	Plant density (no./linear m)	Sesbania yield (g/linear m)	Rice yield (t/ha)
Whole plant	2	10.0	2.0
	4	8.2	2.1
Basal cutting	2	2.7	2.2
	4	3.1	2.2
Seed	4	0.8	2.1
Control (rice alone)		-	2.0
Standard error		0.2	0.2

legumes collection. The accessions were collected from Burundi, Gambia, Guinea, Kenya, Rwanda, Senegal, and Zaire, and were identified and characterized based on phenotype and nodulation pattern. IRRI houses probably the world's largest collection of aquatic legumes, including numerous ecotypes of 41 species belonging to the genera *Aeschynomene*, *Sesbania*, and *Neptunia*. The collection comprises herbs, shrubs, and trees from 28 countries. Fifty-four of 87 screened accessions exhibit varying degrees of nodule formation on aboveground plant parts. Screening to identify species and ecotypes that combine the traits of fast growth, high N_2 fixation, and moderate sensitivity to photoperiod is in progress. Slow- and fast-release GM species may be differentiated by their chemical composition (lignin:N ratio). No pest or disease damage has been observed in some strongly lignified or hairy species. A few accessions seem to perform satisfactorily on acid and saline soils. Collection and characterization of aquatic legume germplasm will continue.

Subprogram II: Germplasm improvement

Breeding and evaluation

This project's principal goal is to develop rice germplasm to suit different rainfed lowland environments (e.g., drought-prone, submergence-prone, and combinations of the two). Emphasis, therefore, has been placed on the generation of germplasm with differing maturity periods, plant heights, adaptation to water regimes, and levels of resistance to pests. The breeding materials have been screened and evaluated for target sub-ecosystems.

In 1991 DS and WS, populations of 156 F_1, 100 F_2, and 12,673 pedigree rows were evaluated. In addition, 450 breeding line entries were formed for the observational nurseries and 50 for the replicated yield trials. These advanced lines were grown in WS in drought-prone and medium-deep conditions.

The materials previously selected for their superior agronomic performance and tolerance for stresses (e.g., drought, submergence) were screened and characterized for disease and insect resistance. Of 10,357 breeding lines screened for bacterial blight (BB) biotype 1, 92% were resistant. Of 76 lines evaluated for BB biotype 2, 26 lines were resistant. Of 6,713 lines screened, 50% were resistant to brown planthopper (BPH) biotype 1; of 621 entries, 30% were resistant to BPH biotype 2; and of 596 entries, 31% were resistant to BPH biotype 3. Of 6,766 lines screened for green leafhopper (GLH), 20% confer resistance.

Evaluation for adaptation to water deficit environments

A total of 1,932 breeding lines were evaluated under field conditions at IRRI in the 1991 DS. These lines were subjected to water stress at seedling stage, about 45 DAS.

The cultivars Salumpikit and IR442-2-58 were the resistant checks and IR20 was the susceptible check. Drought score was taken when soil moisture potential reached –1.0 MPa or when the susceptible check exhibited severe leaf rolling or leaf drying, on a scale of 1-9 (1 = slightly rolled leaf, 9 = severely or tightly rolled leaf). The average drought scores were 3.8 for Salumpikit and 4.0 for IR442-2-58. Under this severe water stress, about 200 lines (10%) were given a score of 4 or better (Table 19).

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A comparative yield experiment was conducted in 1991 WS to observe the performance of the improved rainfed lowland lines in relatively favorable conditions in Tarlac and at IRRI in the Philippines. The Tarlac site was located near the bottom of a field that accumulated water from the neighboring fields, so growth and yields were good. Unfortunately, strong winds and rain during grain filling caused severe lodging of some lines. The IRRI site was rainfed throughout the growing season. Average grain yield of rice cultivars was about 2.0 t/ha higher in Tarlac than at IRRI. The line IR33380-7-2-1-3, which significantly outyielded IR72 in Tarlac, was a top yielder at both locations (Table 20).

Table 19. Improved breeding lines that combine drought tolerance and resistance to diseases and insects.[a] IRRI, 1991 DS.

Designation	Parentage	Drought score[b]		BI	BB biotype 1	BPH biotypes			GLH
		−1.0 MPa	Recovery			1	2	3	
IR36974-1-3-3-3-3	BIET927/IR42	4	1	-	-	1	3	1	-
IR41431-68-1-2-3	IR8234-OT-9-2/ IR19661-131-1-2	4	1	4	1	3	3	3	3
IR42221-2-2-3-1	IR52/MTU7029// IR4215-301-2-2-6	3	1	7	1	3	3	9	5
IR43040-PMI-B-4-1-2-1	Leuang Yai 148/ IR9129-209-2-2-2-1	4	1	6	1	3	7	3	7
IR46331-PMI-53-2-1-3	Leuang Yai 148/ IR18272-27-3-1// IR21231-117-2-2	4	1	9	1	7	7	7	8
IR48088-PMI-8-1-1-4-1	Nam Sagui 19/ BR319-1//IR21848-65-3-2	4	1	1	1	7	7	9	5
IR48852-1-3-3-2	PMI 121/IR25588-7-3-1	4	1	7	1	5	5	2	3
IR49758-UBN-1-B-1-1	Nam Sagui 19/ IR29385-2-2-3// IR24632-34-2	3	1	1	1	5	3	4	4
IR68		4	1	2	2	5	3	5	3
Check variety									
Salumpikit (resistant)		4	1						
IR442-2-58 (resistant)		5	1						
IR20 (susceptible)		7	3						

[a]BI = blast, BB = bacterial blight, BPH = brown planthopper, GLH = green leafhopper. [b]The resistant checks generally score 3-4 at −10 bar.

Table 20. Grain yield and rank (in parentheses), agronomic characteristics, and reaction to disease and insects of selected advanced breeding lines evaluated in favorable rainfed lowland areas in the Philippines, 1991 WS.[a]

Designation	Parentage	Grain yield (t/ha)		Maturity (d)	Height (cm)	BB biotype 1	BPH			GLH
		IRRI	Tarlac				1	2	3	
IR33380-7-2-1-3	IR52/IR13240-39-3// IR50	3.61 (3)	6.14 (1)	133	116	1	2	2	2	3
IR43449-SKN-522-3-1-3	IET1444/KDML 105// IR19660-73-4-2-2	3.39 (5)	5.50 (4)	142	112	1	3	3	3	5
IR55008-74-3-1-1	IR43491-1401-2-3/ IR41183-57-5-2-1	3.38 (7)	5.22 (7)	136	115	1	3	3	3	7
IR55008-33-3-2-1	IR43491-140-1-2-3/ IR41183-57-5-2-1	3.34 (8)	5.79 (2)	138	118	1	3	5	3	6
Check variety										
IR72		3.03 (18)	5.59 (3)	113	94	1	2	3	3	3
IR68		2.87 (22)	4.27 (22)	126	120	2	2	3	4	3
Mahsuri		2.23 (39)	3.28 (29)	137	139	5	8	9	9	8
Average		3.12	5.11							
CV (%)		20.7	16.4							
LSD (0.05)		.789	.888							

[a]Values are means from 3 replications.

Promising elite lines that demonstrated outstanding performance in low fertility, drought-prone environments for several years are listed below.

- IR43450-SKN-506-2-2-1-1, selected in Northeast Thailand, has grain characteristics (e.g., long slender grain, nonglutinous endosperm, and aromatic) similar to those of the popular Thai variety KDML 105, is moderately resistant to blast (Bl) disease, and adapt' to soil fertility.
- IR43506-UBN-520-2-1-1, selected in Ubon, has waxy endosperm, is photoperiod sensitive, 125 cm high, and resistant to Bl and salinity.
- IR43062-PM1-B-15-1-2-1, a glutinous cultivar selected in Pimai, Thailand, is resistant to Bl, BB, and BPH; is moderately resistant to GLH; and is photoperiod sensitive.
- IR19431-72-2 demonstrated outstanding performance in the drought-prone Cagayan Province for several years. It is grown by farmers because its grain quality is similar to that of Wagwag, a popular variety in the region. It has a 135-d cycle, which is shorter than that of the photoperiod-sensitive Wagwag, and is resistant to BB, BPH, and GLH.
- IR29341-15-2-1-1 is resistant to Bl, BB, and GLH. It has performed well in Solana, Cagayan, and Rajshahi, Bangladesh. It matures in 130 d.
- IR41431-68-1-2-3 has shown stability across locations in the Philippines. It is resistant to Bl, BB, and tungro virus; confers resistance to BPH and GLH. It matures in 125 d, and has shown high seedling vigor in direct seeding trials.

The elite cultivars listed below were evaluated in replicated yield trials in Northeast Thailand in 1991. They were consistently selected by Thai and IRRI breeders in four of six locations.

- IR57458-PM1-2-B-1-1, a long slender grain cultivar with intermediate amylose content, is resistant to BB, BPH biotypes 1 and 3, and GLH.
- IR57514-PM1-5-B-1-2 performed well in poor soils of Northeast Thailand, demonstrated high tolerance level in submergence tests at IRRI, and has long slender grain with 23% amylose content.
- IR57519-PM1-5-B-2-2 showed tolerance in submergence trials at IRRI and is resistant to BlB and BPH.

Evaluation for adaptation to water excess environments

The yield potential of 25 breeding lines (Table 21) with submergence tolerance and other desirable traits was evaluated under medium-deep conditions at IRRI in the 1991 WS. The adapted rainfed lowland varieties Mahsuri, Pankaj, and FR13A and the high-

Table 21. Grain yield, submergence score, agronomic characteristics, and reaction to disease and insects of breeding lines evaluated under medium-deep water conditions (30-40 cm). IRRI, 1991 WS.

Designation	Grain yield (t/ha)	Rank	Days to flowering	Height (cm)	Submergence score	BB biotypes		BPH biotypes			GLH
						1	2	1	2	3	
IR49830-7-1-2-2	3.7	2	104	119	4	1	7	1	3	3	3
IR51164-17-1-2-2	2.7	11	118	118	3	2	7	3	5	7	7
IR52586-9-6-5-2-3-B-3-2	2.4	21	100	91	1	1	7	5	7	7	3
IR52533-52-2-1-2-1-B-2-3	2.3	25	102	97	1	7	7	3	7	7	3
IR52586-70-3-2-3-3-B-1-1	2.2	29	95	94	1	1	7	3	5	7	3
IR43559-25-5-3-2	2.2	31	104	107	3	2	7	3	5	3	3
IR43470-7-3-5-1	2.1	33	90	103	-	2	5	3	3	3	3
IR57453-19-3-3-2-3	2.0	35	110	133	3	1	6	7	9	9	3
IR40931-33-1-3-2	2.0	37	90	108	1	1	5	5	9	7	3
IR57478-2-3-2	1.6	43	95	132	2	1	6	7	9	7	3
IR40931-26-3-3-5	1.3	47	100	124	4	1	7	3	7	3	3
Check variety											
IR74	3.0	9	95	95	9	6	6	1	1	3	5
Mahsuri	2.6	14	105	139	9	5	6	9	9	9	7
IR48	2.4	20	107	126	8	1	4	3	5	7	7
Pankaj	2.3	24	95	121	8	5	7	7	9	7	7
IR68	1.7	43	95	120	9	2	6	1	3	5	3
FR13A	1.2	48	102	155	6	5	7	7	9	9	9
Mean	2.3										
CV (%)	25										
LSD (0.05)	812										

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yielding semidwarf cultivars IR48, IR68, and IR74 were used as checks.

Breeding lines with submergence tolerance can yield the same as or more than popular rainfed lowland varieties Mahsuri and Pankaj (Table 21). However, IR49830-7-1-2-2, which derived a submergence gene from FR13A, outyielded all check varieties; possessed resistance to BB biotype 1, BPH, and GLH; and is about 25 cm shorter than FR13A.

These cultivars will be evaluated in the medium-deep condition of eastern India where water stagnation is a major problem.

The same entries and check varieties were evaluated for yield performance in 1991 WS and DS. Many lines performed very well in both seasons, compared with the best irrigated check IR68 (Table 22).

Table 22. Grain yield of rice cultivars evaluated in DS and WS. IRRI, 1991.

Designation	Grain yield[a] (t/ha)		
	WS	DS	Mean
IR48120-49-5-3-2	5.9	4.2	5.0
IR49830-7-1-2-2	5.7	4.0	4.9
IR51089-65-1-1-3	5.5	3.7	4.6
IR31238-474-3-P1	5.0	3.9	4.5
IR47310-117-1-3-3	5.0	3.9	4.4
IR37096-50-1-3-3	4.6	4.3	4.5
IR51164-17-1-2-2	4.7	4.1	4.4
IR33380-60-1-2-2	4.6	4.0	4.3
IR49830-26-1-2-1	4.6	3.9	4.2
IR42241-76-2-3-3	4.5	4.4	4.5
IR19431-72-2	4.5	4.8	4.7
IR43559-25-5-3-2	4.4	2.9	3.6
IR42221-14-1-3-2-1	4.2	3.3	3.8
IR43559-39-2-6-3	4.2	3.5	3.8
IR41431-68-1-2-3	4.0	3.0	3.5
IR41431-11-2-1-3-3	3.9	3.9	3.9
IR46292-24-2-2-1-2	3.6	2.9	3.3
IR43470-7-3-5-1	3.1	3.8	3.4
IR40931-33-1-3-2	3.1	3.6	3.3
IR40931-26-3-3-5	3.0	3.3	3.2
Check variety			
IR68	4.8	5.2	5.0
Mahsuri	4.7	3.5	4.1
IR48	4.7	3.7	4.2
Pankaj	4.4	3.8	4.1
IR74	4.1	3.9	4.0
FR13A	1.2	-	1.2
Mean	2.3	3.9	
LSD (0.05)	2.3	3.9	
CV (%)	11.6	13.5	

[a]Average of 3 replications in WS and 4 replications in DS.

IR49830-7-1-2-2 and IR51164-17-1-2-2, which yielded well in the medium-deep conditions, also performed exceptionally well in irrigated culture.

Varietal performance in drought- and submergence-prone conditions

The rainfed lowland rice ecosystem is characterized by hydrological stresses that may occur at any stage of rice development. Solana, Cagayan Province, Philippines, allows evaluation in three water regimes: drought-prone (stratum I), drought- and submergence-prone (stratum II), and submergence-prone (stratum III).

Breeding lines were evaluated for yield under two water regimes (strata I and II) in rainfed lowland conditions (Table 23). Many cultivars outperformed the irrigated checks and had yields similar to that of Mahsuri, a popular variety in rainfed lowland areas.

IR28526-44-1 (B2025*C-MR-100-2-2/BG90-2// IR48) and IR41431-68-1-2-3 (IR8234-OT-9-2/ IR19661-131-1-2) were outstanding. The latter also performed well when direct seeded. IR43526-523-1-1-1, an improved photoperiod-sensitive line, performed well during 1989 and 1990 trials.

Breeding lines selected from medium-deep conditions were also evaluated at the Solana site, in strata II and III. The area was submerged for 2 d after transplanting, but seedlings were undamaged. Several lines performed better than the check varieties (Table 24). IR41431-68-1-2-3, which yielded well in drought-prone areas for many years, produced the highest grain yield (4.0 t/ha) in this condition. In addition, IR49830-7-1-2-2-13-3-2, IR52533-52-2-1-2-1-B-2-3, and IR52586-9-6-5-3-B 3-2 are improved plant type breeding lines with submergence tolerance; their productivity is superior to that of FR13A, the original parent. These selected lines will be evaluated in major flood-prone rice areas in eastern India and Bangladesh.

Next steps

In 1992, emphasis will shift to increasing breeding activities in the submergence-prone subecosystem. Breeding materials for major rice areas that are prone to this problem will be evaluated and selected. The consortium site at Polba, India, will be a breeding center for screening and evaluation and for conducting strategic research, with strong links with satellite stations in Patna, Raipur, Cuttack, and Masodha. Development of rice germplasm appropriate to dif-

Table 23. Grain yield, flowering date, plant height, and reaction to disease and insects of breeding lines evaluated under drought-prone conditions in Solana, Cagayan, Philippines, 1991 WS.[a]

Designation	Grain yield (t/ha)	Days to flowering	Height (cm)	BB[b] biotypes		BPH[c] biotypes			GLH
				1	2	1	2	3	
Mahsuri	3.7 (1)	119	86	5	6	8	9	9	8
IR28526-44-1	3.6 (2)	122	91	2	7	3	4	6	7
IR41431-68-1-2-3	3.3 (3)	116	75	1	7	3	3	3	3
IR46331-PMI-53-2-1-3	3.2 (4)	112	74	2	5	5	7	7	8
IR48725-B-B-129-1	3.1 (5)	113	81	2	6	3	7	4	3
IR43342-10-1-1-3-3	3.0 (6)	104	74	2	7	4	6	6	3
IR43073-33-3-1-2	3.0 (7)	123	77	1	4	2	4	5	5
IR43526-523-1-1-1	2.9 (8)	113	72	1	6	4	5	7	6
IR50500-52-1-3-2	2.9 (9)	101	70	1	6	4	4	6	8
IR49612-45-6-2-2	2.9 (10)	123	78	7	3	6	5	5	5
Check variety									
IR68	2.1 (43)	95	58	1	6	2	3	3	3
IR72	2.7 (20)	109	75	2	6	2	3	4	3
CV (%)	14.9								
LSD (0.05)	0.5								

[a]Values are means for 2 replications in stratum I and 2 replications in stratum II.

Table 24. Grain yield, submergence score, agronomic characteristics, and reaction to disease and insects of breeding lines evaluated under medium-deep water conditions, Solana, Cagayan, 1991 WS.[a]

Designation	Grain yield (t/ha)	Rank	Days to flowering	Plant height (cm)	Score					
					Submergence	BB biotype 1	BPH biotypes			GLH
							1	2	3	
IR41431-68-1-2-3	4.0	1	92	115	7	1	1	3	3	3
IR48120-49-5-3-2	4.0	2	112	120	8	1	3	3	3	3
IR52533-52-2-1-2-1-B-2-3	3.8	3	102	97	1	7	3	7	7	3
IR41431-19-2-2-3	3.8	4	164	111	8	1	3	3	3	3
IR49755-5-1-1-73-3	3.8	5	113	-	7	1	3	3	3	3
IR53506-B-2-1-1-2-2	3.8	6	107	-	5	1	3	7	3	3
IR43015-90-2-1-1	3.7	8	114	131	9	1	3	3	3	3
IR49612-45-6-2-2	3.7	10	115	130	6	1	3	6	5	5
IR52586-9-6-5-2-3-B-3-2	3.7	11	100	91	1	1	5	7	7	3
IR49830-7-1-2-2-13-3-2	3.7	12	104	119	4	1	1	3	3	3
Check variety										
IR48	3.8	7	107	126	8	1	3	5	7	7
Mahsuri	3.7	9	105	139	9	5	6	9	9	7
Wagwag Ramsi	3.4	22								
Wagwag Faire	3.3	30								
FR13A	2.6	51	102	155	6	5	7	9	9	9
Mean	3.3									
CV (%)	11.4									
LSD (0.05)	761									

[a]Values are means for 2 replications in stratum II and 2 replications in stratum III.

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ferent farming systems will be intensified. Restriction fragment length polymorphism techniques will be employed to tag genes for submergence tolerance and additional gene(s) for photoperiod sensitivity. An attempt will be made to incorporate a higher level of Bl resistance into the advanced breeding lines, as it is anticipated that better crop management may increase the disease inoculum of the susceptible varieties presently grown by farmers.

An appropriate field design will be used to develop the "fertility strips" at Ubon to identify rice cultivars with yield stability in low fertility conditions and responsiveness to additional inputs.

Genetics, physiology, and screening methods

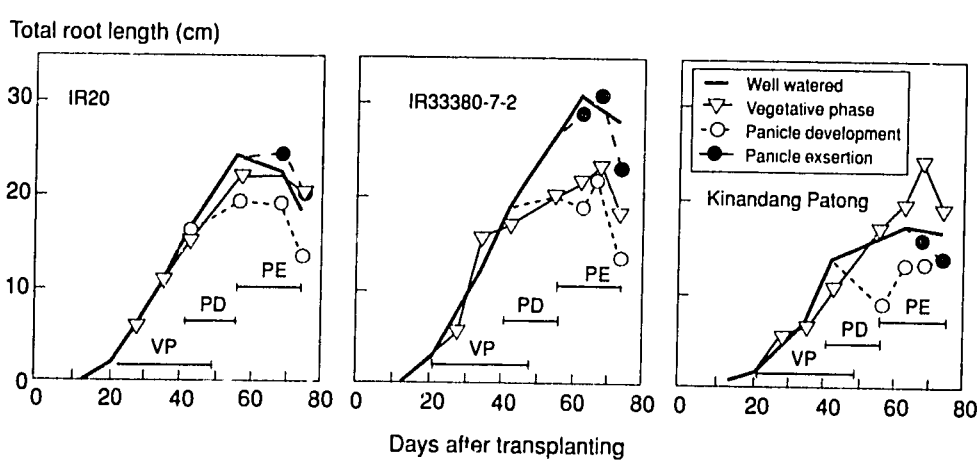
Research has been directed toward understanding the genetics and physiology of rice under different water regimes. Previous work emphasized genetic studies on photoperiod sensitivity, leaf epicuticular wax, and root distribution and penetration as mechanisms for escaping stress; additional research on root responsiveness to water deficit is reported below.

Root growth and distribution under water deficit conditions

Survival and productivity of rice under water-limited conditions depend strongly on the roots' ability to take up water from the soil. Two field experiments conducted during the 1991 DS assessed the growth and development of rainfed lowland rice roots in response to water deficit.

Transplanted rice. An experiment was conducted in puddled, but fast-draining soil with depth to free water below 1 m, so that water deficit developed quickly. The experiment design was a split plot with four replications. Main plot treatments were four water regimes: 1) well watered, flooded daily; 2) vegetative phase stress, nonirrigated from 21 to 49 DT; 3) panicle development stress, nonirrigated from 42 to 56 DT; and 4) panicle emergence stress, nonirrigated from 56 to 74 DT. To impose similar severity of stress for the different stress timings, stress periods were stopped when the leaf rolling score of the most susceptible genotype reached 5 (tightly rolled). All plots were flooded daily except during their stress periods. Subplots were three genotypes: IR33380-7-2, a promising rainfed lowland breeding line; IR20; and Kinandang Patong, a drought-tolerant upland cultivar. As these genotypes had slightly different rates of phenological development, stress periods did not occur at identical stages of development.

Roots were observed weekly with a minirhizotron. Total root length (TRL) was less with water deficit than with the well-watered treatment for all stress timings (Fig. 13). During vegetative and panicle development stresses, TRL continued to increase though more slowly than during the well-watered treatment. During the panicle emergence stress period, TRL declined in both well-watered and stressed plots. Stress effects on TRL were greater during panicle development than during vegetative or panicle emergence stages. Stress effects on TRL persisted after reflooding for vegetative and panicle



13. Total root length of three genotypes in response to water deficit at different growth stages. Horizontal lines indicate stress periods.

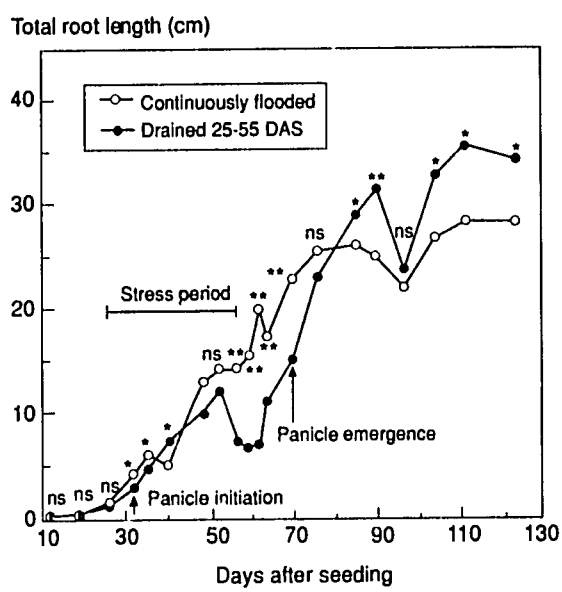
Table 25. Total root length of 12 rice genotypes at the end of and 34 d after a 30-d water deficit under wet seeded lowland conditions.

Genotype	Total root length (cm)			
	56 DAS		89 DAS	
	Continuously flooded	Stressed 25-55 DAS	Continuously flooded	Stressed 25-55 DAS
IR20	21.0	7.9	30.0	21.6
IR72	19.2	3.8	27.5	28.4
IR191431-72-2	19.0	7.2	23.8	22.9
IR43449-SKN-522-3-1-3	16.9	4.6	28.6	31.6
Binato	16.5	10.0	31.3	34.4
IR46331-PM-53-2-1-3	15.9	10.6	34.5	38.6
IR13146-45-2-3	14.2	12.1	17.6	35.8
IR47310-117-1-3-3	13.4	3.4	21.3	25.3
IR43526-523-1-1-1	10.8	6.9	28.4	36.6
IR46	10.0	11.4	20.6	39.1
IR28626-33-3-25-2-3	9.0	6.6	21.2	29.8
IR49612-45-6-2-2	7.8	6.0	22.0	38.6
LSD (0.05) between				
water regimes	2.0		3.0	
genotypes	4.9		7.3	

development stresses, but TRL of all treatments tended to converge as plants neared harvest.

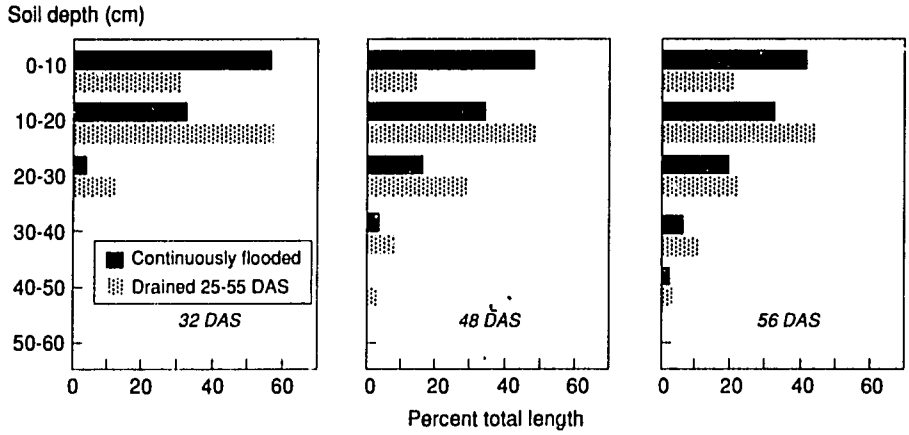
In the well-watered treatment, IR33380-7-2 had the greatest TRL and Kinandang Patong the least (Fig. 13). Under water deficit there were few differences between IR20 and IR33380-7-2, but both had greater TRL than Kinandang Patong. Yields had similar trends to TRL. That IR20, the drought-susceptible check in upland screening, had greater TRL than Kinandang Patong, the drought-tolerant check in upland screening, demonstrates that root traits that confer adaptation to drought conditions differ greatly for upland and rainfed lowland rice ecosystems. The data do not allow identification of those traits, but they do underscore the need for research on beneficial root traits for upland and lowland ecosystems.

Wet seeded rice. In a puddled, slowly draining clay soil, germinated seeds were dibbled in 20- × 20-cm hills with 3-4 seeds/hill. The experiment design was a split plot with three replications. Main plot treatments were two water regimes: continuously flooded and water deficit. Water deficit plots were kept flooded except from 25 to 55 days after seeding (DAS) when irrigation was withheld. Subplot treatments were 12 genotypes including 1 traditional and 3 improved cultivars and 8 promising rainfed lowland breeding lines (Table 25).



14. Total root length of continuously flooded and drought-stressed rice, 1991 DS. Average of 12 varieties.

For the average of all experimental genotypes, water deficit generally reduced TRL from 32 to 72 DAS as compared with the continuously flooded treatment (Fig. 14). Thus, water deficit effects on TRL persisted about 15 d after ending the stress period. From 85 to 125 DAS, TRL was generally



15. Relative root distribution during drought stress (32 and 48 DAS) and 1 d after rewatering (56 DAS).

greater in the water deficit than in the continuously flooded plots. During water deficit, the proportion of roots in deeper soil layers increased more than that in the continuously flooded plots (Fig. 15). After the stress, the distribution of roots through the soil profile in water deficit treatments tended to return to the distribution of the continuously flooded treatment.

Genotypic differences in TRL were significant at 56 and 89 DAS (Table 25), but TRL of well-watered and stressed plants were not significantly correlated, nor was TRL correlated with grain yield (data not shown). Clearly TRL is not the best rice root measure for evaluating responses to water deficit. Future work will emphasize roots in different soil layers.

Water use in response to timing of water deficit

Rice responses to water deficit differ with growth stage. Rice yields are most susceptible to reduction by water deficit during panicle emergence. To elucidate stress effects on productivity, water use patterns of three rice genotypes—IR20, IR46, and IR72—were measured under four water regimes: well watered, vegetative phase stress (16 to 48 DAS), reproductive phase stress (35 to 55 DAS), and boot to early grain filling stress (70 to 86 DAS). Stresses were stopped when the first cultivar reached a leaf rolling score of 5 (tightly rolled leaves).

Cumulative evapotranspiration (ET) deficit, the gravimetrically measured difference in daily ET of control and stress pots, increased faster as stress onset occurred later in the crop growth cycle (Fig. 16). One reason that rice yield is susceptible to reduction by water deficit during panicle emergence is because stress develops faster at this stage.

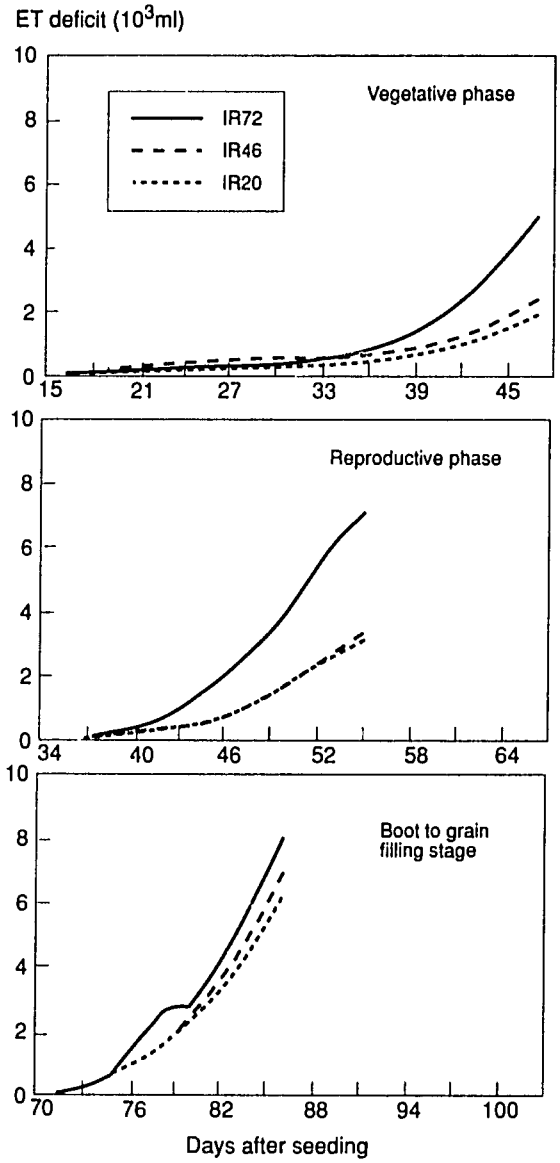
Cumulative ET deficit was significantly greater for IR72 than for the two other cultivars in all stress timings, but the difference was least when stress occurred at boot and early grain filling stages (Fig. 16). Leaf area increased more rapidly in IR72 than in the other cultivars. At the time of the boot and early grain filling stress, the leaf area of the two other cultivars approached that of IR72 and differences in cumulative ET deficit were less.

Grain yield decreased as stress began later in the crop cycle (Table 26). In the well-watered, vegetative phase stress, and reproductive phase stress treatments, IR72 yielded more grain than IR20 and IR46, but with boot and early grain filling stress, the genotypes showed no yield differences. Although

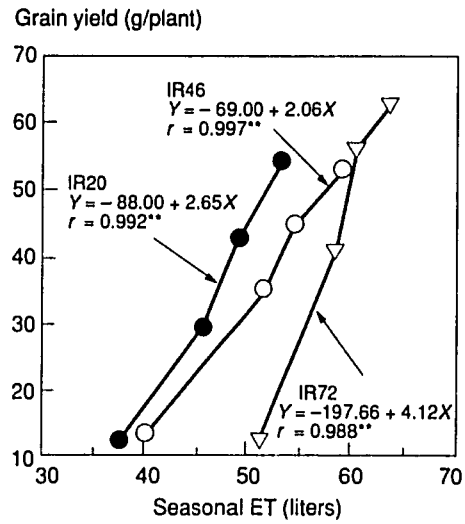
Table 26. Grain yield and water use efficiency of 3 rice genotypes in response to water deficit timings.

Cultivar	Stress timing	Grain yield[a] (g/plant)	Water use efficiency (g/liter)
IR20	Well watered	53.7 b	1.01
	Vegetative phase	42.7 cd	0.87
	Reproductive phase	29.6 f	0.65
	Boot to grain filling	12.6 g	0.34
IR46	Well watered	53.1 b	0.90
	Vegetative phase	44.7 c	0.82
	Reproductive phase	35.2 e	0.68
	Boot to grain filling	14.0 g	0.35
IR72	Well watered	62.2 a	0.98
	Vegetative phase	55.9 b	0.93
	Reproductive phase	40.2 d	0.69
	Boot to grain filling	12.0 g	0.24

[a]Means followed by the same letter are not significantly different at $P < 0.05$ by LSD.



16. Effect of water deficit at 3 growth stages on cumulative ET deficit of 3 rice genotypes.



17. Relationship between seasonal ET and grain yield of 3 rice genotypes.

IR72 was the first cultivar to reach a leaf rolling score of 5 in all stress timings and had greater ET deficit, yield loss was not greater than in the other cultivars.

Water use efficiencies were similar for all cultivars (Table 26), and values in well-watered treatments were similar to the greatest values reported in other experiments. On the other hand, there were significant differences in the relationship between seasonal ET and grain yield for the three cultivars (Fig. 17). In all stress timings, IR72 had the greatest seasonal ET and IR20 the least. In addition, IR72 had a much greater slope for the regression between seasonal ET and grain yield. Greater seasonal ET and faster development of ET deficit may have produced greater yield loss if stress periods were longer, but the results suggest that the ability to use water faster may confer greater productivity even under moderate water deficit conditions.

Next steps

Root systems and drought-related physiological traits of improved rainfed lowland breeding lines that have consistently performed well in drought-prone environments will be characterized. Emphasis will be placed on the genetics and physiology of the improved lines for tolerance for submergence and stagnant flooding.

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Upland rice ecosystem

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Upland rice ecosystem

Subprogram I: Sustainable land and resource management

Factors determining productivity

UPLAND RICE FARMER PRACTICES IN SUMATRA, INDONESIA

In Sitiung, Indonesia, scientists from the Sukarami Agricultural Research Institute for Food Crops (SARIF), the Sitiung Research Sub-Station, and IRRI conducted a diagnostic survey to 1) characterize the upland rice (UR) agroecosystem; 2) understand farmers' upland rice cropping practices, constraints. and problem-solving capabilities; 3) identify and prioritize problems resulting in low or declining yields; and 4) identify and prioritize future research activities.

The survey area was divided into two agroecosystems. The first (Sitiung I and II) features level to gently rolling lands and permanent animal-drawn plow agriculture, with some areas being converted to lowland rice cultivation since completion of government irrigation systems. The importance of UR is expected to decline in these areas as that of lowland rice, perennial and plantation crops, and legumes continues to increase. The second agroecosystem (Sitiung III, IV, and V) is characterized by sloping, forested, or recently forested land and by slash-and-burn or hoe agriculture.

In the first agroecosystem, land was cleared by slash and burn, then plowed, harrowed, possibly hoed, and dibble seeded. The farmers applied substantial quantities of inorganic fertilizer. They also applied farmyard manure (FYM) in small continuous lots to UR, nonrice crops after rice, low-yielding plots, and areas planted to rice in rotation.

In the second agroecosystem, lands are cleared initially by slash and burn and then dibble seeded. After several croppings, fields are hoed after slashing and before seeding in response to increased weed infestation. In some areas, farmers work in cooperative groups to clear land, seed, weed, and, sometimes, harvest and thresh.

Farmers burn rice stubble to speed land preparation for crops of soybean, mungbean, or peanut after rice; improve soil nutrient cycling; and improve crop stand in order to reduce weed pressure.

Of the total 135-165 d of labor inputs/ha, weeding labor consumes from 40 d/ha for sloping upland fields to 65 d/ha for plowed, permanently cultivated fields. Older sloping upland fields require about 40 d additional labor/ha for hoeing for land preparation (Table 1). Yields range from 0.6 t/ha from older sloping fields to 1.3 t/ha on permanent plow-cultivated fields. In all areas, farmers provide large and perhaps increasing amounts of weeding labor, inorganic fertilizers, and insecticides to realize low, declining, and risky rice yields.

Farmers ranked wild pigs as the major cause of reduced yields, with insects (rice bug) and weeds as equal second. From field observations and past research in the area, the survey researchers ranked wild pigs first, soils second, and weeds third in importance.

Pigs are a major cause of crop damage in fields close to forests or tree plantations. Because SARIF and IRRI have no expertise in this area, a consultant may be needed to address the problem.

Farmers reported moderate yields on newly opened lands, but low and declining yields over time. Moderate amounts of inorganic fertilizer are applied in some areas, but crops respond poorly to fertilizer. In the past, farmers applied lime when it was subsidized by the government, and some burned crop residues to improve soil fertility. Goals of suggested research include 1) obtaining a better understanding of farmers' crop and soil management practices; 2) devel-

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Table 1. Rice crop input-output budget on plowed and slash-and-burn lands.[a] Siklung, Sumatra, Indonesia.

Item	Plowed land		Slash-and-burn land: Newer fields		Slash-and-burn land: Older fields	
	Mean	Range	Mean	Range	Mean	Range
Labor (d/ha)						
Slash, burn	13	8 - 20	32	18 - 45	15	
Plow	6	4 - 11	na	na		
Hoe	na		0		42	6 - 100
Harrow	7	2 - 14	na		na	
Dibble	15	8 - 20	19	15 - 24	19	16 - 20
Fertilize	1		4	3 - 4	4	
Weeding	64	30 - 100	38	12 - 60	39	28 - 60
Spray	1		3	2 - 5	3	
Harvest, thresh	32	23 - 40	39	29 - 60	40	24 - 66
Total labor	139		135		164	
Materials						
Seed (kg/ha)	45	30 - 70	48	40 - 80	35	30 - 40
Farmyard manure (t/ha)	3	1.5 - 4	-		-	
Fertilizer						
Urea	53	20 - 100	37	8 - 150	30	10 - 100
TSP[b]	75	50 - 100	34	0 - 150	125	25 - 250
KCl	60	50 - 100	0		8	0 - 25
Insecticide[c]	85%[c]	3-6 sprays			60%	1 spray
Yield (t/ha)	1.3	0.8 - 2.4	1.0	0.3 - 1.7	0.6	0.4 - 0.8

[a]na = not applicable. [b]TSP = triple superphosphate. [c]Mean is percentage of farmers using insecticide; range is frequency of use.

oping methods to assess yield potentials and input costs as functions of rainfall distribution, subsoil acidity, cultivar tolerance for subsoil acidity, and farmers' practices; 3) develop cost-effective means of leaching lime materials downwards; and 4) do further research on organic matter management.

Farmers reported that insect problems have increased over time and identified rice bug as a major problem in all areas. Stink bugs, locusts, hoppers, and ants are also problems. Research needs to 1) develop low-cost insect control methods, 2) investigate dry season (DS) dormancy sites of the rice bug to determine off-season control methods, 3) establish economic thresholds for rice bugs, and 4) develop rice cultivars that mature at the same time.

Basic and applied research are required because farmers need problem-solving innovations to improve their current conditions. Substantial on-farm interdisciplinary team research is essential.

Improving rainwater management in eastern India

The uplands in eastern India cover several million hectares and are contiguous in the Chotanagpur plateau in Bihar. Because of low and concentrated rainfall (1,130 mm from June to October), the uplands are traditionally cultivated only in wet season (WS) to grow a 4-yr crop-fallow rotation cycle of millet - black gram - rice - fallow. Lands generally remain fallow during DS for lack of soil moisture.

Analysis of existing farming systems and hydrological mapping of the area indicated potentials for collecting rainwater in valley check reservoirs. The reservoirs could be used to supplement the water needed for rice during droughts and to irrigate short-duration DS crops. The analysis included land, labor, and cash resources; land types and use patterns; and crop calendars indicating rainfall pattern and labor availability and use. Hydrological mapping determined water resources, surface and subsurface hydrology, water losses and recharge characteristics of the soil, occurrence and severity of drought, and climatic factors.

The possibility of on-farm rainwater collection and management was explored at Handio village in Hazaribagh. Villagers constructed 16 rainwater-holding structures (reservoirs and ponds) ranging in surface area from 1.75 ha in the uppermost topose-

quence with large runoff catchment areas, to 0.25 ha in lower lands along the slope. During the summer months, family and exchange labor was used to construct the tanks. The catchment-to-storage ratio in terms of land surface area varied from 10:1 to 6:1. On average, each person moved 0.6 to 1.0 m^3 of earth per day The volume of available water in these structures varied from 0.91 ha m to 1.69 ha m for 7 to 10 mo (July-April). With government support, farmers also constructed 37 concrete wells.

The water from tanks is distributed for irrigation by gravity through concrete culverts placed at varying depths from the water surface and connected to earthen channels at different elevations. The system reduces dike maintenance because it allows drawing water at different levels in the tank without cutting the dike or siphoning.

Through these practices, the cropping intensity in the area has increased from <100% to 160% in the upper toposequence and from 150% to almost 250% in the lower lands. Increased cropping intensity is achieved through vegetable cultivation during DS, including legume - potato + spices from October to February, and a summer crop of tomato by some farmers. All farmers continue to grow rice, legume, and some vegetables during WS. Rice - legume - potato + spice - tomato is the most common crop sequence.

Three farmers also started raising fish (common carp) at low stocking densities (6,000/ha). Results with older fingerlings weighing 50 g or more are promising. With the increase in cropping intensity, the village farmers have also started stall feeding livestock and using animal manure in vegetable production, practices not followed previously because of difficulties in collecting dung from distant, open-land grazing areas.

Losses from insect and vertebrate pests

The UR agroecosystems can be classified into three successional types. The types represent degrees of land use, from forest to extensively tilled farmland. The kinds and intensities of insect and vertebrate pests differ with each agroecosystem. From analysis of pest sampling and yield loss studies carried out across the range of successional types, a general picture of the succession process can be drawn.

Pioneering slash-and-burn agriculture often includes patches of UR planted by dibbling. Forest-dwelling animals lingering in the patches of standing forest forage on the small patches of UR and frequently cause crop failure. Yield loss can be extreme (as in Sitiung, Sumatra) because for wild pigs, rats, squirrels, deer, birds, monkeys, elephants, and rhinoceroses, rice is a highly preferred food. The rice bug can seek out patches of rice and is an important pest.

Grassland often replaces the forest before human population pressure converts it all to farmland. When the forest is replaced, most forest-dwelling animals except rats and birds disappear. Pests adapted to the grasslands are often able to infest rice. They include 1) soil pests such as white grubs *Leucopholis irrorata* (Chevrolat), *Holotrichia mindanaoana* Brenske, and *Anomala* spp.; 2) termites *Macrotermes gilvus* (Hagen); 3) root aphids *Tetraneura nigriabdominalis* (Sasaki), *Rhopalosiphum rufiabdominalis* (Sasaki); 4) mole cricket *Gryllotalpa orientalis* Burmeister; 5) seedling maggot *Atherigona oryzae* Malloch; 6) striped stem borer (SB) *Chilo suppressalis* (Wlk.), pink SB *Sesamia inferens* (Wlk.), and gold fringed SB *Chilo auricilius* Dudgeon; and 7) armyworms *Mythimna separata* (Wlk.), *Spodoptera mauritia acronyctoides* Guenée; or 8) other defoliators (as in Claveria, Mindanao, Philippines). Losses are chronic and range from 20 to 40%.

As more settlers arrive and plow under the perennial grasslands, alternate hosts of rice pests are reduced, and pest problems decline, probably in direct proportion to the number of tillage operations on the farmland. Soil disturbance exposes soil pests to desiccation and natural enemies. Reduced grassland means reduced habitat for the seedling maggot and defoliators. Losses are less than 5% from insects in intensive systems such as those in Batangas, Luzon, Philippines, and are even smaller from vertebrate pests whose habitats have vanished.

As upland areas are planted more intensively to annual crops, perennial habitats decline. Because UR is planted only once a year, pests must survive on alternate hosts, which decline as crop intensification increases. In the lowlands, on the other hand, multiple rice cropping increases pest problems as the protective dry fallow is broken by irrigation and DS rice.

^{15}N technique to quantify biologically fixed nitrogen contribution of leguminous trees in hedgerows

Leguminous trees such as *Gliricidia sepium* and

Cassia spectabilis play a major role in hedgerow intercropping systems by providing or recycling nutrients, particularly N and organic matter. However, data are lacking on the long-term N contribution to hedgerow systems through biological N fixation (BNF) of leguminous trees. This is mainly because suitable methods to quantify the BNF of trees are unavailable.

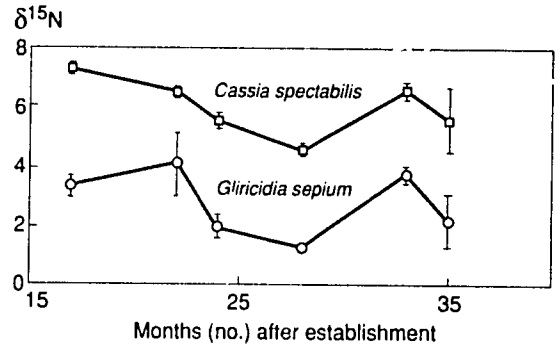
In collaboration with the Commonwealth Scientific and Industrial Research Organization (CSIRO), Canberra, and the University of Queensland, Australia, we assessed the suitability of the natural abundance ^{15}N ($\delta^{15}N$) dilution method to estimate N_2 fixation by *G. sepium* and to evaluate the N_2 fixation ability of *C. spectabilis* in hedgerow intercropping systems. This assay, when used with appropriate caution, may overcome some of the important constraints to the successful estimation of BNF in leguminous trees.

Hedgerow species were planted in double rows during the 1988 rainy season in Claveria, northern Mindanao. The seedlings were established along the contour line in rows spaced 50 cm apart on a 25-cm-high contour bund. Each species was planted in a 5-m-long hedgerow with 5 m between hedgerows. The trees were pruned to about 50 cm aboveground 4 times a year. Plant subsamples were analyzed for total N by the micro-Kjeldahl method. The $\delta^{15}N$ analysis was made on a dual collecting isotope ratio mass spectrometer (Model VG 903) and expressed as $\delta^{15}N$ with reference to air N_2, where

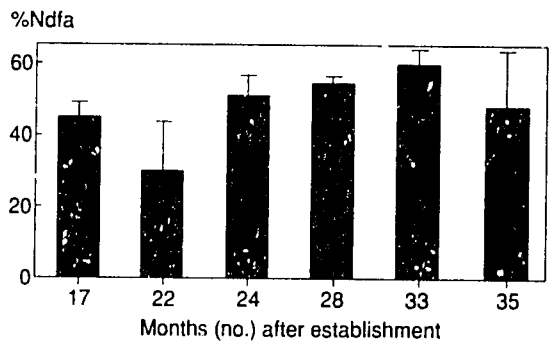
$$\delta^{15}N = 1{,}000\,(R_{sample} - R_{air\ N_2})/R_{air\ N_2}$$

R is the ratio mass 29/mass 28 = $^{15}N\ ^{14}N/^{14}N_2$. The variation in plant extractable soil N and its $\delta^{15}N$ was examined in *Oryza sativa* grown for 7 wk on soil from the *G. sepium* and *C. spectabilis* hedgerow treatments from depths of 0-15, 15-30, 30-60, and 60-100 cm.

Figure 1 shows $\delta^{15}N$ of the total N of *C. spectabilis* and *G. sepium* prunings from six samplings from January 1990 to July 1991. The mean and standard error of $\delta^{15}N$ of the samplings were 6.00% $\pm$ 0.29 ‰ for *C. spectabilis* and 2.79% $\pm$ 0.44 ‰ for *G. sepium*. The overall trends of $\delta^{15}N$ for the two species were similar. The $\delta^{15}N$ (‰) contents of *C. spectabilis* were very similar to those of soil extractable N (5.95% $\pm$ 0.82 ‰) at different soil depths, suggesting that *C. spectabilis* did not fix N_2. The



1. Changes over time in the $\delta^{15}N$ (‰) of total N of *Cassia spectabilis* and *Gliricidia sepium* in hedgerow intercropping systems.



2. BNF (%Ndfa) in different prunings of *Gliricidia sepium* hedgerow intercropping system.

data indicate that this species may be suitable as a non-N_2-fixing reference. The biologically fixed N in *G. sepium* ranged from 30 to 60% of the total N, with an average BNF percentage of 43% (Fig. 2).

The results show that *C. spectabilis*, a commonly grown non-nodulating leguminous tree, is not an N_2 fixer. Its consistently high N content is due to extraordinary efficiency in exploiting native soil N. N_2-fixing trees such as *G. sepium* not only recycle soil N, but contribute a substantial proportion of their total N as biologically fixed N, enhancing the fertility of sloping acid upland soil for alley crops such as upland rice.

Synergistic productivity interactions in an integrated contour hedgerow system

Leguminous trees are widely used in alley farming research, but farmer adoption is low because of the high labor investment required to prune tree hedgerows. Multiple-purpose hedgerows, which both minimize soil erosion and provide cash incomes,

may overcome some of the problems of monoculture tree hedgerows.

Arabica coffee was evaluated as a cash-generating hedgerow species in an on-farm experiment at Claveria. The trial investigated the interaction of coffee with the hedgerow as green leaf manure for soil amendment or with grass fodder for livestock, and their effects on cereal crops.

Coffee was planted 2.5 m apart in the hedgerows and interplanted with either *G. sepium* or napier grass *Pennisetum purpureum*, or a combination of both. Each coffee seedling was fertilized at planting with 200 g chicken manure and 53 g lime, except for two treatments that received no inputs. UR was planted in the alleys during early WS, followed by maize late in WS. The experiment consisted of seven treatments in a randomized complete block design in a farmer's field with a 20% slope.

Hedgerows were pruned 7-10 d before planting rice. Prunings were applied to the alley and plowed under. Subsequent prunings 30 and 55 d after emergence (DE) of rice were applied as surface mulch. The hedgerows were pruned immediately after sowing of maize and at 35 DE, and prunings were applied as surface mulch.

P. purpureum was pruned 3 mo after establishment and once a month thereafter, with prunings removed.

Upland rice IR30716-B-1-B-1-2 was seeded at 100 kg/ha and maize Pioneer hybrid at 20 kg/ha. Rice was drilled in rows 30 cm apart, and maize in rows 60 cm apart. P was applied basally at 20 kg/ha to rice and 30 kg/ha to maize.

Initial coffee growth was enhanced by *G. sepium* even though the trees were planted in close proximity and at high density. Coffee yields were increased by the intercropped *G. sepium*, in the presence or absence of external nutrient inputs (Table 2), but yields were reduced when coffee was planted with napier, in the presence or absence of *G. sepium*. The dry herbage of napier ranged from 5.23 to 6.40 t/ha, which would support 3-4 cattle in a cut-and-carry system.

G. sepium produced total dry matter pruning yields of 3.40 to 6.63 t/ha. Yields were reduced 45% in the presence of napier. Prunings contributed means of 88 kg N/ha, 6 kg P/ha, and 52 kg K/ha (Table 3). N yields exceeded 100 kg/ha when the *G. sepium* was not intercropped with napier.

Both rice and maize responded well to green leaf manure (Table 2). Rice yields averaged 0.9 t/ha without *G. sepium* as a hedgerow component, but ranged from 1.7 to 2.4 t/ha when *G sepium* leaf biomass was applied (Table 2). A strong positive linear relationship ($Y = 1.022 + 0.035X$, $R^2 = 0.90$) existed between the quantity of dry pruning biomass applied and rice yield, which averaged 0.4 t/ha per ton of biomass applied.

Maize yields were also stimulated by *G. sepium*. They averaged 1.7 t/ha among treatments without

Table 2. Agronomic data on hedgerow combinations.[a] Ane-i, Claveria, Misamis Oriental, Philippines, 1990.

Hedgerow combination[b]	*G. sepium* TDMY[c] (t/ha)	*P. purpureum* dry herbage (t/ha)	Grain yield		
			Coffee (kg/ha)	Upland rice (t/ha)	Maize (t/ha)
GS + PP	3.7 b	5.4		1.9 ab	2.21 ab
C			132	0.9 c	1.59 c
C + GS	6.4 a		155	2.1 ab	2.94 a
C + PP		6.4	7	0.8 c	1.58 c
C + GS + PP	3.4 b	5.2	27	1.7 b	1.99 b
C with no input			13	0.9 c	2.01 b
C + GS with no input	6.6 a		43	2.4 a	2.73 a
Mean	5.0	5.7	63	1.5	2.15
CV (%)	14.67	27.53		22.1	18.60
LSD (0.01)	2.2	5.9		0.8	1.00
(0.05)	1.5	3.5		0.6	0.71

[a]Means are for treatments with *G. sepium* and *P. purpureum*. The first pruning excluding stems was incorporated as green manure; subsequent prunings were applied as mulch. Coffee received 200 g chicken manure and 53 g lime applied as basal and every 6 mo thereafter (except in the 2 treatments with no input). [b]GS = *Gliricidia sepium*; C = coffee, PP = *Pennisetum purpureum*. [c]Total dry matter yield.

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Table 3. Cumulative macro- and micronutrient yields of *G. sepium* in hedgerow combinations from a total of 3 successive prunings[a] during the first upland rice (UR) crop. Ane-i, Claveria, Misamis Oriental, Philippines, 1990 wet season (WS).

Hedgerow combination[b]	Macronutrients (kg/ha)			Micronutrients (kg/ha)		
	N	P	K	Ca	Mg	Si
GS + PP	70.6	4.5	41.2	4.9	47.1	9.4
C + GS	104.6	6.6	61.0	7.3	69.8	13.9
C + GS + PP	64.4	4.1	37.5	4.5	42.9	8.6
C + GS	113.4	7.2	66.2	7.9	75.6	15.1
Mean	88.3	5.6	51.5	6.2	58.8	11.8
CV (%)	17.0	17.1	17.0	17.1	17.0	17.0
LSD (0.01)	45.5	2.9	26.6	3.2	30.4	6.1
(0.05)	30.2	1.9	17.5	2.1	20.0	4.0

[a]Average nutrient concentration in the prunings: 3.00% N, 0.20% P, 1.75% K, 2.00% Ca, 0.21% Mg, 0.40% Si. [b]GS = *Gliricidia sepium*, PP = *Pennisetum purpureum*, C = coffee.

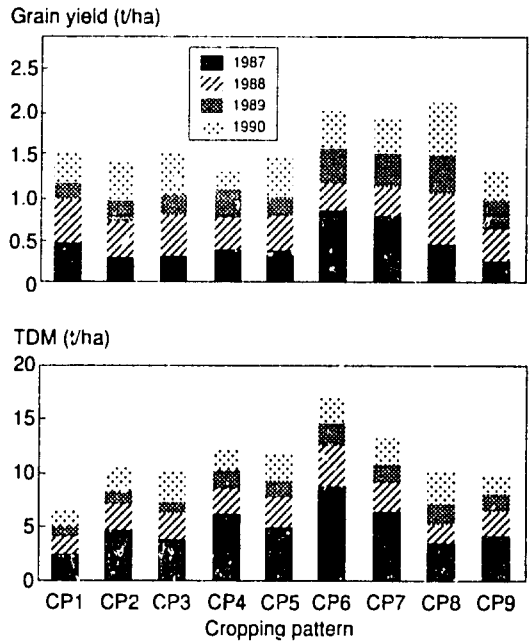
the legume, and 2.5 t/ha in treatments with *G. sepium* as a hedgerow component. *G. sepium* had a more modest effect on rice and maize yields when combined with napier, presumably due to lower green leaf manure production in these treatments and competition between napier and the annual crops.

G. sepium intercropped in a coffee hedgerow stimulated both perennial and annual crops grown in the alleys. The napier was competitive with other hedgerow components and with the annual crops, but did provide fodder. The economic viability of such integrated hedgerow systems will depend on relative prices of the various commodities.

Forage legumes as on-farm nitrogen source for upland rice - maize

The soils in which UR is grown are usually acidic and low in inherent fertility. Where N seriously limits biomass and grain yield production, inclusion of legumes may increase N supply through symbiotic N fixation.

We conducted a 4-yr study to evaluate the management requirements and effectiveness of indeterminate lablab *Lablab purpureus* and cowpea *Vigna unguiculata* in supporting the N requirement of UR and maize when inserted in the crop sequence. Management alternatives were intercropping, relay-cropping, and sequential cropping of legume and UR. The legume contributed N to the cereal crops mainly through incorporation at the end of DS, or between crops in WS. Slashing during the crop



3. Cumulative grain and total dry matter (TDM) yields of upland rice (UR) UPLRi-5 in cropping patterns with indeterminate forage legumes as a source of N for UR - maize (M) cropping sequence, IRRI, 1987-90. L = lablab, C = cowpea. Spacing for L is 160 cm in CP2, CP3; 180 cm in CP5, 6, 7, 8; and 240 cm in CP4, CP9. CP1 = UR - M, CP2 = UR + L/M, CP3 = UR + C/L/M, CP4 = UR + L/M, CP5 = UR + L/M, CP6 = UR - M + L, CP7 = UR - M + L, CP8 = UR - L, CP9 = UR + L - M.

growth period also contributed modest amounts of N.

The experiment started with monoculture, intercrop, and relay combinations of UR, cowpea, and lablab. After the rice harvest in 1986, lablab was allowed to grow through the 5-mo DS each year.

Rice was seeded at the rate of 70 kg/ha in rows 20 cm apart. In the intercrop, lablab was spaced at 160-cm row distance (7 rice rows in between), 180 cm (8 rice rows), or 240 cm (11 rice rows). At the onset of WS, about 2-3 wk before UR seeding, lablab was cut, chopped, and incorporated into the soil. In 1987, cutting height was varied between 30 cm from the ground for the third and fourth cropping pattern treatments (CP3 and CP4) or at 10 cm aboveground for CP5. In subsequent years the cutting height was standardized at 50 cm aboveground because low cutting heights resulted in poor vegetative regrowth. Excess vegetative growth of lablab was pruned and applied as mulch.

In general, the average yields of UR were low across the years and cropping patterns (Fig. 3). Grain

yield differences among cropping patterns were significant (P<0.01) in all years. For total dry matter (TDM), differences were significant except in 1988. The highest cumulative grain and TDM yields came from monocropped UR followed by lablab or by maize + lablab (CP6, CP7, and CP8).

Grain yields of rice + lablab (CP2, CP3, CP4, and CP5) were similar to the control pattern (CP1) without the legume; but dry matter yields in all these treatments were substantially higher (Fig. 3). Although the intercrop stimulated the vegetative growth of rice, interspecies competition later in the growing season overcame the beneficial effects on biomass, and caused a lower harvest index.

Cumulative grain yields were lowest from CP4 and CP9, in which UR was intercropped with lablab spaced at 240 cm followed by maize. Lablab biomass from CP4 was removed, simulating its use as fodder. Removed biomass was applied to the crop in CP8, where the N addition did not offset the depressive effect of competition and the rice did not benefit from the lablab intercrop.

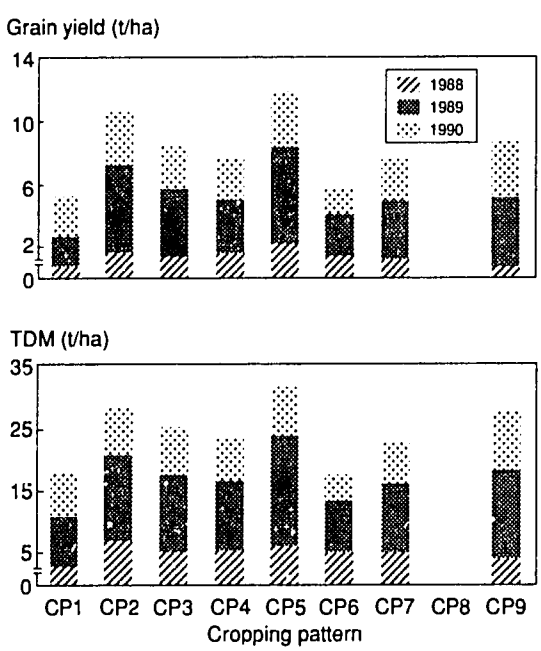
Figure 4 presents grain and TDM yields of the DS maize crop (IPB Var 1) in the different cropping patterns for 1988 to 1990. Except during 1988, maize grain yield variations among cropping patterns were statistically significant. UR - maize (CP1) and UR - maize + lablab (CP6 and CP7) consistently produced low grain and TDM yields. These treatments had maize intercropped with lablab following an UR monocrop. Maize monocropped, relayed, or following UR + lablab (CP2, CP5, and CP9) consistently produced high grain and TDM yields.

Two processes could be influencing maize grain and TDM yields: 1) yield is depressed when maize follows UR or UR + lablab, regardless of lablab spacing; and 2) yield increases when maize follows UR + lablab when lablab is at a relatively close row spacing.

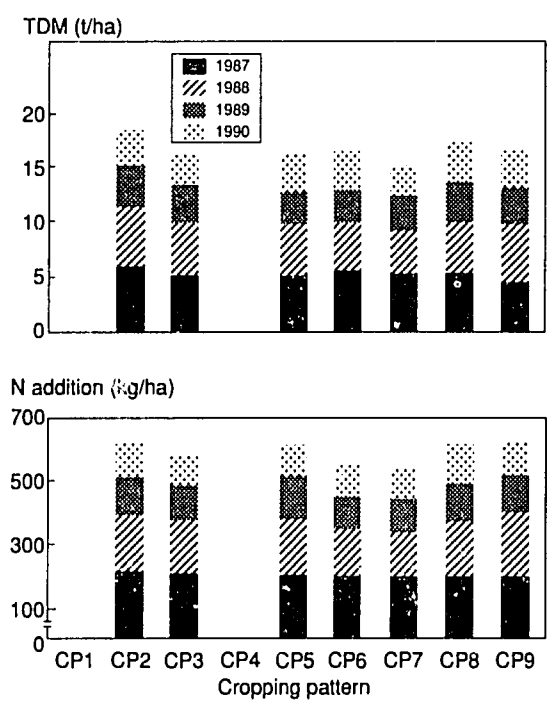
TDM contributed by lablab ranged from 3 to 6 t/ha per yr among the cropping patterns (Fig. 5).

Across years the total N addition ranged from 80 to 211 kg/ha, which came mostly from the plowed-down green manure. Treatments with closest spacings of lablab rows in the intercrop (160 and 180 cm) tended to have the highest cumulative N contribution (CP2 and CP5).

Forage legumes integrated into UR-based cropping systems can supply N and organic matter to the cereal crops, resulting in increases in the yields of



4. Cumulative grain and TDM yields of M IPB Var 1 in cropping patterns with indeterminate forage legumes as a source of N for UR - M cropping sequence, IRRI, 1988-90. For cropping patterns legend, see Figure 3.



5. Cumulative TDM and N additions from lablab in the different cropping patterns, IRRI, 1987-90. For cropping patterns legend, see Figure 3.

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rice and maize in sequence. Whether such a system is viable depends on opportunity costs of labor and the extent to which N is the dominant limiting factor.

Soil management for an upland rice-based system in western Sumatra

Acidity, low soil fertility, and erosion are major soil constraints in Sitiung. Similar conditions are extensive in other parts of Indonesia and Southeast Asia. Oxisols and Ultisols are the predominant soils in the area.

The project objectives are to identify factors that limit yields of UR and other food crops and to develop management strategies to overcome those factors and sustain reasonable yields. One set of trials conducted at the Sitiung research station addresses the sustainability of cropping on newly opened forested areas. Another set of trials in farmers' fields in Sitiung IV addresses the problem of *Imperata cylindrica* infestation. On-station trials started in late 1990, and trials in farmers' fields commenced in late 1991. Both trials will be conducted for a minimum of 5 yr. We will evaluate yields and changes in soil chemical, physical, and microbiological properties. This report presents results of three trials at the experiment station.

Experiment 1. Soil and fertilizer management of a newly opened, acid upland soil. Short-term objectives were to assess the contribution of NPK fertilizer and lime on yields of UR and other crops in rotation, and to identify factors that limit the effectiveness of fertilizers. Longer term objectives were to 1) determine the role of fertilizer in combination with soil-conserving practices, 2) determine the role of hedgerows in maintaining productivity of acid upland soils, 3) identify soil indices of the productivity of acid upland soils, 4) determine the effects of cover crops and crop residue incorporation on soil fertility, 5) monitor changes in soil properties over the long term, and 6) monitor effects of soil management on weed populations.

The trial was conducted in two lots, both having the same crop sequences and fertilizer treatments. Lot A had hedgerows of *Flemingia* and Lot B had 1-m grassy strips between plots. Prunings from *Flemingia* hedgerows were returned to the upper plots adjacent to the hedgerows. The initial soil analysis is given in Table 4.

UR variety Danau Atas was dibbled on 30 Oct 1990 at 3 seeds/hill, with 10 cm between hills and 30 cm between rows. After rice, soybean variety Willis was planted in half of the plots and maize variety C-1 in the other half, both on 5 Apr 1991. Soybean and maize were sown in furrows 30 and 60 cm apart, respectively.

Carbofuran was applied to UR 10 d after planting and every 20 d thereafter. It was applied at 40 kg/ha to soybean and maize at sowing to safeguard against nematodes. Insect control was carried out as needed, using monocrotophos.

Although UR was planted on newly opened land, grain yields in Lots A and B were generally low (Table 5). P and K did not increase the yield signifi-

Table 4. Initial analysis of the surface soil[a] of lots A, B, C, and D, Sitiung Experiment Station, Sumatra, Indonesia.

Soil property[a]	A	B	C	D
pH (1:1 H_2O) (wt/vol)	4.3	4.3	4.6	4.3
Total N (%)	0.122	0.133	0.136	0.148
Organic C (%)	1.35	1.59	1.66	1.87
Available P (ppm)				
Bray 2	3.8	6.0	7.6	7.9
Olsen	1.6	3.5	2.8	3.7
CEC[b] (meq/100 g)	6.64	6.87	7.13	7.89
Exchangeable bases (meq/100 g)				
K^+	0.092	0.124	0.103	0.074
Na^+	0.039	0.059	0.055	0.049
Ca^{++}	0.405	0.572	0.645	0.642
Mg^{++}	0.108	0.188	0.191	0.245
Exchangeable Al (meq/100 g)	2.94	2.67	2.59	2.95
Active Fe (%)	2.25	1.97	1.83	2.01
Active Mn (%)	Below detection level at 0.003%			
Available Zn (ppm)	0.42	0.43	0.43	0.54
Soil texture	Clay	Clay	Clay loam	Clay loam

[a]At 0-20 cm. [b]CEC = cation exchange capacity.

Table 5. Grain yield of UR variety Danau Atas as influenced by fertilizer and lime. Sitiung, Indonesia, 1990-91.

Treatment[a] (NPK)	Yield (t/ha)	
	Lot A	Lot B
0-0-0	0.8 b	1.0 b
60-0-0	1.0 ab	1.0 b
60-26-0	0.9 b	1.3 b
60-26-50	1.0 ab	1.4 ab
60-26-50 + lime	1.2 a	1.7 a
CV (%)	29	32

[a]N was split-applied as urea, P as TSP (45% P_2O_5), K as muriate of potash (60% K_2O), and lime as calcite (47% CaO) at 2 t/ha applied at planting.

cantly, lime and NPK did. However, the yield increase attained may not cover the cost of the inputs. Yields from Lot B were generally higher than from Lot A, probably due to differences in initial soil fertility.

Fertilizer and lime significantly increased panicles per hill and spikelets per panicle. However, the percentage of unfilled spikelets was relatively high (50%), did not vary among treatments, and could be a reason for the very low harvest index (HI): 0.11 for the control and averaging 0.17 among fertilized and treated plots. Brown spot *Helminthosporium* was severe and could be a major factor in the low HI.

Grain yields of soybean and maize grown after rice were higher in Lot B than in Lot A (Table 6). Application of N tended to decrease soybean yield, but had no effect on maize yield. Applying P in addition to N significantly increased yields of both soybean and maize.

Table 6. Effect of fertilizer and lime on yields of soybean and maize grown after UR. Sitiung, Indonesia, 1991.

Soybean		Maize	
Treatment[a] NPK	Yield (t/ha)	Treatment[b]	Yield (t/ha)
Lot A		*Lot A*	
0-0-0	0.49 c	0-0-0	1.36 b
20-0-0	0.47 c	80-0-0	1.90 a
20-26-0	1.01 b	80-26-0	2.08 a
20-26-37	1.22 ab	80-26-60	2.77 a
20-26-37 + lime	1.48 a	80-26-60 + lime	2.75 a
Lot B		*Lot B*	
0-0-0	0.86 bc	0-0-0	1.62 b
20-0-0	0.48 c	80-0-0	1.68 b
20-26-0	1.22 ab	80-26-0	3.76 a
20-26-37	1.33 ab	80-26-50	3.24 ab
20-26-37 + lime	1.79 a	80-26-50 + lime	4.13 a
CV (%) Lot A	35		23
Lot B	36		38

[a]N as urea was applied at planting. [b]N as urea was split-applied (50% at planting).

Partial budget analysis showed the UR - soybean rotation to be more sensitive to fertilizer than UR - maize, primarily because of the large price difference between soybean and maize. For both cropping sequences, economic benefit was greatest when NPK plus lime were applied.

Experiment 2. Response of crops in rotation to nutrients other than NPK in an acid soil. Objectives were to 1) determine the effect of nutrients other than NPK on the yield of UR and crops in sequence with UR, and 2) compare a legume and a nonlegume in rotation with UR in terms of soil nutrient depletion as affected by root activity and crop residue incorporation.

The initial soil analysis of the site (Lot C) is given in Table 4. The site is newly opened forest land with a uniform slope of about 15%. No cultivation was done prior to planting. *Flemingia* hedgerows were established 5 m apart along the contour.

The experiment was laid out in a randomized complete block design with five fertilizer treatments, two cropping patterns, and four replications. The cropping patterns were UR - soybean and UR - maize.

Danau Atas was planted on 31 Oct 1990. Soybean variety Willis was planted at 2 seeds/hill in shallow furrows, with 10 cm between hills and 30 cm between furrows. Maize C-1 hybrid was sown in shallow furrows 60 cm apart with 25 cm between hills.

Differences between UR mean grain yields (Table

Table 7. Grain yields of UR, soybean, and maize and selected yield components of UR. Sitiung, Indonesia, 1990 WS.

Treatment	Upland rice					Soybean	Maize
	Grain yield (t/ha)	Panicles (no./hill)	Spikelets (no./ panicle)	Unfilled spikelets (%)	Harvest index	yield (t/ha)	yield (t/ha)
Control	1.0	7.5 b	67.2 b	45	0.21	0.7 b	2.1 c
NPK	1.2	8.7 a	93.0 a	55	0.19	0.9 b	5.7 ab
NPK+Ca+Mg+S	1.2	8.6 a	92.6 a	57	0.19	1.4 a	6.6 a
NPK+Ca+Mg+S+Zn	1.3	8.6 a	86.9 a	57	0.24	1.4 a	4.4 b
NPK+Ca+Mg+S+Zn+B+Mo	1.4	8.9 a	87.1 a	51	0.21	1.5 a	6.8 a
F-test	ns	*	**	ns		**	**
CV (%)	34	11	10	19		20	26

7) were more apparent than real since the experimental error was large (CV = 34%). Yield tended to increase as micronutrients were applied. The number of panicles per hill and number of spikelets per panicle were low, with both parameters significantly lower in the unfertilized plots. Application of nutrients other than NPK had no effect.

The low grain yield of UR was associated with poor spikelet filling. Unfilled spikelets reached 57%. A 20% increase in filled spikelets could markedly increase UR productivity at Sitiung. The low spikelet number per panicle and the high percentage of unfilled spikelets could be responsible for the low HI (about 0.20).

Soybean yield was highest (1,500 kg/ha) when micronutrients Zn, B, and Mo were applied together with NPK + Ca + Mg + S (Table 7). Yield was not significantly different from that in the NPK + Ca + Mg + S treatment, suggesting that the micronutrients are not limiting. Applying NPK alone gave higher yields, but not significantly more than that from the unfertilized plot. This suggests that Ca, Mg, and probably S may be limiting, as is evident from the site soil analysis.

Nutrients other than NPK had less effect on maize than on soybean. Although maize yield increased with addition of Ca, Mg, and S to NPK, the increase was not significant. The addition of Zn to NPK + Ca + Mg + S significantly reduced yield. The effect of Zn was masked when B and Mo were added.

Experiment 3. Response of crops in rotation to P and lime. The objectives of this experiment were to 1) determine the response to P of UR and other crops in rotation, 2) determine the effect of lime and organic matter incorporation on P uptake by UR and other crops in rotation, and 3) monitor changes in soil fertility and soil physical properties. The experiment was conducted on a newly opened, sloping (15%) forested area. Hedgerows of *Flemingia* were planted along the contour. The initial soil analysis for Lot D is given in Table 4.

The two cropping patterns evaluated were UR - soybean and UR - maize. All plots received N and K fertilizers. The fertilizer treatments consisted of P and lime application. They differed in terms of whether P, with or without lime, was applied to UR or to the subsequent crops of soybean or maize.

Danau Atas was dibbled at 10 cm between hills and 30 cm between rows in November 1990. After the UR harvest in March, shallow furrows were made between the rows. Half the plots were planted to soybean Willis and half to maize hybrid C-1.

Despite the high CV, results indicate the influence of P and lime on yields of the crops in rotation (Table 8). P and lime with NK produced the highest UR grain yield, followed by NPK alone and no lime. Trends were similar for soybean and maize, except that soybean appeared to benefit from P and lime applied to UR. Maize yield was highest when both P and lime were applied. Maize also benefited from the P and lime applied to UR (Table 8).

Lime and P application on rice significantly increased spikelet number compared with the other treatments. However, because the percentage of unfilled spikelets was also high, the HI was low. The P and K uptake in UR straw was highest when P and P + lime were applied. Ca and Mg uptake in rice straw was highest when P and lime were applied.

Table 8. Grain yield of UR, soybean, and maize as influenced by P and lime application.

Treatment 1[a]	Upland rice yield (t/ha)	Treatment 2[b]	Soybean yield (t/ha)	Treatment 3[c]	Maize yield (t/ha)
60-0-60	1.2	20-0-30	0.50	80-0-60	3.73
60-60-60	1.3	20-0-30	0.81	80-0-60	4.83
60-0-60	1.2	20-45-30	1.04	80-60-60	5.02
60-0-60	1.0	20-45-30 + lime	1.10	80-60-60 + lime	7.00
60-60-60 + lime	1.5	20-0-30	1.65	80-0-60	5.77
F-test	ns		**		*
CV (%)	34		48		23

[a]N was applied as urea at 20 kg N/ha at planting and 40 kg N/ha at panicle initiation; lime was applied as calcite at 2 t/ha. ns = not significant. [b]N was applied as urea at planting; lime was applied as calcite at 2 t/ha. [c]N was applied as urea at 40 kg N/ha at planting and 40 kg/ha when plants were waist high; lime was applied as calcite at 2 t/ha.

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Results suggest that application of P and lime on rice benefited not only UR, but also the soybean crop that followed. Maize following UR did not benefit as much as the soybean from the P and lime applied on the preceding crop of rice. This suggests that to realize a greater yield of maize following UR, P and lime have to be applied to maize.

Subprogram II: Germplasm improvement and crop management

UR ecosystems are characterized by strongly acidic soils, highly competitive weeds, periodic drought, and Bl infestation. The subprogram focuses on finding new cultivars and methodologies that will provide higher yields and yield stability under these conditions.

UR ecosystems have a wide range (from about 3.5 to higher than 8), but soils with pH lower than 4.5 predominate. The research primarily uses upland japonicas that are well adapted to acidic soils.

Weed control is a major problem in the uplands. Weeding drastically improves yields, but weeding cost is often prohibitive for cash-poor farmers. Thus, we are investigating low-cost, efficient methodologies, and developing cultivars that compete successfully with weeds.

Durable resistance to Bl is needed in UR, where chemicals cannot be used to combat Bl. Biotechnologies can provide a better understanding of the complex mechanism involved in durable resistance.

Breeding

Upland rice for strongly acidic soils

The traditional upland cultivars grown by farmers on adverse upland soils show good yield stability but low yield potential, and only moderate levels of disease resistance. An upland breeding program initiated in 1983 aimed to produce donors with improved yields under low to moderate inputs; increase disease resistance to blast (Bl) and brown spot; and provide good adaptation to adverse soils, high tolerance for drought, and stable yields over years and sites.

From 1985 to 1991, 47 trials were conducted at sites with strongly acidic soils—Cavinti, Laguna, and Matalom, Leyte, Philippines; and at Sitiung, West Sumatra, Indonesia—in collaboration with the national rice improvement programs of the Philippines and Indonesia. The trials had very low to moderate fertilization, good weed control, and land preparation practices by local farmers.

The most promising progenies from crosses made in 1983 were evaluated in 42 trials. Their yields were compared with the trials' yield average, with the yield of the traditional check Azucena, and with the yield of improved check UPLRi-5. The average yield was 1.09 t/ha, with a maximum yield average of 3.37 t/ha and a maximum recorded yield of 5.35 t/ha. The average yields of the check cultivars were 9.3-22.3% lower than the yield average for the trials. The most promising progenies yielded 26-40% more than the checks. The most productive and consistent improved line was IR47686-12-5-B-1.

Results from 30 trials with advanced progenies derived from the 1984-89 crosses gave an average yield of 1.01 t/ha. Average maximum was 2.64 t/ha, and maximum recorded yield was 4.57 t/ha. Entries IR53234-27-4 and IR55442-10 showed the greatest yield advantage. IR55419-04 and IR57893-60 also performed well, yielding 250-290% more than the local check Azucena.

In 12 trials with early progenies from the 1988-89 crosses, impressive entries include IR63370-54 and IR63372-09, which yielded 200% more than Azucena and 160% more than UPLRi-5.

From the performance of lines in the trials, some useful parents were identified. They include UPLRi-5 (group 1 = indica), Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres (IRAT) lines (group 6 = japonica, especially IRAT104 and IRAT216), some CT lines from the Centro Internacional de Agricultura Tropical, and some CNA lines from Centro Nacional de Pesquisa-Arroz, Feijao, Goiania, Brazil.

The expected yields of promising lines under strongly acidic soils and low to moderate inputs are shown in Table 9. Although UPLRi-5 is expected to yield more than Azucena under these conditions, it actually has low yield stability because it is susceptible to Bl. The improved lines show both higher yield and greater stability. They have reduced duration, shorter stature, and higher tiller number.

Collaboration with national research services for upland rice improvement

Breeding for UR has also involved germplasm exchange and collaborative testing with many national programs.

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Table 9. Expected yields of IRAT/IRRI progenies with moderate and low fertilization in strongly acidic soils (pH <4.5).

Entry	Expected yield (t/ha)	
	Moderate	Low
Checks		
Azucena	1.00	1.11
UPLRi-5	1.60	1.00
Progenies		
IR47684-05-1-B	1.76	1.75
IR47686-01-1-B	1.80	1.83
IR47686-01-4-B	1.69	1.53
IR47686-06-02-2-1	1.69	1.45
IR47686-06-04-1-1	1.63	2.47
IR47686-09-1-B-1	2.55	1.37
IR47686-09-4-1	2.43	1.61
IR47686-12-5-B-1	1.88	1.91
IR47686-18-7-B	1.49	1.65
IR47686-19-1-1 (B)	1.58	1.95
IR47686-31-1-1	2.32	1.81
IR47691-27-7-2-2	1.64	1.66
IR53234-27-4	2.83	3.03
IR53236-275-1	1.80	2.48
IR53236-280	1.72	1.50
IR53236-342	1.76	1.97
IR53236-064	1.62	1.99
IR55411-50	1.48	1.66
IR55419-04	3.80	1.36
IR55433-21	2.16	1.83
IR55442-10	2.11	2.03
IR55521-75	1.49	1.69
IR55537-32-A	1.73	1.26
IR57893-60	3.40	1.43
IR60080-41	1.94	2.18
IR60080-46A-Straw	2.37	2.30
IR60080-46B-Gold	2.19	2.82
IR62751-06	3.60	2.89
IR62751-45	4.42	3.32
IR62760-07	3.24	2.86
IR62761-25	4.42	3.18
IR62761-37	3.61	2.58
IR62761-38	3.43	2.97
IR62761-41	3.08	2.87
IR63370-01	3.13	2.83
IR63370-54	3.75	3.45
IR63371-38	4.58	2.70
IR63372-07	4.36	3.18
IR63372-09	3.92	3.65
IR63372-15	3.63	2.64
IR63372-25	4.37	3.30
IR63372-26	3.93	2.89
IR63374-03	3.83	2.82
IR63381-165	3.41	2.50
IR63381-174	4.78	3.38

Bihar, India. IR55419, IR57920 (AC25-2), and IR57918 (AC1-6) were top yielders in a screening activity for drought resistance conducted by the Upland Rice Consortium. They provided 214, 54, and 44% more yield, respectively, than the local check Brown Gora, a widely grown traditional UR.

Saudi Arabia. With its extremely dry climate, Saudi Arabia is suitable for screening for adaptation under limited irrigation in sandy soils. IR47686-06-02-2-1 was the top yielder among 20 entries. The yield achieved (1.8 t/ha) will be the base for further improved crop management studies.

China. An estimated 500,000 ha of UR is cultivated in southern China at elevations of 300-1,200 m. Environmental conditions and cultivation practices are similar to those prevailing in northern Lao People's Democratic Republic, Myanmar, Thailand, and Vietnam. Soil pH is not very acidic (5.0-6.5) and the chemical properties are not very adverse, but soils are deficient in most major elements, especially P, as well as in minor elements. Bl incidence is not very serious, but brown spot and sheath diseases occur frequently.

In collaboration with the Changsha Institute of Agricultural Modernization at the Chinese Academy of Sciences in Hunan, 160 upland entries were tested at 2 sites for 4 yr. The 20 outstanding entries are given in Table 10. IR47686-06-02-2-1 was one of the most outstanding entries, because of its drought tolerance and brown spot resistance.

In Hunan, false smut is common and IRAT104 is particularly susceptible to it.

Among the new progenies tested in 1990, IR55419-04, IR55419-32, IR55423-01, IR55423-15, and IR55423-09 were the most promising.

Weed management

UR is particularly susceptible to competition from weeds, which limit yields and frequently negate the advantages of good cultivars. Thus, good weed control may be the best way to improve UR crop yields.

Rottboellia cochinchinensis control

Weeds are frequently regarded as the greatest yield-limiting constraint on UR. Season-long competition from grasses taller than the crop canopy may result in complete yield loss.

An experiment conducted in Claveria tested the efficacy of different herbicides in controlling

Table 10. Highest yielding lines[a] in South China, 1988-90.

Entry	1987		1988	1989	1990	
	Changsha	Tao yuan	Tao yuan	Tao yuan	Changsha	Tao yuan
CNA4123	x	x	x			
CNA4130	x	x	x	x		
CNA4136	x	x				
IAC118/81	x			x		
IRAT177		x		xx		x
IRAT104	x		x	x	x	x
IRAT140	x	x	x	xx		
IRAT013	x		x	x		
IRAT112			x	x		
IRAT115	x		x			
ITA130	x		x	xx		
ITA186	x		x	xx		
ITA235			x	xx		x
IR47686-04-5-B-1	x	x	x		xx	
IR47686-06-02-2-1	x	x	x	xx	x	
IR47686-06-04-4-1	x		x	x	xx	
IR47686-11-2-3-1	x	x	x	x	x	
IR47686-18-7-B	x	x	x	x		
IR47690-39-2-B	x		x	x		
IR47701-06-13-3			x	xx	x	

[a]x = outstanding, xx = very outstanding.

Table 11. Effect of weed control treatments on grain yield of UR IR30716-B-1-B-1-2 and weed weight. Ane-i, Claveria, Misamis Oriental, Philippines, 1991 WS.

Treatment[a]	Weed weight (g/m²)		Grain yield (t/ha)
	27 DE	45 DE	
Pendimethalin (1.0) + HW, PE + 28 DE	20.8 bcd	8.1 a	3.7 a
Pendimethalin (1.0) + propanil (3.0), PE + 28 DE	14.9 bc	12.9 ab	3.7 a
HW, 14, 28 + 45 DE	6.8 ab	6.0 a	3.3 ab
HW, 14 + 28 DE	6.4 ab	8.6 a	3.1 abc
IRC + HW, 14 + 28 DE	15.3 bc	22.7 b	3.1 abc
Propanil (3.0) + HW, 14 + 28 DE	28.6 cde	11.2 ab	2.9 abc
Fenoxaprop-ethyl (0.045) + HW, 26 + 35 DE	55.2 ef	12.2 ab	2.3 bcd
HW, 14 DE	3.4 a	24.5 b	2.1 cd
Pendimethalin (1.0) + fenoxaprop-ethyl (0.045), PE + 26 DE	12.3 bc	79.8 cd	1.3 de
Propanil (3.0), 14 DE	43.8 def	157.4 de	1.0 e
IRC, 25 + 40 DE (FP)	79.7 f	269.5 e	0.8 e
Pendimethalin (1.0), PE	18.2 bc	54.5 c	0.8 e
Fenoxaprop-ethyl (0.045), 26 DE	51.9 ef	186.0 de	0.4 e
No weeding	94.8 f	305.8 e	0.3 e

[a]HW = hand weeding, PE = preemergence, DE = days after emergence, IRC = interrow cultivation, FP = farmer's practice. Herbicide rate indicated in parentheses are in kg ai/ha.

Rottboellia cochinchinensis, the predominant grass weed. The experiment was in a randomized complete block design with four replications. Land preparation consisted of one plowing and two harrowings with a 2-wk interval between plowing and harrowing and a 1-wk interval between harrowings. Furrows 30 cm apart were opened using a wooden-toothed furrower. Seeds of IR30716-B-1-B-1-2 were drilled

into the furrows at 100 kg/ha and fertilized with 25-25 kg NP/ha. Another 25 kg N/ha was applied at panicle initiation.

Weed growth was reduced initially by preemergence application of pendimethalin (Table 11), but the herbicide's residual effect was short-lived and there was substantial weed regrowth. The yield was not significantly different from that of the unweeded check. The postemergence herbicides propanil and fenoxaprop also performed poorly when applied alone.

Pendimethalin application followed by hand weeding or propanil application greatly reduced weed growth and significantly increased grain yield. Labor inputs were 65% less for herbicide use + hand weeding than for two hand weedings, and were 96% less for a herbicide combination.

No single weed control practice provided satisfactory weed control. In all cases, two weeding operations were needed to control weeds adequately and produce optimum yields.

Cultivar competitiveness against weeds

In UR, plant breeders have focused most of their research efforts on stable yield, disease resistance, and tolerance for adverse soils. Weed competitiveness has received little attention. Identification and use of competitive cultivars will reduce the inputs needed for hand weeding, which is the predominant weed control method used in UR. In Claveria, northern Mindanao and Matalom, Leyte, 14 cultivars were tested for their ability to suppress weeds or to give high yields in the presence of weeds.

In Claveria, the experiment was laid out in a split-plot design replicated four times with hand weeding regimes as main plots and the different cultivars as subplots. The regimes were 1 weeding 14 DE; 2 weedings, 14 and 28 DE; and 3 weedings, 14, 28, and 42 DE. The dominant weed species are *R. cochinchinensis*, *Digitaria setigera*, and *Borreria laevis*. Failure to weed when they are present resulted in crop failure. Only the data for one weeding are presented.

IR47686-09-1-B-1 had the lowest rice:weed ratio and weed weights (Table 12), indicating high competitive ability. It was followed by the local cultivars Dinorado and Speaker. In contrast, IRAT216 and IR30716-B-1-B-1-2 competed poorly against weeds. Yield was highest from IR47686-09-1-B-1. The next highest yielders were IRAT216 and IR30716-B-1-B-1-2, indicating their ability to yield well in the presence of weeds even if they are poorly competitive.

In Matalom, IR47686-09-1-B-1 was not as competitive as the local check Lubang Red but it was the highest yielder.

Table 12. Weed weight, plant dry weight, rice-to-weed ratio at harvest, and grain yield of different cultivars. Claveria, Misamis Oriental, Philippines, 1991 WS.

Cultivar	Rice-to-weed ratio[a]	Plant dry wt (g/m²)	Weed wt (g/m²)	Grain yield (t/ha)
IR47686-09-1-B-1	0.15 a	648 abc	132 a	2.3 a
IRAT216	0.43 de	418 c	336 d	1.7 ab
IR30716-B-1-B-1-2	0.38 cde	462 c	334 d	1.7 ab
IR57924-09	0.23 abc	528 c	168 a-d	1.6 abc
Dinorado	0.18 ab	862 a	140 ab	1.5 abc
IR57924-08	0.23 abc	632 abc	166 a-d	1.5 abc
UPLRi-5	0.20 abc	638 abc	130 a-d	1.4 abc
Speaker	0.18 ab	818 ab	156 a-d	1.4 abc
B2997C-TB-4-2-1	0.25 a-d	650 abc	200 bcd	1.3 abc
IR57662-11-B-Bulk	0.30 a-e	538 c	286 cd	1.3 abc
IR57924-24	0.35 b-e	516 c	300 bc	1.2 bc
CT6510-24-1-3	0.45 e	398 c	332 d	0.9 bc
IR55419-04	0.43 de	232 c	165 d	0.8 bc
IR55435-05	0.38 cde	291 bc	173 d	0.7 c

[a]Weed dry weight ÷ weed + rice dry weight.

Blast management

Blast (Bl) is one of the most important biotic constraints to rice production in the uplands. Bl lowers and destabilizes rice yields under present conditions, and could become increasingly devastating as production intensifies. This report discusses progress in research aimed at improved breeding for durable Bl resistance. The research involves analysis of Bl fungus populations and of the genetics of host resistance.

Identifying genes for blast resistance in near-isogenic lines

To increase the efficiency of mapping and utilizing known genes for Bl resistance, the resistance genes in the near-isogenic lines (NILs) developed previously at IRRI and those in Kiyosawa's differential cultivars were compared. This work was part of the Japan-IRRI Shuttle Research Project.

The reaction of the differentials to Philippine isolates of *P. grisea* and the number of genes in each were determined. Most differentials were resistant to at least one of the isolates used to develop the NILs. Testcrosses indicated that each differential had zero, one, or two resistance genes.

Allelism tests between the differentials and NILs were conducted. All the necessary crosses were attempted for the 264 combinations to be tested. Hybrid sterility prevented some combinations. F_2 populations of 87 of the crosses were inoculated and scored. The following are tentative conclusions:

- *Pi-2(t)* in C101A51 is allelic to *Pi-z*,
- *Pi-1(t)* in C101LAC and the Bl resistance genes in other NILs in group 1 are allelic to *Pi-k*,
- *Pi-3(t)* is not present in the Japanese differentials, and
- the NILs in groups 3 and 4 have a gene allelic to *Pi-ta*.

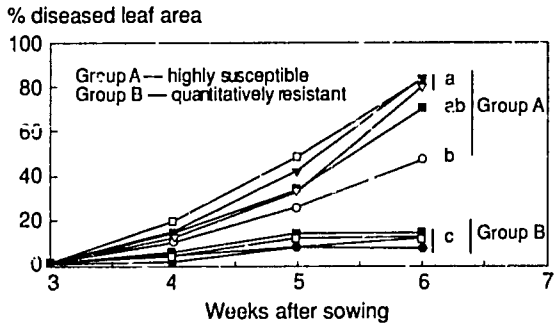
Mapping major and minor genes for blast resistance

Moroberekan is an UR cultivar that has shown durable resistance to Bl. To map the genes involved in resistance of this cultivar, we analyzed a population of 278 recombinant inbred (RI) lines from the Moroberekan/CO 39 cross for 100 polymorphic DNA markers (restriction fragment length polymorphisms [RFLPs]) and for various aspects of Bl resistance. Based on segregation of the molecular markers, a map of the rice chromosomes was constructed for the cross. Segregation was strongly skewed, favoring CO 39 (indica) over Moroberekan (japonica) alleles. A single major gene conditioning qualitative resistance to five isolates of the blast fungus was identified and mapped between markers RG 788 and RG 449 on chromosome 4.

The RI lines were tested in the field at Cavinti. Significant differences in DLA and in the rate of disease progress were detected (Fig. 6), suggesting the presence of genes for partial resistance ("minor genes"). To map minor genes for resistance, data on lesion type, number, and size for the RI lines were collected using a polycyclic test with a single Bl isolate PO6-6. We are statistically analyzing the data to allow mapping of quantitative trait loci for Bl resistance.

Progress was also made in mapping resistance genes for several other crosses. Crosses between CO 39 and IAC47, IRAT104, and IRAT216 were advanced to the F_6 and over 100 polymorphic probes were identified for each. For the IAC165/CO 39 cross, F_6 lines were found to be 97.3% homozygous, and thus suitable as a population for mapping and phenotypic analysis. Allelic segregation in the F_6 RI lines from IAC165/CO 39 were found to be only slightly skewed; the lines showed an average of 46% japonica for 41 lines analyzed at 9 RFLP loci.

Compatible pathogen isolates would be useful for analyzing the genes involved in partial resistance. To identify such isolates, more than 300 isolates of the Bl fungus were tested for reaction on the parents used for the crosses being analyzed. Useful isolates were identified for three of the resistance donors, including IAC165.



6. Disease progress curve for selected RI lines in Cavinti. Areas under disease progress curve followed by a common letter are not significantly different (at 0.05 level) by DMRT.

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Table 13. Summary of 1990 WS tests at 5 upland screening sites.[a]

Cultivar	Sitiung Indonesia		BRRI Bangladesh		Cavinti Philippines		IRRI Philippines		Santa Rosa Colombia	
	Final % DLA	RADPC	Final % DLA	RADPC	Final % DLA	RADPC	Final % DLA	RADPC	Final % DLA	RADPC
Moroberekan	0.00	0.99	0.63	0.13	0.23	0.13	0.00	0.17	11.25	2.77
IRAT216	0.13	0.51	0.30	0.14	0.02	0.01	0.00	0.00	18.75	4.03
OS6	1.25	1.94	2.50	0.82	11.50	1.88	7.00	4.91	26.25	6.64
Azucena	4.75	3.42	-	-	1.28	0.52	2.88	2.88	13.25	2.96
Iguape Cateto	5.00	5.48	0.75	0.16	2.38	0.49	0.01	0.12	7.50	1.88
Danau Laut Tawar	20.00	13.38	1.13	0.47	7.25	1.62	4.50	3.69	15.00	3.03
Kinandang Patong	33.75	14.55	9.88	2.45	1.28	0.34	0.16	0.29	25.00	6.09
CNA4130	16.25	7.28	0.40	0.10	5.25	1.16	1.38	1.97	11.20	2.43
IR47686-18-7B	3.50	4.03	0.40	0.12	1.38	0.60	0.58	1.18	7.50	1.58
Shenshou Ibaraki 1	27.50	10.17	1.13	0.47	14.75	3.51	10.50	7.06	23.75	6.07
KU115	2.38	3.07	0.50	0.17	0.13	0.15	0.00	0.00	4.00	0.83
HD14	0.00	0.36	0.53	0.16	0.01	0.02	0.00	0.00	4.00	0.84
IAC47	8.75	7.96	0.65	0.20	16.00	2.89	3.75	3.66	12.50	3.40
IAC165	16.25	10.61	0.63	0.16	8.75	2.14	1.88	2.45	13.75	3.12
IRAT13	0.00	0.05	0.40	0.07	0.01	0.00	0.00	0.00	1.00	0.37
IRAT104	0.13	0.32	0.50	0.11	0.01	0.03	0.00	0.00	1.00	0.37
CO 39	85.00	34.63	100.00	35.91	71.25	13.93	100.00	45.94	100.00	33.85
Yamada Baki	93.75	34.66	2.75	0.61	100.00	24.41	100.00	48.64	100.00	22.77
BR21	16.25	14.64	4.13	1.17	6.50	0.99	-	-	7.50	1.45
Arias	17.75	9.16	1.50	0.65	20.50	5.49	18.00	11.10	41.25	10.18

[a]DLA = diseased leaf area, RADPC = relative area under the disease progress curve.

Table 14. Spearman rank correlation analysis of reactions of 20 UR cultivars (based on ranking of RADPC values) at 5 sites. 1991.

	Indonesia	Bangladesh	Colombia	Cavinti, Philippines
Bangladesh (BRRI)	0.74			
Colombia (CIAT)	0.42	0.56		
Philippines (Cavinti)	0.78	0.65	0.59	
Philippines (IRRI)	0.78	0.73	0.71	0.94

COMPARISON OF KEY BLAST SCREENING SITES

In a collaborative study to assess the population structure of *Pyricularia grisea* at key screening sites in different parts of the world, the relative susceptibility of a set of diverse upland cultivars was compared at five sites in 1990 and three sites in 1991. In 1990, the materials were evaluated at the CIAT substation in Santa Rosa, Colombia; at the Sitiung substation of SARIF in Indonesia; at the Bangladesh Rice Research Institute; at IRRI; and in Cavinti, Laguna, Philippines.

At each site, miniplots were established for each of 20 UR cultivars. The relative area under the disease progress curve (RADPC) and the percentage of diseased leaf area (DLA) were evaluated using standardized methodology (Table 13). The results varied, suggesting differences among the pathogen populations at the sites. Some cultivars were highly resistant in only two or three locations. Yamada Baki showed a high degree of susceptibility in Sitiung and Cavinti, but not at IRRI.

To systematically evaluate the differences among sites, the varieties were ranked according to RADPC values, and varietal rankings at the sites were compared by Spearman rank correlation analysis (Table 14). As expected, the two Philippine sites showed the most similar ranking. The ranking in Indonesia was fairly similar to the rankings observed in the Philippines. The ranking in Colombia differed from those in Indonesia, Bangladesh, and Cavinti in the Philip-

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pines. In general, the geographic distance between sites paralleled the difference in ranking between them.

Rapid method for DNA typing of blast fungus

Repetitive DNA probes used as genetic markers for defining pathogen lineages have been very useful for elucidating the structure of pathogen populations. Simplified DNA analysis techniques could improve efficiency in characterizing pathogen populations. We compared the DNA profiles produced by single-copy DNA probes, middle-repetitive probes, highly repetitive probes, and by a polymerase chain reaction-based technique termed random amplified polymorphic DNA (RAPD).

Fourteen 10-base primers were screened, and three showed polymorphisms between diverse strains of *P. grisea*. One of these primers, 5'-TCGTTCCGCA-3' (J-06, Operon), generated clear DNA profiles and defined groups of isolates that corresponded well with the groupings defined by repetitive DNA probe MGR586 (DuPont) for 54 isolates collected from the IRRI Bl nursery and from the IRRI upland screening site in Cavinti (Table 15).

Distinct blast isolates infecting IR50

Isolates infecting IR50 and several traditional Philippine cultivars were collected from the IRRI Bl nursery and tested for DNA profiles using two single-copy probes, one middle-repetitive probe, and RAPDs primer 5'-TCGTTCCGCA-3' (Fig.7).

The DNA profiles clearly distinguished the strains infecting IR50 from those infecting the traditional cultivars. The isolates infecting IR50 were more diverse than those infecting the traditional cultivars. The five isolates infecting IR50 showed three distinct types, whereas the 13 isolates infecting the 6 traditional cultivars were all the same.

We speculate that a combination of resistance factors from IR50 and the traditional cultivars could be useful in conditioning resistance against a wide range of Bl fungus types.

Table 15. Association between DNA profiles obtained using RAPD primer 5'-TCGTTCCGCA-3' and RFLP probe MGR586 (DuPont), for 70 *Pyricularia grisea* isolates from Laguna, Philippines.[a]

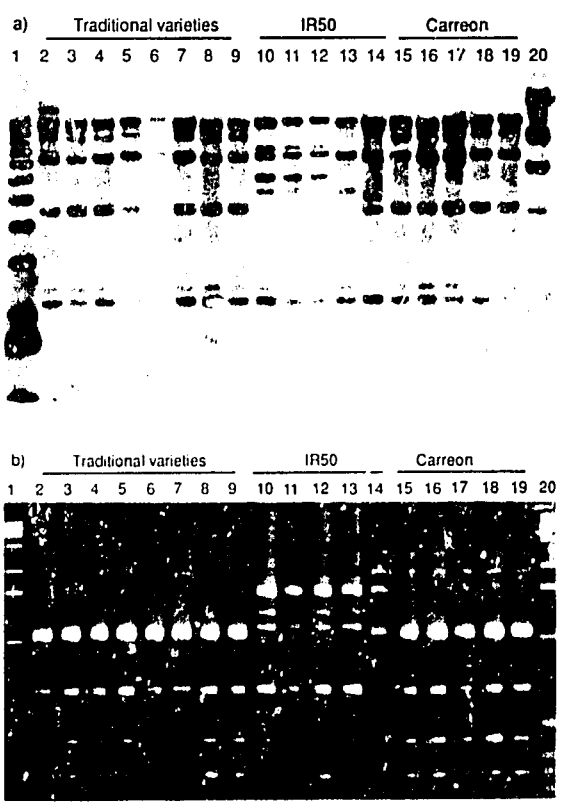
RAPDs profile	RFLP profile	Isolates (no.)
1	1, 1d, 1c, 1e	17
2	7, 7a	7
3, 3a, 3b	4, 4a, 4b, 4c	33
9	10	1
12	3	1
13	5	1
4	2	1
5	3	2
6	9	1
7	11	1
8	14	3
10	6	1
11	13	1

[a]Each distinct DNA profile was given a different designation. Profiles with approximately 80% or greater band similarity were given the same numerical designation, followed by a different letter, while profiles with less than approximately 80% band similarity were given different numerical designations.

Drought

Vegetative stage drought screening

During the vegetative stage of rice, drought may



7. DNA profiles of *Pyricularia grisea* from traditional varieties and from IR50. a) The hybridization profile of middle-repetitive probe p64 (Univ. of Wisconsin). b) DNA profile generated by random amplified polymorphic DNA using primer 5'-TCGTTCCGCA-3' (J-06; Operon). In both a and b, the end lanes show marker DNAs, lanes 2-9 and 15-18 show DNA from *P. grisea* isolates infecting traditional varieties, and lanes 10-19 show DNAs from *P. grisea* isolates infecting IR50.

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occur in any rainfed rice ecosystem. Tolerance for drought is a trait sought by most breeders of rainfed rice. For more than 15 yr, IRRI has screened about 6,000 cultivars and breeding lines and 6,000 germplasm bank accessions for drought tolerance under upland conditions at IRRI.

On 11 Feb 1991, we drilled 10 g seed of each of 6,593 entries from the Plant Breeding, Genetics, and Biochemistry Division, the Agronomy, Plant Physiology, and Agroecology Division, International Network for Genetic Evaluation of Rice, and International Rice Germplasm Center (Table 16) in a Maahas granular clay soil in 2-row plots, each 2.5 m long and 25 cm apart. Plots were sprinkler-irrigated until 12 March, 25 d after 50% seedling emergence, after which irrigation was stopped. We scored for drought reaction at –0.2, –0.5, and –1.0 MPa soil matric potential, then re-irrigated and scored for recovery after 7 d. Scoring was based on the *Standard evaluation system for rice*: for drought, 0 = no visible symptoms of stress, 9 = all plants apparently dead; for recovery, 1 = >90% of plants fully recovered, 9 = <20% of plants fully recovered. The drought-tolerant check was Salumpikit and the susceptible check was IR20.

Among the entries, 128 scored better than Salumpikit at –1.0 MPa and 401 equaled Salumpikit (Table 16). The rices with the greatest proportion of tolerant entries were from the upland ecosystem. Three breeding lines—two from cross IR46331 and one from cross IR47686—and two cultivars—Moroberekan and RD19—have shown good drought tolerance over the past 3 yr (Table 17). Cross IR61042 appears promising as 7 of 27 lines were equal to or better than the tolerant check.

Stable cultivars from well-maintained seed stocks tend to perform consistently across years, at least on a relative basis. As reported in the 1990 Program report, on the other hand, grain yield under soil moisture-deficit conditions, the ultimate measure of drought resistance, has not been shown to be related to vegetative drought tolerance. Furthermore, upland conditions at IRRI are atypical of those found in most farmers' fields. Therefore, this study is the last upland drought screening trial of this sort to be conducted on the IRRI farm. In the future, we will conduct ecosystem-specific drought screening in conjunction with the international rice research consortia.

Simulation of upland rice responses to soil moisture

The growth and yield of rainfed UR is affected by crop, soil, and weather factors. A Centre for Agrobiological Research growth model that integrates the interacting effects of these factors was used to simulate UR growth and yield. The model incorporates soil water balance processes and effects of water

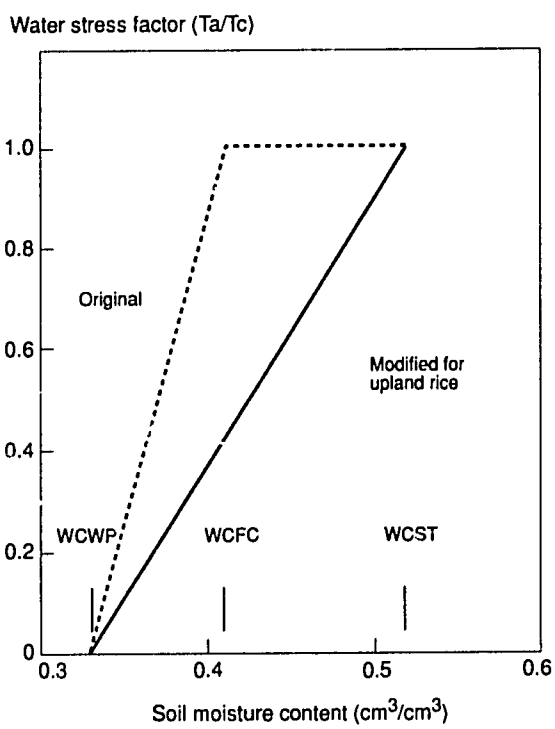
Table 16. Drought-tolerant selections in vegetative phase drought screening in the field. IRRI, 1991 dry season (DS).

Source of entries	Entries (no.)	Outstanding selections[a] (no.)	Other selections[b] (no.)
Plant Breeding, Genetics, and Biochemistry Division			
Rainfed lowland	1929	39	132
Upland	464	10	50
Deepwater	529	12	33
Hybridization block	221	7	11
Bulu rices	328	5	15
Oryza sativa/O. australiensis	407	2	14
Doubled haploid lines	107	1	5
Agronomy, Plant Physiology, and Agroecology Division			
Upland rice	112	11	9
International Network for Genetic Evaluation of Rice	781	12	57
International Rice Germplasm Center	1715	29	75
Total	6593	128	401

[a]Drought tolerance score of 2-3 at soil matrix potential (SMP) –1.0 MPa, better than that of drought-tolerant check Salumpikit. [b]Drought tolerance score of 4 at SMP –1.0 MPa, similar to that of Salumpikit.

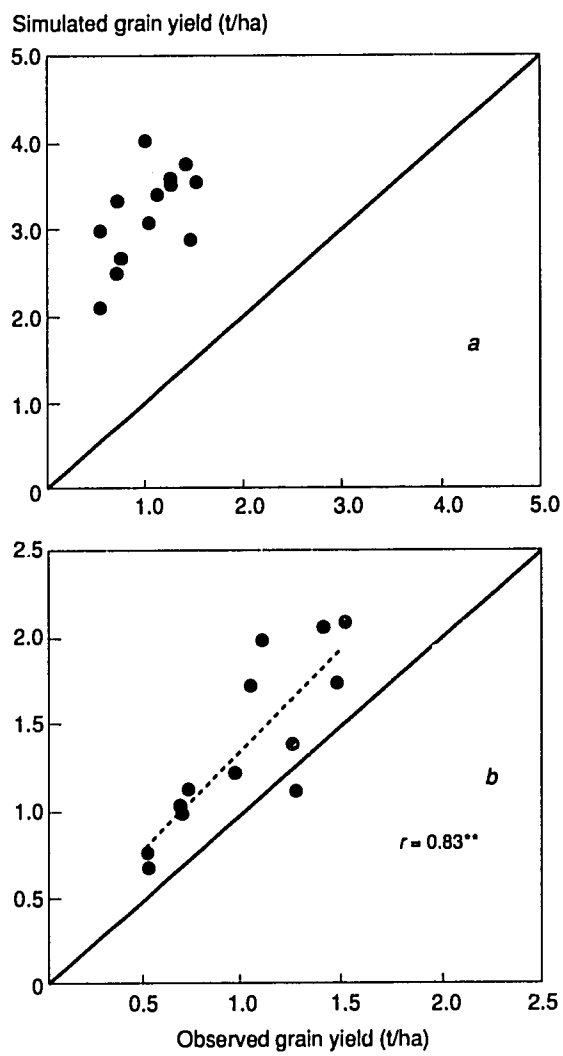
Table 17. Selected outstanding varieties and the lines in vegetative phase drought screening in the field. IRRI, 1991 DS.

Designation	Seed source	Drought score			Recovery score
		–0.2 MPa	–0.5 MPa	–1.0 MPa	
IR46331-PMI-32-2-1-1	Rainfed lowland	1	2	3	1
IR46331-PMI-53-2-1-3	Rainfed lowland	1	2	4	1
IR47686-6-2-2-1	Upland	0	2	3	1
Moroberekan	International Network for Genetic Evaluation of Rice	0	1	4	1
RD19	International Network for Genetic Evaluation of Rice	0	2	3	1
Salumpikit (tolerant check)		1	2	4	1
IR20 (susceptible check)		3	5	7	3



8. Relationship between soil moisture content and water stress factor (Ta/Tc). WCWP = permanent wilting point, WCFC = field capacity, WCST = saturation.

stress on crop growth. The model decreases growth in response to stress by multiplying photosynthesis by the ratio of actual to potential transpiration (stress factor). Using previous greenhouse experiments, we modified the relationship between the stress factor and volumetric soil moisture content (Fig. 8). For rice, actual transpiration falls below potential transpiration as soil moisture becomes less than satura-



9. Observed and simulated grain yields using a) original and b) modified water stress factor-soil moisture content relationships.

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Table 18. Correlation coefficients of the linear relationships between simulated and observed soil water contents at different depths, 1985-89. n = 94-96.

Year	Correlation coefficient[a]		
	10-cm depth	20-cm depth	30-cm depth
1985	0.60**	0.94**	0.95**
1986	0.74**	0.81**	0.75**
1987	0.80**	0.81**	0.89**
1988	0.68**	0.74**	0.72**
1989	0.59**	0.64**	0.62**

** = significant at $p < 0.01$.

tion instead of field capacity as in other upland crops.

Simulated results were compared with data from rainfed yield trials conducted at an upland site at IRRI from 1979 to 1989, where plots received 80-13-25 kg NPK/ha. The experiments were protected from insect pests, rats, and birds.

The original version of the model greatly overestimated grain yields (Fig. 9a). With a modified relationship between the water stress factor and soil moisture content, the model much more closely simulated grain yields for different years although estimates were still high (Fig. 9b). There was a significant relationship between simulated and observed soil moisture contents at all soil depths in all years, but correlations were much stronger below the 10-cm depth (Table 18).

The current simulation study improved our understanding of rice response to water stress. Simulation results confirm that the ratio of actual to potential transpiration rate decreased near saturation. Future research, both experimental and simulation, will determine whether the ratio is in fact linearly related to soil water content from saturation to permanent wilting point in rice.

Conclusion and next steps

Important progress has been made in breeding cultivars tolerant of strongly acidic soils and resistant to Bl. Collaborative breeding programs with national programs are on-going. Ecosystem-specific drought screening will be done in collaboration with the international rice research consortia.

Because of increasing labor shortage in rural areas, improved weed control methods are needed for UR. Weed management activities will emphasize land preparation, selection of more competitive cultivars, and use of implements for interrow cultivation.

We will continue to analyze the population structure of the Bl fungus and will use the resulting understanding to assist our breeding efforts. In 1992, we expect to advance our analysis of genes for qualitative or complete resistance, and to conclude a detailed analysis of genes for complete and partial resistance in a durably resistant upland cultivar with the use of molecular markers. We will further identify and characterize the genetic lineages of the Bl fungus. Information on the pathogen population will be used to improve the characterization of resistance gene.

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Deepwater and tidal wetlands rice ecosystems

Although deep flooding destroys most rice varieties, the stems of deepwater rice (DWR) elongate when stimulated by submergence. DWR is called floating rice in the very deep water areas. The rice grows 1-3 mo in rainfed lowland fields that are prone to drought or shallow flooding, and are subsequently flooded to depths of more than 50 cm for 1 mo or longer. The peak water levels usually occur before flowering. Tidal wetlands rice does not elongate. It is similar to rainfed lowland rice, but grows in coastal lowlands where water levels fluctuate as tides rise and fall and soils are often saline, acid, or peat.

The deepwater and tidal wetlands rice ecosystems program aims to develop improved rice cultivars and more efficient cultural methods and farming systems for these ecosystems. Because national agricultural research systems (NARS) and IRRI have limited resources for research in these areas, a collaborative approach is emphasized. The target ecosystems have a sustainable system of agriculture, and yields can be increased without detriment to the environment. Alternative cropping systems will provide greater employment and improved diets.

Subprogram I: Increased productivity and land-use efficiency of deepwater ricelands

Because of successful crop substitution programs in Bangladesh and Vietnam, about 1.8 million ha of deepwater ricelands have been converted for irrigated crops, but nothing is grown during the flood period. These conversion programs should be continued where they are environmentally sound and economically viable, but more research is needed to combine DWR and irrigated crops more effectively. In more than 6 million ha of lands, DWR is the only feasible main crop, and its productivity must be improved.

Improved deepwater rice germplasm

This project aims to provide breeding materials to NARS and to conduct prebreeding research on elongation ability and submergence tolerance. Although the current yields of deepwater ricelands are less than 2 t/ha, breeding research has demonstrated that some new strains often double this yield potential. However, the difficult task of fitting new strains into specific niches can be achieved only by an extensive field testing program.

Thai-IRRI breeding materials

Our collaboration with Prachinburi Rice Research Center in Thailand expanded during the year.

F_1 hybrids. A total of 192 F_1 hybrids were produced—64 at IRRI and 128 at Prachinburi. Scientists at IRRI concentrated on early-maturing types while those at Prachinburi emphasized crosses involving late-maturing types.

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Bulk populations. At IRRI, 93 F_2 populations were evaluated for submergence tolerance and 20 with desirable genotypes were selected for advancement. For slow elongation in water up to 1 m deep, 135 F_2 populations were selected from 386 tested. Of 294 populations evaluated in 1990 for plant type, duration, and resistance to major pests and diseases, 169 were selected for testing in different water depths.

A total of 999 bulk populations ranging from F_2 to F_4 were evaluated under natural flooding conditions at Prachinburi. Bulk selections were made every 2 wk from late October until late December.

Pedigree nurseries. Nearly 6,000 lines from 216 crosses were evaluated at IRRI for duration and resistance to pests and diseases. A total of 404 lines from 81 crosses were selected for distribution to NARS.

Pedigree evaluation was also done in Prachinburi. Of the 730 lines tested, 482 were selected for farmers' field observation tests.

Characterization of advanced lines. Characterization, which is essential to determining target areas to which the new lines could adapt, was carried out at IRRI and Prachinburi. Of the 405 lines studied at IRRI, 98 matured in late October, 275 in early November, and 32 in late November. An additional 1,028 lines were characterized at Prachinburi.

Prebreeding research

Submergence beyond 10-12 d usually kills rice. The rice varieties adapted to long-duration flooding survive by elongating their internodes and leaves, and thus emerging above water. Plant elongation is considered a key trait in DWR improvement. Experiments in 1991 identified procedures to screen for rapid elongation ability in a nondestructive manner.

Seedling age. Experiments with three seedling ages (2, 3, and 4 wk) assessed variation in plant elongation ability induced by short-duration flooding.

Entries differed significantly in plant elongation (Table 1). Percent increase after flooding was higher in the 2-wk-old seedlings, but actual elongation was greater at the 3- and 4-wk seedling ages. At all three seedling ages, high repeatability values for plant elongation indicated good precision. This method is nonlethal and can be used to distinguish the elongat-

Table 1. Increase in plant height of seedlings of 3 ages submerged for 7 d in 100 cm water and elongation score of some deepwater rice(DWR) varieties. IRRI, 1991.

Variety	Increase in plant height (cm)			Elongation score
	2 wk	3 wk	4 wk	
FR13 A	-	13.2	5.1	9
BKNFR76106-16-0-1	-	8.3	4.6	9
IR36	10.7	8.9	7.1	9
Ghoghari	-	23.6	8.9	7
Shayma	-	15.2	9.1	7
IR42 (susceptible check)	13.6	8.7	7.9	7
IR11288-B-B-69-1	13.2	12.4	10.6	7
NDGR150	21.8	21.5	7.4	5
FRG15	-	23.6	8.9	5
Madhukar	-	17.7	9.9	5
NDGR207	15.3	20.9	12.4	5
IR11141-6-1-4	17.3	15.9	11.8	5
IR28273-R-R-R-29-38-2-3-3	-	17.2	18.2	5
Chakia 59	-	33.8	15.9	3
IR40905-11-3-1-5-3-3	-	24.6	16.1	3
NC492	-	27.9	20.1	3
Baisbish	26.0	23.0	21.0	3
Saingar	-	37.3	13.1	1
Barogar	-	37.3	19.8	1
LMN111	-	41.8	20.9	1
Jalmagna	24.1	26.8	35.8	1
NDGR407	25.4	-	-	1
CV (%)	9.2	17.6	25.0	
Repeatability (*r*)	91.7	85.8	80.9	

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ing types from the nonelongating ones without destroying the entries. The expriments show that, for best precision, 3- to 4-wk-old seedlings should be used for screening.

Shallow-flooding techniques. To minimize the need for deep flooding to assess the rate of internode elongation, we conducted an experiment with six elongating and three nonelongating varieties in tanks at IRRI. Six weeks after seeding, the water depth was raised to 50 cm. To stimulate elongation and kneeing, the portion of the plants that remained above water level was submerged using a horizontal iron bar. The iron bar was moved forward across the horizontal line 2-3 times a week depending on the increase in stem length. This procedure allowed all plants, including nonelongating varieties, to be submerged but to survive. This horizontal forcing method induced test plants to express their potential for elongation at most internodes without necessitating deep flooding.

Varieties differed significantly in total internode length. Floating types had the greatest length, followed by elongating modern types and tall traditional DWR (Table 2). Floating varieties produced 10-15 internodes, at least 7 of which were elongated (more than 6 cm long). Elongating modern types had eight to nine internodes, at least five of which were elongated.

Screening for elongation using gibberellic acid treatment. We evaluated 48 entries including nonelongating modern, elongating modern, tall traditional, tall elongating, and floating types from several countries. At the 4-leaf stage, each plant was sprayed with 3 ml of 500 and 1000 ppm gibberellic acid (GA_3). A control treatment was included.

We found no significant difference in length of internodes between the 500 and 1000 ppm GA_3 treatments. Therefore, the average internode length of these two treatments was used for interpreting results. Results suggest that internodes of floating rice are more sensitive to GA_3 than are those of nonfloating rice (Table 3). However, when compared by *Standard evaluation system for rice* (SES) scores and classified into highly elongating (SES score of 1-3), moderately elongating (5), and nonelongating (7-9) groups, no clear distinction between groups was observed. Furthermore, among the floating rice varieties, plants with good elongation ability were more sensitive than those with moderate elongation ability.

Findings reveal that floating and nonfloating rice varieties differ in sensitivity to GA_3. Foliar application of 500 ppm GA_3 could be used during seedling stage to distinguish floating rices with good elongation ability from those with poor elongation ability and from nonfloating rices.

Identifying elongating rices without flooding. To study the developmental-morphological differences between elongating and nonelongating rices in the absence of water, 36 entries including floating, elongating modern, and nonelongating modern types were grown under normal irrigated lowland condition. At panicle emergence, we examined 30 randomly selected main tillers for plant height and number and length of internodes.

Table 2. Internode characteristics and elongation score of some rice varieties under forced elongation. IRRI, 1991.

Variety	Internodes			Elongation score
	Total (no.)	Elongated (no.)	Total length (cm)	
		Elongating varieties		
Jalmagna	15	12	135	1
Baisbish	13	10	116	1
NDGR417	10	7	111	1
NDGR150	8	6	79	5
IR11141-6-1-4	9	6	58	5
IR11288-B-B-69-1	8	5	62	5
		Nonelongating varieties		
NDGR207	7	4	67	5
IR42	6	3	37	9
IR36	6	4	44	9

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Table 3. Internode elongation induced by GA_3 at 7- to 8-leaf stage in some rice varieties.

Variety	Country or place of origin	Internode elongation (cm)		Elongation score
		With GA_3	Without GA_3	
Nonelongating type				
Safri 17	India	41.3	0	9
IR5	IRRI	42.9	0	9
Dulhabhog	Bangladesh	43.2	0	9
IR42	IRRI	46.4	0	9
Mahsuri	Malaysia	47.6	0	9
Jaya	India	49.4	0	9
TN1	Taiwan	56.8	0	9
	Average	46.8	0	
Tall traditional				
Manoharsali	India	34.7	0	9
Rajasail	Bangladesh	36.3	0	9
Maliabanger	Bangladesh	37.4	0	9
NC492	India	38.8	0	9
Ashini	Bangladesh	39.4	0	
NDGR207	India	42.5	1.5	9
Patnai 23	India	46.4	0	9
Sugapankhi	India	50.2	0	9
Nam Sagui 19	Thailand	54.7	0	9
	Average	42.3	0.2	
DWR and MV[a] elongating types				
Bhainslot	India	50.5	0	5
Pin Gaew 56	Thailand	52.2	0	5
Girmi	Bangladesh	54.3	0	5
IR11288-B-B-69-1	IRRI	55.7	0.2	5
Pan Tawng	Thailand	56	0	5
Walihandiran	Sri Lanka	60.5	0	5
Jaisaria	Bangladesh	61.3	0	5
Bhadoia 293	Bangladesh	61.8	7.9	5
BKNFR76106-16-0-1	Thailand	65.6	0	5
NDGR150	India	65.8	0	5
RD19	Thailand	75.3	0	5
IR11141-6-1-4	IRRI	79.8	0	5
	Average	56.8	0.7	
Tall elongating type				
Rayada 16-05	Bangladesh	51.3	0	5
Rayada 16-06	Bangladesh	62.9	0	5
IR40905-11-3-1-5-3-3	IRRI	63.7	4	3
Sran Kraham	Cambodia	64.9	3.2	3
TCA148-3	India	65	4.1	3
Chakia 59	India	70.7	8.2	3
	Average	57.3	1.7	
Floating type				
Anlong Phnom	Cambodia	64.8	6.4	3
Vear Sar	Cambodia	66.2	6.8	3
Digha	Bangladesh	70.4	0	3
Baisbish	Bangladesh	72.7	3.9	3
Chamara	Bangladesh	77.5	6	3
Rayada 16-04	Bangladesh	81.3	0	1
Bazail 65	Bangladesh	88.8	9.8	1
LMN111	Thailand	97.8	14	1
Chhota Bhawalia	India	101.5	15.7	1
Khama	Bangladesh	102.4	13.9	1
BR516-48-3	Bangladesh	102.5	26.3	1
Sarsari	Bangladesh	103.9	9.5	1
Bhadoia 303	Bangladesh	112	32.9	1
Jalmagna	India	122.6	26.6	1
	Average	88.1	11.3	

[a]Modern variety.

Average internode length among the entries ranged from 29.5 to 128.3 cm. In general, nonelongating modern types had fewer and shorter internodes, and were shorter than the tall traditional DWRs. Nonelongating modern types had two to three elongated internodes out of a total four or five, most elongating modern types produced five elongated internodes out of a total five or seven, and traditional floating rices had six of six to nine internodes elongated (Table 4).

The results confirmed that developmental-morphological differences between elongating and nonelongating rice varieties exist and can be detected without flooding, although there is considerable overlap between groups.

Next steps

IRRI will concentrate on prebreeding research and development of breeding materials for early maturity and medium water depths. We will investigate the

Table 4. Internode characteristics of some rice varieties grown under irrigated lowland conditions. IRRI, 1991.

Variety and type	Internodes			Plant ht (cm)
	Total (no.)	Elongated (no.)	Total length (cm)	
Nonelongating dwarf				
IR36	4	2	29.5	75.0
BKNFR76106-16-0-1	5	3	47.8	104.6
IR42	5	3	48.2	98.5
IR50	5	3	59.0	132.4
Tall traditional				
Madhukar	4	4	64.6	121.3
FR13 A	5	4	68.0	130.8
NDGR207	4	4	68.1	126.7
Nam Sagui 19	5	4	75.1	131.4
Shayma	4	4	75.6	135.9
Bhatin	5	4	80.2	133.2
FRG15	5	4	88.6	147.9
Amara	6	4	95.1	146.3
Elongating modern variety				
IR11141-6-1-4	7	5	63.5	117.3
NDGR150	4	4	67.9	142.8
NC492	5	5	79.1	133.2
Kekuabao	6	5	79.6	139.0
Chakia 59	5	5	80.4	143.9
NDGR149	5	5	83.0	152.5
NDGR151	6	5	82.8	144.3
Maguri	7	5	92.2	151.4
Kalaungi	6	5	94.9	151.4
Agahani	6	5	95.2	156.8
IR28273-R-R-R-29-38-2-3-3	7	5	98.4	167.4
Sainger	5	5	99.8	156.9
IR40905-11-1-5-3-3	7	5	101.5	165.5
Floating				
Ranga Bao	6	6	90.3	145.3
NDGR404	6	6	95.0	157.3
Raj Bhawalia	8	6	97.3	158.3
Padmapani	9	6	101.6	153.7
Bazail 65	7	6	100.4	165.7
Chamara	7	6	103.6	150.5
Nagheri Bao	6	6	106.9	164.0
NDGR402	6	6	113.5	165.2
Rayada 16-06	8	6	118.3	176.6
Jalmagna	9	7	123.1	174.1
Barogar	8	7	128.3	180.3

genetics of elongation ability, and characterize advanced breeding lines for duration, plant type, pest and disease resistance, and adaptation to submergence and slow and fast rising water. Breeding for late maturity and higher water depths will be done at Prachinburi Rice Research Center and Huntra Rice Experiment Station in Thailand.

Improved crop and resource management for deepwater rice areas

This project supports the breeding program by developing more efficient testing methods for DWR germplasm. It also focuses on plant nutrition and cropping systems that will allow farmers to benefit most from increased productivity of the whole system, not just the rice crop. As with the different rice types, cropping systems must be adapted to specific combinations of a wide range of soil, climate, and flooding conditions.

Collaborative research with Thailand

Testing deepwater rice for fertilizer response with different plot sizes. Improved DWR lines tend to respond to N and P fertilizer, but full-scale testing of promising lines on broadcast plots has not been carried out because of the amount of seed, land, and other resources required. To determine if experiments in small plots can give sufficient information for classification of entries before testing in farmers' fields, row-sown rice, which has less spatial variability than broadcast rice, was used. The experiment used fertilizer rate as main plot, plot width (5 or 10 rows) as subplot, and genotypes as sub-subplots. The first fertilizer application was incorporated at sowing; the second was broadcast near the commencement of flooding. Eight entries were used at Prachinburi, but only four at Huntra where an additional treatment was added to determine the effect of removing border rows before maturity.

Rows were hand sown at Prachinburi and machine sown at Huntra. In half of the plots at Huntra, border rows were removed 7 wk before harvest. Data for both sites are given in Tables 5,6.

Grain yields at Huntra (Table 5) show that removing the border rows 6 wk after flooding gave higher mean yields for the remaining rows than removing the borders at maturity, and that the effect was greater for 5-row plots than for 10-row plots. The difference was greatest for the plots without N fertilizer. However, despite the differences in yield levels, there was little difference in the ranking of the entries for any treatment. At Prachinburi, borders were removed at maturity only (Table 6). Plant establishment was uneven, but entries in both 5- and 10-row plots gave similar rankings between entries for yield and for average response to fertilizer.

Thus it appears that if seed is evenly distributed in rows, as can be done by machine, 5-row plots can economize the use of resources and allow a valid

Table 5. Average grain yield in 5- and 10-row plots for measuring fertilizer response. Huntra Rice Experiment Station, Thailand, 1991.

Entry	Average grain yield (g/m²)													
	No N				30 kg N/ha				60 kg N/ha				Av	Rank
	5-row	Rank	10-row	Rank	5-row	Rank	10-row	Rank	5-row	Rank	10-row	Rank		
Border rows removed at maturity														
LMN111	261	2	255	3	237	3	265	3	284	3	302	3	267	3
DWCT'82-2-2	321	1	322	1	352	1	384	1	376	1	412	1	361	1
BKNFR-76042-18-1	238	3	249	4	276	2	294	2	298	2	261	4	269	2
SPR7411-7-2-3-2	232	4	269	2	228	4	244	4	265	4	324	2	260	4
Average	263		274		273		297		306		325		289	
Border rows removed 6 wk after flooding														
LMN111	327	2	287	3	338	3	286	3	318	3	322	2	313	2
DWCT'82-2-2	378	1	356	1	416	1	340	1	405	1	406	1	384	1
BKNFR-76042-18-1	253	4	310	2	345	2	304	2	349	2	290	4	308	3
SPR7411-7-2-3-2	295	3	239	4	310	4	270	4	336	4	293	3	291	4
Average	313		298		352		300		352		328		324	
Difference means	50		25		79		4		47		3		34	
Overall mean	288		286		313		298		329		326		307	

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Table 6. Average grain yield in 5- and 10-row plots for measuring fertilizer response. Prachinburi, Thailand, 1991.

Entry	Average grain yield (g/m²)												Av	Rank
	No N				12.5 + 12.5 kg N/ha				25 + 25 kg N/ha					
	5-row	Rank	10-row	Rank	5-row	Rank	10-row	Rank	5-row	Rank	10-row	Rank		
LMN111	158	1	152	1	211	1	172	1	246	1	231	1	195	1
DWCT'82-2-2	129	2	112	4	141	3	163	3	180	4	217	4	157	4
BKNFR-76042-18-1	96	5	108	5	128	5	162	4	155	8	220	3	145	5
SPR7411-7-2-3-2	103	4	107	6	148	4	154	5	174	5	171	7	143	6
SPR'76Com3-5-2	48	7	71	7	90	8	126	8	166	6	205	6	118	7
HTA60	26	8	40	8	113	6	129	7	162	7	141	8	102	8
Plai Ngham	92	6	130	2	172	2	150	6	217	3	226	2	164	2
PG56	124	3	124	3	102	7	173	2	233	2	212	5	162	3
Average	97		106		138		154		192		203		149	

comparison of DWR responses to fertilizer early in the breeding program.

Nitrogen uptake and productivity of deepwater rice in farmers' fields. To determine N uptake in both the preflood and flooded periods, 99 farmers' fields in the provinces of Ayutthaya, Lopburi, Nakorn Nayok, Prachinburi, and Singburi were sampled for dry matter and N content before flooding and at harvest. The preflood samples were taken as close as possible to the start of flooding. A sample area was selected in each farm and the plants cut off at ground level. Soil samples from the site were analyzed for pH, total N, and available P. At maturity, grain yields were obtained from 49 m² and four other samples were taken outside the corners of the harvest area for dry weight, yield components, and N.

Excluded from the analysis were 14 fields with incomplete data. Significant correlation coefficients showing relationships between environmental and plant factors for 85 sets of data are shown in Table 7. The center column correlates yield with the main production components. For example, weight per panicle had a correlation of 0.22 with yield and panicle number had a correlation of 0.59 with yield. The left-hand column (precursor) shows factors that affected the central component (e.g., increasing stems/m² had a negative effect on weight per panicle, but a positive effect on number of panicles/m²). The right-hand column shows factors dependent on the central components; for example, harvest index is increased by greater weight per panicle, decreased by dry weight at maturity, and not affected by number of panicles/m².

N uptake during the flood (mg N/m² per d) had a closer relationship with total N uptake at maturity than did N uptake during the rainfed preflood period, indicating that the rate of N supply to plants during flooding is a significant factor in production. Soil pH was negatively correlated with total N uptake, whereas soil N was positively correlated, suggesting that soils with higher pH had lower total N than soils with lower pH. Rainfall in the preflood period was not analyzed; it may have had a dominant effect on many of the relationships.

Effect of sowing time of deepwater rice intercropped with sesame. An experiment was conducted at Huntra Rice Experiment Station to determine the optimum time of sowing DWR intercropped with sesame to obtain maximum economic return. On 15 May 1991, red sesame was sown in rows spaced 50 or 100 cm apart. DWR variety Huntra 60 (HTA60) was broadcast at the same time as sesame or at 2, 4, 7, and 10 wk after sesame emerged, either into the sesame crop or as a separate monoculture. Fertilizer was 156 kg/ha of 15-15-15 NPK for sesame and 16-20-0 NPK for DWR. Weed and insect control was as recommended for sesame.

When sesame and DWR were sown together at day 0, competition from DWR reduced the yield of sesame to 0.55 t/ha in 50-cm rows and to 0.34 t/ha in 100-cm rows, compared with best yields of more than 1.0 t/ha (Table 8). Average DWR yield was higher with sesame at 100-cm row spacing than at 50-cm row spacing. In mixed stands, DWR yield was in turn reduced by competition from sesame, with greatest reduction in late-sown DWR; however, the

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Table 7. Correlation coefficients showing relationships between environmental and plant factors in 85 farmers' fields, Thailand.

Precursor	Correlation: With yield component	Correlation: With grain yield	Correlation: With dependent factors	Dependent factors
		Grain yield		
Stems/m² preflood	−0.39		−0.25	Harvest index
N uptake/d of flood	0.34	Weight/		
N (g/m²) at maturity	0.32	panicle (0.22)		
Stems/m² preflood	0.51	Panicles/m²		
Dry wt/m² preflood	0.27	(0.59)		
Dry wt/m² maturity	0.60			
Stems/m² preflood	0.24	Dry weight	−0.49	Harvest index
Dry wt/m² preflood	0.42	at maturity		
N/m² preflood	0.35	(0.69)		
N/m² maturity	0.56			
N/d of flood	0.25			
No significant precursor		N uptake/day	0.30	Dry wt/panicle
		during flood	0.25	Dry wt/m² at maturity
		(0.33)	0.80	N/m² at maturity
Soil pH	−0.30	N/m² at maturity	0.3	Dry wt/panicle
Soil N	0.27	(0.42)	0.5	Dry wt/m² at maturity
N/m² preflood	0.42		−0.26	Harvest index
Dry wt/m² preflood	0.40			
N/d of flood	0.82			
Soil pH	0.34	Harvest index		
Soil N	0.35	(0.25)		
N/m² preflood	−0.37			
Dry wt/stem preflood	−0.25			
Dry wt/m² preflood	−0.33			

reduction was less than expected, because maximum water depth was only 60 cm. Financial return was best with DWR sown 4 wk after emergence of sesame with 50 cm between rows. The gross income was double that of monoculture DWR even though the average yield of rice was much higher than usual.

Intercropping deepwater rice and upland crops. Intercropping experiments with upland crops and DWR have been conducted at Huntra for 3 yr, using HTA60 with upland crops red sesame, Kampansaeng 1 mungbean, or Hysun 33 hybrid sunflower (and an open-pollinated Myanma variety in 1991). In 1991, DWR was sown at the same time as the three upland crops or broadcast 65 d after their emergence. Mungbean and sesame were broadcast or sown in rows 50 cm apart. Sunflower was sown at 50 cm spacing in rows 75 cm apart. Plots were 9 × 9 m, with drains constructed between them to remove surface water after heavy rains.

Yield of upland crops and DWR are given in Table 9. The monoculture of DWR sown at day 0 yielded 3.6 t/ha (relative yield 100). The season favored DWR recovery after harvest of the upland crops, and only in treatment 8 was the relative yield of DWR less than 100. Early competition apparently was not detrimental to DWR production. However, competition from DWR reduced the yield of sesame and mungbean, particularly of broadcast mungbean.

Market prices were $0.32/kg of mungbean, $0.68/kg of sesame, $0.28/kg of sunflower, and $152/t of DWR. Treatment 8 gave the highest gross income (relative 234) despite the relatively low yield of DWR. The other sesame treatments and row-sown mungbean also gave high incomes. Sunflower pro-

Table 8. Average yield of DWR and sesame, Huntra Rice Experiment Station, Thailand, 1991 wet season (WS).

Treatment		Sowing date	Sesame yield		DWR yield	
Sesame[a]	DWR[b]		t/ha	Relative	t/ha	Relative
No sesame	DWR day 0	15 May	-	-	4.2 ab	100
Sesame 50	DWR day 0		0.55 bc	63	3.0 d	71
Sesame 100	DWR day 0		0.34 c	40	4.2 ab	99
No sesame	DWR 2 WE	07 Jun	-	-	4.7 a	111
Sesame 50	DWR 2 WE		0.92 a	106	2.8 d	66
Sesame 100	DWR 2 WE		0.80 ab	92	3.3 cd	78
No sesame	DWR 4 WE	21 Jun	-	-	4.6 a	109
Sesame 50	DWR 4 WE		1.07 a	124	3.8 bc	90
Sesame 100	DWR 4 WE		0.93 a	107	3.8 bc	91
No sesame	DWR 7 WE	12 Jul	-	-	3.8 bc	91
Sesame 50	DWR 7 WE		1.01 a	117	2.9 d	68
Sesame 100	DWR 7 WE		1.03 a	119	2.9 d	68
No sesame	DWR 10 WE	02 Aug	-	-	3.9 bc	93
Sesame 50	DWR 10 WE		0.86 ab	99	1.0 f	23
Sesame 100	DWR 10 WE		0.89 a	102	2.0 e	48
CV (%)			25.5		13.5	
LSD (0.05)			0.31		0.6	

[a]Row spacings of 50 and 100 cm. [b]WE = weeks after emergence of sesame.

Table 9. Yield of upland crops followed by DWR or intercropped with DWR. Huntra Rice Experiment Station, Thailand, 1991 WS.

Treatment			Upland crop yield		DWR yield	
no.	Upland crop[a]	DWR[b]	t/ha	Relative	t/ha	Relative
1	-	B	-	-	3.6 bc	100
2	-	B at 65 DE	-	-	4.6 a	129
	Mungbean					
3	Mixed	B	0.29 c	25	4.1 ab	115
4	50 cm	B	0.74 b	66	4.7 a	131
5	50 cm	B at 65 DE	1.10 a	100	3.7 bc	105
	Sesame					
6	Mixed	B	0.74 b	62	4.0 ab	112
7	50 cm	B	0.60 b	51	3.8 bc	107
8	50 cm	B at 65 DE	1.18 a	100	3.1 c	88
	Hybrid sunflower					
9	75 x 50 cm	B	0.70	106	4.0 ab	113
10	75 x 50 cm	B at 65 DE	0.67	100	3.5 bc	99
	Open-pollinated sunflower					
11	75 x 50 cm	B	0.23	79	4.1 ab	116
12	75 x 50 cm	B at 65 DE	0.29	100	3.8 bc	105

[a]Figures show spacing. [b]B = broadcast, DE = days after emergence of the upland crop.

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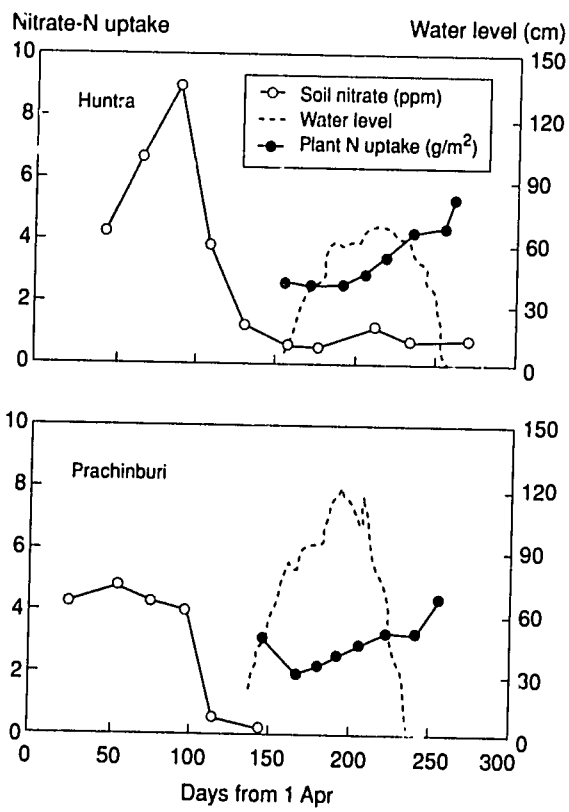
duction was low because of poor establishment. The crop will not be attractive economically unless the germination problem can be solved. At present, sesame is the best of the three crops to intercrop with DWR in the preflood period.

Soil nitrate accumulation and nitrogen uptake by deepwater rice. Appreciable soil nitrate can accumulate during the aerobic dry season fallow of tropical lowland ricefields, but few field studies have measured nitrate accumulation and loss in DWR systems, or their relation to production. DWR soils are alternately wet and dry in the first 2-3 mo of the growing season. Changes in soil nitrate were measured at Prachinburi and Huntra during the fallow preflood and early flooding periods. Dry seed was sown at a rate of 120 kg/ha. Soil samples were taken from 0-20, 20-40, and 40-60 cm on plots without N fertilizer until deep flooding at Prachinburi and until harvest at Huntra. Plant samples were taken from preflooding to harvest.

Mean values for the three soil layers are given in Figure 1. Nitrate at Huntra rapidly increased after commencement of wet season, decreased after planting, and was low during flooding. Large differences in soil nitrate between the sites may reflect differences in soil microorganism activity. Measured soil ammonia values were less than 0.1 ppm, probably because of sensitivity to NaOH used to adjust the pH of the leachate to 5.5 during analysis for nitrate.



1. Changes in soil nitrate and plant N uptake with time at Huntra and Prachinburi, Thailand, 1991.

One ppm of nitrate in the top 40 cm of soil is approximately equal to 1.4 kg of N/ha. A comparison of the average curves of nitrate and N uptake indicates a maximum of about 12 kg N/ha as nitrate in the soil at Huntra and 7 kg N/ha at Prachinburi, whereas the first measurements of N uptake gave nearly 30 kg/ha for Huntra and more than 20 kg/ha for Prachinburi. The source of this additional N is still to be identified.

Collaborative research with Vietnam

Effect of plant spacing on deepwater rice yield. A study in Myxuyen District of Hau Giang Province aimed to determine optimum spacing between hills for four DWR varieties—Mong Chim Lun, Mot Bui, Khmer Do, and Do Mo Coi—commonly grown in the region. The closest spacings (20 × 30 cm or 20 × 40 cm) gave the highest yields, averaging 3.3-3.4 t/ha for the varieties.

Effect of nitrogen, phosphorus, and potassium on deepwater rice yield. A study in Myxuyen District showed that N increased plant height, yield components, and grain yield of DWR Mong Chim Lun from 1.5 to 2.2 t/ha. Additional P or K had no positive effects.

Integrated pest management for deepwater ricelands

The main thrust in 1991, nematode research in Vietnam, showed that water control could result in a drastic reduction in the occurrence of ufra disease. Other research on integrated pest management (IPM) was built into the collaborative programs with Bangladesh, India, and Thailand, which were developed under a project assisted by the Asian Development Bank. The project, which terminated on 28 Feb 1991, aimed to help national programs develop a coordinated IPM system within and between DWR areas of South and Southeast Asia.

Collaborative research with Vietnam

Plant-parasitic nematodes and deepwater rice in the Mekong Delta. Populations of root-parasitic

Table 10. Average absolute densities (D) per dm³ of soil and g of root, and absolute frequency (F) of occurrence (% of fields where the species has been detected) of root-parasitic nematodes associated with DWR in the Mekong Delta.

Nematode species	D	F
Hirschmanniella oryzae		
Soil	1238	99
Root	49	99
Hirschmanniella mucronata		
Soil	191	96
Root	4	77
Meloidogyne graminicola		
Soil	408	20
Root	39	20
Tylenchorhynchus annulatus		
Soil	261	5
Root	12	11

nematodes associated with DWR were estimated in 164 farmers' fields scattered among the DWR-growing areas in five provinces of the Mekong Delta in Vietnam. Samples were collected in fields where water depth ranged from 50 to 350 cm. IR66 and IR42 were the main cultivars grown in shallow water areas, whereas traditional varieties Hay Ran, Do Lun, Do Mo Coi, and Nang Soi were grown in deep flooding areas. Four nematode species were present (Table 10).

Rice-root nematodes *Hirschmanniella oryzae* and *H. mucronata* were omnipresent at high population densities. Pathogenic to rice and capable of causing yield losses in irrigated rice under field conditions, they are potentially important pests as irrigated rice progressively replaces DWR (Table 11). *Meloidogyne graminicola*, present in high populations in 20% of the fields and pathogenic to DWR, may locally cause yield losses.

In 1990, 1,730 ha in provinces of the Mekong Delta were damaged by ufra disease, which is caused by the stem nematode *Ditylenchus angustus*. In the past 15 yr, however, the area damaged appears to be decreasing (Table 11). The development of supplemental irrigation facilities has allowed the progressive abandonment of low-yielding DWR in favor of one or two high-yielding irrigated rice crops during the dry season. This change in agricultural environment seems to have reduced ufra disease occurrence.

Collaborative research with Bangladesh

Yellow stem borer egg predation. Use of sticky traps with yellow stem borer (YSB) egg masses in the fields and subsequent tests in the laboratory indicated that the meadow grasshopper *Conocephalus longipennis* (de Haan) is the lone YSB egg predator in Bangladesh. Field monitoring in four rice crops of boro, aus, transplanted Aman, and DWR showed very low average egg mass (10%) and egg predation (7.3%), with 10.6% egg mass and 8.5% egg predation in DWR. The results indicate that the role of egg predators in YSB population suppression is insignificant.

Table 11. Areas damaged by *Ditylenchus angustus* and land use in different years in 5 provinces of the Mekong Delta.

Year	Damaged area (ha)	Area planted (ha)	
		Deepwater rice	Irrigated rice
		Cuu Long	
1985	2,798	141,970	40,824
1988	1,133	105,845	75,366
1990	906	95,245	80,870
		Dong Thap	
1976	60,000	110,839	0
1981	10,000	80,000	0
1990	20	15,000	60,000
		Hau Giang	
1982	17,900	320,517	27,378
1985	3,700	296,242	56,100
1988	1,284	252,068	71,287
1990	804	210,830	104,323
		An Giang	
1976	2,500	152,692	31,509
1980	210	145,875	79,066
1985	5	83,964	97,632
1990	0	37,347	141,210
		Beu Tre	
1976	10,000	83,975	0
1980	71	54,834	3,500
1985	62	63,133	19,160
1990	0	53,420	23,536

Varietal tolerance for yellow stem borer. Twenty deepwater and tidal wetlands rice cultivars were evaluated by artificial infestation in a controlled water pond. One set of plots was infested with 5-d-old, unparasitized YSB egg masses at the rate of three egg masses per nine hills. The acceptable level of YSB resistance was set at less than 5% yield loss in infested plots. Tidal wetlands rice cultivar Datarangi and the DWR advanced breeding line Habiganj Aman II-HR48 were selected as YSB-resistant lines. Both were also resistant in 1991.

Tabio 12. Rice entries with different susceptibility reactions to ufra. Bangladesh Rice Research Institute (BRRI), 1991.

Materials and source	Rice entries[a] (no.)						
	HR	R	MR	MS	S	HS	Total
DWR, BRRI	0	0	3	91	89	100	238
IRUN, IRRI	0	2	7	7	9	13	38
F_3, IRRI	0	6	3	0	5	13	27
Other BRRI rice	0	10	18	4	16	143	191

[a]HR = no stem infestation, R = 1-20% stem infestation, MR = 21-40% stem infestation, MS = 41-60% stem infestation, S = 61-80% stem infestation, HS = 81-100% stem infestation. IRUN = International Rice Ufra Nursery.

Screening entries for ufra resistance. Resistance to the ufra nematode was assessed in 384 DWR varieties and breeding lines, including 38 entries from the International Rice Ufra Nursery (IRUN) and 27 selected F_3 populations from IRRI. Screening and scoring followed the standard procedure specified in the IRUN field book. Eighteen were found resistant and 31 moderately resistant (Table 12). Four entries (IR59239, IR63188, IR63225, and IR63226) had R-MR reaction (1-40% stem infestation) both in F_2 and F_3.

Effect of leaf cutting on ufra incidence and yield. Farmers in many areas of Bangladesh traditionally cut leaves and terminal stems of DWR at the elongation stage. We investigated the efficiency of this practice in reducing ufra incidence in a deepwater pond. With cutting 2-4 times, stem infestation was less than 70% and rice yielded 0.26-0.92 t/ha; however, with 0-1 cutting, stem infestation exceeded 80% and yield decreased to 0.20 t/ha. Nematode recovery was 1-4/cut shoot. Herbage production in the leaf cut treatments was 2.2-5.8 t/ha.

Effect of silicon on susceptibility to ufra. In 1990, incorporation of calcium silicate and rice husk into the soil increased silicon content in the leaf sheath and reduced ufra infestation in a susceptible variety. A similar result was observed in 1991. Ufra infestation in treatments with calcium silicate and rice husks was 45-58% compared with 74-84% in the control.

Collaborative research with India

Management of ufra through cultural methods. An experiment to develop a suitable cropping system to reduce the stem nematode *D. angustus* population in DWR was conducted in a field subject to severe outbreak in Assam. Six DWR varieties were either direct seeded on 28 M[illegible].91 or transplanted on 4 Jun 1991. The percentage of ufra-infested tillers averaged 73.8% in the direct sown crops and 12.5% in the transplanted crops.

Screening deepwater rice for ufra resistance. At the test site in Assam, high ufra damage had caused total DWR failure during successive seasons. Of 19 entries, RDA-B-Sel, RDA14, RDA3, RDA-16-06-1-2, and RDA-B-Sel-7 had less than 9% infestation, compared with more than 95% in the susceptible checks Neghiri and Rangabao.

Stem borer tolerance. There are no stem borer-resistant varieties. This experiment in Assam tested tolerance for infestation under field conditions. Twenty DWR varieties either were protected by spraying with monocrotophos at 15-d intervals after transplanting until the late elongation stage, or were left unprotected. Dissection of the stems at maturity showed a relatively low level of infestation. Sprayed plants averaged 16% infested stems and unsprayed plants 23.8%. Sprayed entries had no significant difference in infestation, but in the unsprayed plots the variety Herepi had the lowest infestation at 14.6% and Amana the highest at 33%. Average yields over the 20 varieties were 2.6 t/ha for the sprayed plants, and 2.0 t/ha for the unsprayed plants.

Studies on DWR in Orissa indicated some varietal differences in tolerance for stem borer. Application of phosphamidon to late-planted DWR at the boot leaf stage increased yield from 0.8 t to 1.1 t/ha.

Rice-fish culture. Fingerlings of the common carp (*Cyprinus carpio*) were released on 28 May 1991 at 1/m^2 into plots transplanted on 15 May with DWR Maguri. Treatments were DWR alone, with fish, and with fish plus feed supplements. Fish were harvested in mid-November. The highest fish production was 1,596 kg/ha with supplement of rice bran plus mustard oil cake. Without supplement the fish yield was 1,200 kg/ha Grain yields were 2.7

t/ha without fish and 3.1 t/ha with fish. The net return was $42/ha for rice alone, $820/ha for rice + fish, and $916 for rice + fish + supplement.

Conclusion and next steps

In 1992, research on DWR lands will focus on building the strength of the program through enhanced collaboration with NARS. The program appeared to be seriously weakened by reduction in DWR plant breeding input, but adjustments have been made within IRRI and good progress is being made by Thailand in strengthening its breeding program to undertake much of the responsibility for Southeast Asia. These efforts will be supported by the other national programs, particularly in Cambodia, India, and Vietnam. Collaborative research on IPM in DWR will be expanded in eastern India during 1992. The Indian Council of Agricultural Research has already approved funding for an enlarged IPM project following the success of our joint project with the Asian Development Bank for strengthening research on IPM in Uttar Pradesh, Assam, Bihar, and Orissa.

Subprogram II: Improved productivity and sustainability of tidal wetland rice

Soil-related stresses are predominant in tidal wetlands. Productivity will be improved by appropriate combination of tolerance genes of traditional varieties and water management technologies that reduce stress.

Improved germplasm and management for tidal wetland rice

The project aims to conduct prebreeding and soil and water management research that will help NARS develop better varieties and management technologies for tidal wetlands.

Salinity

Mass screening. Salinity constrains high yields in many tidal wetlands. Using salt-tolerant rices will increase present yields and expand cultivated areas. A total of 2,136 breeding lines and accessions of the International Rice Germplasm Center were screened in the greenhouse using Maahas clay salinized to electrical conductivity (EC) 10 dS/m with NaCl. Highly tolerant types identified were included in IRRI's hybridization block for crossing purposes.

Genetic components of salinity tolerance. Genetic components of salinity tolerance in rice were investigated by a nine-parent complete diallel crossing of susceptible (IR28, IR29, and M1-48), moderately tolerant (IR4595-4-1-13, IR9884-54-3-1E-P1, and IR10206-29-2-1), and tolerant (Nona Bokra, Pokkali, and SR26B) parents. Two-week-old seedlings were grown in salinized (EC = 12 dS/m) culture solution under controlled conditions at the IRRI phytotron. After 19 d, when susceptible varieties were severely affected, shoots of all entries were analyzed for Na and K.

Some susceptible parents absorbed less Na^+, and thus were classified as moderately tolerant. Some tolerant parents could be classified as moderately tolerant and vice versa. However, no susceptible variety could be reclassified as tolerant, nor a tolerant variety as susceptible. The same trend was observed with K^+ absorption. However, for the Na:K ratio, classification as susceptible, moderately tolerant, and tolerant was clearly delineated and could be used as a valid criterion in measuring salinity tolerance.

Table 13 presents the estimated genetic components of variation and proportional values. Additive and dominance components and environmental effects showed significant influences. These revealed the complexity of salt tolerance. Low Na:K ratio in the shoot is controlled both by additive and dominance gene effects. Two groups of genes were found

Table 13. Estimates of genetic parameters for Na:K ratio in 9 × 9 diallel crosses.

Genetic parameters	Estimate ± SE[a]
(D) Additive effect	0.0014 ± 0.0002*
(H) Dominance effect	
H_1	0.0016 ± 0.0005*
H_2	0.0007 ± 0.0004[ns]
h^2	0.0011 ± 0.0003*
(F) Gene distribution	0.0019 ± 0.0005*
(E) Environmental effects	0.0006 ± 0.0001*
	Proportional values
$(h_1/D)^{1/2}$ Mean degree of dominance	1.0701
(h_2/H_2) Number of gene groups which control tolerance and exhibit dominance	1.6273
(h_{ns}) Heritability narrow sense	0.1918

[a]* = significant, ns = not significant.

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to control tolerance and exhibit dominance. The first group may control the Na^+ exclusion and the other K^+ absorption. The mean degree of dominance is within the range of overdominance, i.e., some hybrids are more tolerant than their parents.

The extensive environmental influence and low heritability (19.18%) suggest that salt-tolerant phenotypes selected in an early generation may not be tolerant in subsequent generations.

Analysis of variance of combining ability estimates showed highly significant difference in general combining ability (GCA) and reciprocal effects and significant difference (at 5%) for specific combining ability (SCA) effects. Also, the influence of additive gene action in the inheritance of salinity tolerance was more significant than nonadditive gene action.

Among the varieties tested, IR4595-4-1-13 was the best combiner. IR9884-54-3-1E-P1, Pokkali, IR29, and Nona Bokra were good combiners, exhibiting high, desirable negative GCA values. M1-48, a susceptible parent, was an extremely poor combiner, showing very high, undesirable positive GCA values. The best combiners will produce salt-tolerant progenies when crossed with other varieties. However, the highly significant reciprocal effects suggest, that IR29 must be the male and Nona Bokra the female parent in the hybridization program to improve their combining abilities.

The SCA effect values showed that the best combination, IR9884-54-3-1E-P1/IR4595-4-1-13, exhibited high, desirable negative SCA values. Other good specific combinations were IR9884-54-3-1E-P1/IR29, Nona Bokra/IR28, SR26B/IR28, SR26B/Pokkali, and Pokkali/IR29. Significant reciprocal effects for SCA imply that the male and female parent must be selected correctly. For the first two best combinations, low reciprocal effect values suggest that the choice of male and female parent is not important. However, for the three other identified best specific combiners, susceptible varieties (IR28 and IR29) must be used as males and tolerant varieties (Pokkali and SR26B) must be used as females to obtain a better hybrid. These significant heterotic effects suggest good potential for developing salt-tolerant hybrid rices.

These findings have implications for breeding salt-tolerant rice varieties: 1) parents must be chosen carefully, 2) a wide range of early generation breeding materials must be available, 3) selection for tolerance must be delayed to generations when unpredictable gene effects are dissipated, and 4) environmental variables must be minimized during the development of hybrids.

Improved donors for salt tolerance. Among the several thousand varieties and breeding lines screened for salt tolerance, traditional varieties Cheriviruppu, Nona Bokra, and Pokkali are the most tolerant. These varieties, however, are of poor plant type, are susceptible to pests and diseases, are photoperiod sensitive, and have poor grain quality. Hybrids with them rarely produce desirable genotypes and previous attempts to transfer their salt tolerance to an improved plant type have been unsuccessful.

In 1987, we crossed IR28, a semidwarf, high-yielding, salt-sensitive variety with Nona Bokra. Segregating generations were evaluated by planting 2-wk-old seedlings on salinized culture solution (EC 12 dS/m obtained by 1:1 of NaCl and $CaCl_2$) for 6 wk in the phytotron. Using the parents as checks, plants that exhibited high levels of salt tolerance were selected, and shoot samples were taken for Na analysis. The plants were then grown to maturity on normal soil. Individuals with low Na content and good plant type at maturity were selected to establish the next generation. We used the pedigree method to isolate by the F_7 generation six agronomically uniform lines with improved plant type. These lines' salt tolerance was studied in depth during the 1991 dry season. We grew 2-wk-old seedlings on salinized culture solution (EC 10 dS/m) for 6 wk in the phytotron, with IR28 and Nona Bokra as checks. There were three replications and each replication had five plants per test entry. We measured seedling height, shoot weight, root weight, and Na and K content of shoots and roots at the end of the salinization period.

All the new lines show a level of vegetative phase salt tolerance comparable with or better than that of Nona Bokra. Reduced seedling height and root weight due to salinity in the new lines was less than in Nona Bokra (Table 14). The Na:K in shoots and roots showed that some lines possess greater tolerance than Nona Bokra. The new lines, as in the case of Nona Bokra, retained most of the absorbed Na in the roots.

Five of the six lines were tested for yield under stress conditions in the phytotron by growing on salinized (EC 10 dS/m) sand culture from the 21-d-old seedling stage to maturity. There were four

Table 14. Effect of salinity on seedling height, shoot weight, root weight, and shoot Na:K of improved salt-tolerant donors and their parents. IRRI, 1991 DS.

Designation	Percent increase or decrease (–)			
	Seedling ht	Shoot wt	Root wt	Shoot Na:K
IR63731-1-1-1-1-2	–5.0	–7.2	–21.8	108
IR63731-1-1-1-4-3	–8.1	–8.2	–28.0	83
IR63731-1-1-3-3-2	–5.3	–8.1	–20.2	84
IR63731-1-1-4-2-3	–3.7	–7.1	–27.4	55
IR63731-1-1-4-3-2	–7.1	–3.4	–17.8	176
IR63731-3-5-14-1-2	–7.6	–2.6	–19.4	104
IR28	–6.7	–23.7	–44.4	433
Nona Bokra	–13.8	1.8	–36.1	136

Table 15. Some agronomic characteristics and yields of photoperiod-sensitive lines or varieties grown under tidal wetland conditions in San Jose, Pampanga, Philippines, 1990-91.

Designation	Culm ht (cm)	Lodging (%)	Tolerance for		Yield (t/ha)
			Submergence	Salinity	
Bg 407	109	0	9	3	4.7 a
IR39537-4-2-2-3	67	0	9	9	4.6 a
Wagwag (check)	137	100	9	9	4.2 a
IR37260-6-1-1-1-6-1	106	0	9	3	3.6 b

replications, and each entry had five plants per replication. Due to space limitations, plants were spaced at 9 x 9 cm. IR28 and Nona Bokra were the checks. Results confirmed that the new lines possess a salt tolerance level equal to or higher than that of Nona Bokra. Grain yield per plant from Nona Bokra was 57% higher from Nona Bokra than from IR28. For the improved lines the increase ranged from 47% in IR63731-1-1-3-3-2 to 157% in IR63731-1-1-4-3-2. The results also revealed that salt tolerance and modern plant type characteristics can be combined. These lines will be included in INGER's International Rice Salinity Tolerance Observational Nursery beginning in 1992.

Photoperiod-sensitive varieties. Tidal wetlands of northern Luzon, Philippines, are planted to photoperiod-sensitive traditional varieties. Three improved photoperiod-sensitive varieties (two from IRRI and one from Sri Lanka) and the popular Philippine variety Wagwag were evaluated in a farmer's field in San Jose, Pampanga, northern Luzon. The test site represents moderately saline tidal wetlands. Following farmer practices, only N (25 kg/ha) was added at maximum tillering. Because of heavy rains and flash floods, salinity did not affect the test. Test entries did not significantly outyield Wagwag (Table 15). Moreover, the level of photoperiod sensitivity of IR lines was inadequate to suit local climate conditions. Bg 407 had the same level of sensitivity as Wagwag and greenhouse tests showed it to be more tolerant than Wagwag. Bg 407 was therefore selected for multilocation farmer field tests.

Acidity

Multiple stresses occurring in acid soils include Fe toxicity, P deficiency, and K deficiency. We conducted experiments on acid soils in farmers' fields in San Dionisio, Iloilo, and Pangil, Laguna. The San Dionisio site is rainfed acid lowland (pH 4.3, 2.1% active Fe, 1.5 ppm available P, nil exchangeable K). The fields receive a lateral flow of Fe from the highly weathered highland. In Pangil, Laguna, the fields are irrigable, and the soil is acidic and P deficient (pH 4.3, 2 ppm available P).

Growth-limiting factors. A split-plot experiment with fertilizer (NPK, NP, NK) in the main plots and variety (14 cultivars) in the subplots was conducted in San Dionisio. K deficiency proved to be the growth-limiting factor in rice: 1) visual symptoms correlated with K content of plant tissue at 8 wk after

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Table 16. Means of different variables of fertilizer treatment in an acid soil at San Dionisio (Tropaquult) deficient in K and P.

Fertilizer treatment	Deficiency score	Content in plant					Grain yield (t/ha)
		Mn (ppm)	Fe (ppm)	P (%)	K (%)	P:K	
NPK	4.3 ab	145 a	317 a	0.225 a	1.51 a	0.16 ab	2.0 a
NP	4.7 a	155 a	359 a	0.272 a	0.99 c	0.40 a	1.4 b
NK	3.8 b	146 a	310 a	0.287 a	2.18 a	0.14 b	1.8 a

Table 17. Some agronomic characteristics and grain yields of Fe toxicity-tolerant lines under acid soil conditions. San Dionisio, Iloilo, Philippines, 1990-91.

Designation	Maturity (d)	Culm ht (cm)	Fe toxicity score	Yield (t/ha)	Yield (kg/d)
IR24637-38-2-2-1	113	71	3	4.2 a	37
IR74 (check 1)	130	50	3	3.7 ab	29
IR31361-8-3-2-2	136	97	2	3.4 abc	25
IR53649-AC3	125	74	5	2.9 bc	24
Mahsuri (check 2)	136	90	3	2.7 cd	20
IR31432-7-2	123	71	5	2.6 cde	21
IR8192-200-3-3-1-1	125	66	5	1.9 def	15
IR29137-16-1-6	125	50	7	1.9 efg	15
IR31376-1-2-1-1	162	75	2	1.6 fg	10
IR37260-6-1-1-1-6-1	162	77	3	1.5 fg	9
IR9764-45-2-2	160	65	7	1.4 fg	9
IR51485-AC1-6	161	75	3	1.0 g	6

transplanting; plant K decreased when only N and P were applied, and 3) grain yield was significantly lower without K (Table 16). An antagonistic relationship between K and P is suggested: plant K content is higher when K is applied singly than when it is combined with P. The P:K ratio in plant tissue correlated negatively with grain yield. K deficiency must be corrected before P is applied.

Yield trial. Ten advanced breeding lines identified in previous tests as tolerant of P deficiency and Fe toxicity were evaluated for yield in San Dionisio. IR72 and Mahsuri were used as checks. The trial was fertilized with 50 kg N/ha (urea), but no P or K was added. IR24637-38-2-2-1 outyielded Mahsuri and was comparable with IR74 (Table 17). Under rainfed conditions, however, its yield per day is higher than that of either Mahsuri or IR74. IR24637-38-2-2-1 was selected for distribution to NARS.

P deficiency. A P-deficient, lowland, irrigated soil in Pangil, Laguna, was used to identify P-efficient varieties for the hybridization program. During the year, 32 rices were tested without P and with 25 kg P/ha added. IR64, IR74, IR37873-16-2-3, and IR41996-118-2-1 yielded more than 3 t/ha whether or not P was applied.

Generation of breeding materials

In 1991 we produced 50 advanced breeding lines for acid and acid sulfate soils, and 40 for saline soils. They were given to collaborating NARS (India, Indonesia, Sri Lanka, Thailand, and Vietnam) for evaluation and selection at their key sites.

Future plans

Prebreeding research related to soil stresses will be continued. For salinity tests, we will attempt to develop a simple screening method for Na exclusion. We will investigate the salinity tolerance mechanism of newly developed lines, initiate research on the submergence tolerance mechanism, and continue to generate breeding materials for the use of NARS. In collaboration with NARS, we will perform experiments to establish an understanding of processes in acid and acid sulfate soils associated with different water regimes.

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Cross-ecosystems research

Many issues affecting rice production and productivity are ecosystem-neutral or cut across several types of ecosystems. The Cross-ecosystems Research Program meets the challenges provided by these issues by fielding critical masses of scientists in projects that focus on upstream research and accelerate the application of new concepts and tools to rice research and issue resolution. The objectives of the program are to 1) use and/or develop modern scientific tools, methods, and knowledge for addressing current and anticipated rice production problems common to several ecosystems at different levels of integration, and 2) develop promising technologies that might be derived from more basic research available to national programs.

In 1991, we further sharpened our focus by adopting thrusts in the following subprograms: germplasm evaluation; genome manipulation; ecosystem characterization and impact analysis; pest science and management; plant, soil, water, and nutrient process; and rice grain and seed quality, and postharvest and biomass issues.

Characterization of traditional varieties and wild rice species is a prerequisite to sustained rice improvement across ecosystems. Research was done on 1) evaluation methods, systematic evaluation, and analysis of the behavior of genes identified; 2) coordination and analysis of evaluation data; and 3) the supply of germplasm and related information to collaborators associated with the international program on germplasm conservation dissemination. Classification of conserved germplasm was improved in 1991 by incorporating isozyme profiles into the International Rice Germplasm Center (IRGC) data base. The data can now allow choice of germplasm for breeding purposes, which represent broad genetic diversity. The International Rice Genealogy Data Base (IRGDB) was completed, with 3,600 varieties and 100,000 crossing records, and is now available for routine user queries. Screening work showed that two *Oryza* species from Africa, *O. glaberrima* and *O. barthii*, exhibited severe necrosis, and may offer a source of genes for immunity from rice tungro disease (RTD).

Manipulation of the rice genome has long been a major focus of IRRI research. New techniques being developed in this program should allow relatively more rapid, precise manipulation of plant genomes. Further application of these techniques to rice will speed the development of improved rice varieties in all ecosystems. In 1991, new hybrids were produced through embryo rescue using *Oryza sativa* and eight wild species. The hybrids will be useful in breeding for resistance to yellow stem borer (YSB) and RTD. Progress was also made in marker-assisted selection when we tagged a recessive gene, *xa-5*, for bacterial blight (BB) resistance with three markers. The program also introduced new molecular marker technology to IRRI through the use of random amplified polymorphic DNA (RAPD), which allows more rapid gene tagging than restriction fragment length polymorphism (RFLP). Further progress was made in transforming and regenerating indica rice.

Since optimization of nutrient and water management is a key issue in many rice-producing systems, special attention is focused on processes that determine water and nutrient availability in the soil, uptake by the plant, and the utilization of water and these nutrients by the crop. In 1991, we further developed root gas transport and rhizosphere chemistry models and documented the software. Results show that rice rhizosphere conditions greatly influence N transport to absorbing root surfaces.

Pests—insects, weeds, pathogens, rodents, birds, and nematodes—continue to threaten the stability of rice production. In 1991, we emphasized strategic research needed to develop technologies for implementing integrated pest management (IPM) as an economically efficient and environmentally sound approach to pest control. Research was on the etiology, biology, and population dynamics of pests and predators, and on pest-rice interactions. We completed the first exhaustive study of arthropod community structures in rice ecosystems and showed that pest populations are more resilient to insecticide interferences than are predators. Several new diseases were studied, such as the leaf yellowing symptom in Vietnam. Strain differences in the rice tungro bacilliform virus (RTBV) were evaluated for their contribution to symptom expression. Using RFLP analysis, we ascertained that host diversity did not always result in diversity of the BB pathogen. Within the program, we have also quantified the relative importance of leaf-feeding insects at different rice growth stages and showed that early applications of insecticides against these insects may lead to destruction of predators of other insects. Models of the population dynamics of key pests such as brown planthopper (BPH) and blast (Bl) were further validated in 1991 for use as tools to delineate zones of high risk for these pests. In addition, the effects of BPH and Bl on yield were successfully simulated by two rice models.

Several aspects of rice grain quality were studied in 1991. A core collection of germplasm from IRGC was analyzed for amylose, gel consistency, alkali spreading value, glutelin, and waxy gene protein. Eleven wild rice species used in wide hybridization were found to be similar to cultivated rice in amylose, alkali spreading value, and lysine levels in protein.

Our activities in ecosystem characterization led to completion of mesolevel analyses in East India for upland and rainfed lowland systems. A sample survey procedure was also initiated in East India for pest characterization using correspondence analyses. Simulation models were used in conjunction with geographic information systems (GIS) to define yield reductions in a Philippine province. The link between characterization and impact analysis and research prioritization was further strengthened by these case studies. The long-term socioeconomic and environmental impact of new rice technologies reflects the value of rice research to society. Research conducted in 1991 aimed to 1) develop new methodologies for impact assessment, 2) promote their empirical application, and 3) synthesize their results. The focus was on ex ante impact assessment for effective research planning or prioritization. We initiated the development of country and global rice supply-demand-trade models for technology impact assessment, medium- and long-term projections, and policy analysis. A workshop was conducted to stimulate activities for more formal methods of research prioritization at national and international levels. The world rice statistics data base was updated with assistance from national programs and was published for wide dissemination. The program was also a major sponsor of the international symposium Systems Approaches for Agricultural Development, held in Thailand, in December 1991.

Subprogram I: Germplasm evaluation

To sustain rice research for crop improvement over diverse ecosystems, conserved germplasm of rice cultivars and wild relatives must be evaluated for useful agronomic traits. This subprogram's activities will 1) streamline and accelerate the evaluation of IRRI's conserved germplasm for important traits, 2) develop new methods of evaluation, and 3) make information from evaluations more easily available to users via improved electronic communication hardware and software. In 1991, evaluation activities became more focused on desired traits in specific rice-growing environments and on the needs of national systems.

Evaluation of conserved germplasm

Efficient use of IRRI's germplasm collection

In recent years, we have used different approaches to provide scientists with sets of germplasm specific to their needs. Special purpose collections with the breadth of genetic diversity of the entire collection or which are known or believed to have one or more valuable traits have been prepared. Previously, we had limited evaluation data from sites other than IRRI. To use the research consortia sites with their ecological conditions, we prepared small nursery sets of about 100 accessions that can be used for efficient evaluation of the conserved germplasm. We have used past data to choose varieties that are genetically diverse and are thought to have some traits that may suit them to the conditions of the consortia sites (Table 1).

Improved classification of unimproved germplasm

Accurate classification of rices into their principal varietal groups is essential to help germplasm users such as plant breeders and scientists conserve the germplasm. Morphoagronomic characteristics do not provide data accurate enough to use as a basis for varietal classification. Consequently, we have used isozyme classification to consolidate past information on more than 2,000 accessions into the central data base and we are adding to this information.

Specific sets of conserved germplasm for which passport data are available are being analyzed. We have focused on varieties from Sumatra, where one new consortium site is located. So far, 153 varieties have been analyzed. These varieties can be evaluated for various traits at the site.

Furthermore, in collaboration with scientists from the National Institute of Agricultural Sciences in Vietnam, we have been analyzing the varietal diversity of germplasm from villages in northwest Vietnam to obtain a better understanding of the relationship between varietal diversity, ethnic group, and cultural type (Table 2). Such detailed information is expected to be helpful for national agricultural research systems (NARS) and IRRI outreach scientists working on varietal improvement in the hill regions of Southeast Asia.

Table 1. Example of one unimproved germplasm nursery set for the acid uplands.

Trait	Descriptor state	Accessions (no.)
Varietal group based on isozymes	Indica	46
	Japonica	40
	Intermediate	6
	Unclassified	4
Region of origin	Africa	19
	South Asia	6
	Southeast Asia	54
	East Asia	1
	America	15
	Unknown	1
Maturity (d)	<100	3
	101-119	34
	120-139	24
	>140	35
Culm length (range, in cm)	64-164	96
Plant height (range, in cm)	85-195	96
Panicle length (range, in cm)	18-32	96

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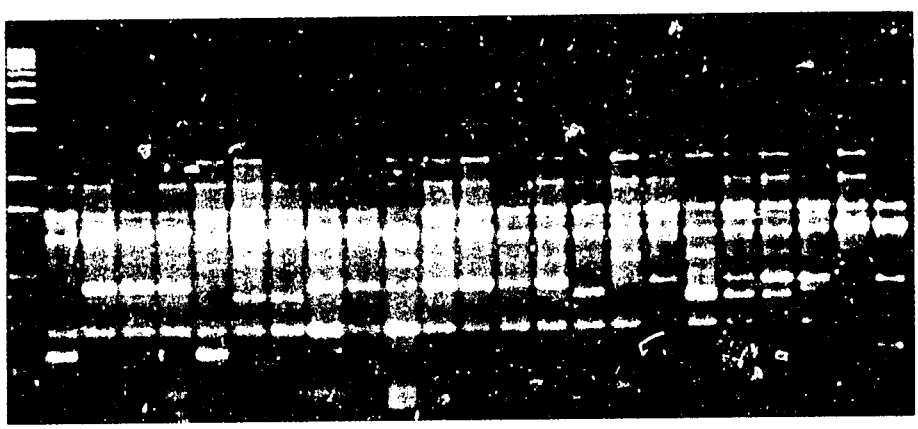
Table 2. Classification and quality of varieties from Sothan Village, northwest Vietnam.[a]

Variety	Cultural type	Isozyme group[b]	Varietal group[c]	Seed coat color	Amylose content (%)
Ble Te	Upland	VI	J	Red	20.6
Ble La	Rainfed	I	I	White	25.8
Ble Blau	Rainfed	I	I	White	3.1
Blau Tan	Upland	VI	J	White	2.6
Blau Blau	Rainfed	VI	J	White	0.9
Talensoi	Rainfed I	i	I	White	17.4
Blau Bla	Rainfed (deepwater)	NC	NC	White	1.5

[a]Sothan Village is inhabited by Hmong people and is at 1,175 m above msL. [b]Glaszmann 1985. [c]J = japonica, I = indica, NC = not classifiable.



1. Random amplified polymorphic DNA bands as observed from a set of *O. sativa* cultivars. At the extreme left is a 1 kb-ladder molecular weight marker.

Molecular evaluation of germplasm diversity

When scored over many loci and analyzed with multivariate statistical methods, deoxyribonucleic acid (DNA) polymorphism gives a representation of the diversity of germplasm's genetic background. This information is important for designing sampling strategies for the conservation, evaluation, and utilization of germplasm, particularly with respect to molecular marker-aided selection. We used two sets of cultivars in our study:

- 250 accessions as a representative subset of the world collection for *O. sativa*; and
- 250 accessions to represent successful rice varieties and elite lines along with their ultimate parents and donors of resistance or tolerance for stresses, pests, and diseases as well as other characteristics.

Most of the accessions have been analyzed for 15 isozyme loci. Analysis of these accessions for 30 mapped RFLP probes is nearly completed.

We are using another type of molecular marker for evaluating rice diversity, the RAPD, using polymerase chain reaction technology (Fig. 1). We are testing the potential of this technique over a representative subset of 70 varieties already analyzed for 15 isozyme loci and 61 RFLP probes (including 4 mitochondrial DNA probes). Ten different primers have been used and 20 additional primers are being scored. Results look very promising and a setup for a larger scale analysis is underway.

Screening wild collections for tungro resistance

Wild species of rice may have some useful genes for resistance to RTD. Thus, to systematically screen the wild relatives of rice for RTD resistance, we selected a core collection of 263 accessions, representing the genetic and geographic diversity in the genus *Oryza*. Out of 263 accessions in a core collection, 157 accessions belonging to 19 species had been evaluated by the end of 1991 (Table 3).

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Table 3. Reactions of wild rice accessions to rice tungro disease (RTD) viruses.[a]

Species	Genome	Tested (no.)	Accessions (no.) resistant to		
			RTBV+RTSV	RTBV	RTSV
O. brachyantha	FF	5	1	0	4
O. sativa complex					
O. nivara	AA	38	0	0	6
O. rufipogon	AA	6	0	0	0
Natural hybrids	AA	25	0	0	4
O. glaberrima	AA	4	0	0	0
O. barthii	AA	6	0	0	0
O. meridionalis	AA	2	0	0	0
O. ridleyi complex					
O. longiglumis	Tetraploid	3	0	1	0
O. ridleyi	Tetraploid	5	0	2	0
O. officinalis complex					
O. officinalis	CC	15	2	2	3
O. rhizomatis	CC	6	1	0	0
O. eichingeri	CC	5	0	0	2
O. malampuzhaensis	BBCC	3	0	0	1
O. minuta	BBCC	13	0	0	5
O. punctata	BB, BBCC	7	0	0	2
O. latifolia	CCDD	5	0	1	1
O. alta	CCDD	3	0	2	0
O. grandiglumis	CCDD	2	0	0	0
O. australiensis	EE	4	0	0	2
Total		157	4	8	30

[a]RTBV = rice tungro bacilliform virus. RTSV = rice tungro spherical virus.

Eleven-day-old seedlings were inoculated with viruliferous green leafhopper (GLH) adults at 10 insects/plant for 4 h. Leaves were individually sampled 2-3 wk after inoculation (WAI) to test by enzyme-linked immunosorbent assay (ELISA) for RTBV and rice tungro spherical virus (RTSV) infection. The accessions resistant to any virus particle were determined from data for more than 10 plants.

Although RTSV resistance is important in preventing the spread of RTD, RTBV resistance would be a more effective control because it would prevent symptoms from developing in plants. In the *O. sativa* complex, *O. nivara* and natural hybrids were resistant to RTSV, but no accession was resistant to RTBV infection. Twelve accessions, which were not infected by RTBV either alone or with RTSV, were tested for antibiosis to GLH (Table 4). Either a 10-d-old seedling or a leaf tip of an adult plant from each accession was placed in a test tube with five GLH nymphs (second instar); the procedure was replicated 10 times. Antibiosis of each accession was graded as high, moderate, and low by counting the surviving GLH nymphs every day for 3 d. Accessions that were not infected with RTBV showed a low infection rate with RTSV, except *O. longiglumis* (IRGC 105146). One accession of *O. brachyantha* (IRGC 100115), two *O. officinalis* (IRGC 105100, 105365), and one *O. rhizomatis* (103421) were not infected by either RTBV or RTSV (Table 4). The accessions resistant to RTBV infection showed a high level of antibiosis to GLH. Thus, it is difficult to distinguish the resistance to virus infection from the resistance to the vector. To overcome this problem, we are trying to inoculate RTD viruses using another vector, *N. nigropictus*.

Necrosis caused by tungro viruses. In 1990, we found that all four *O. glaberrima* accessions (Table 3) showed severe systemic necrosis 2-3 WAI and few plants survived 3 WAI. This is distinct from normal symptoms of RTD observed in susceptible populations of other species, which show stunting, yellow-orange discoloration, and reduced tillering. Necrosis of the *O. glaberrima* plants could be used as the indicator of RTD infection. To confirm whether the necrosis caused by RTD is species-specific, 100 accessions of *O. glaberrima* were selected at random and evaluated. Fifty-six accessions of *O. barthii*, the close wild relative of *O. glaberrima*, were also evaluated for necrosis. Most showed necrosis either uniformly or segregating. Three accessions of *O. glaberrima* and two of *O. barthii* accessions did not show systemic necrosis.

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Table 4. Reaction of RTBV-resistant wild rices to RTSV infection and antibiosis to green leafhopper (GLH).

Species	IRGC acc. no.	Country of origin	Plants tested (no.)	RTSV infection (%)	Antibiosis to GLH[a]
O. brachyantha	100115	Guinea	29	0	H
O. longiglumis	105146	Indonesia	24	33	H
O. ridleyi	100821	(unknown)	11	9	H
	101453	Malaysia	30	3	-
O. officinalis	104672	Malaysia	20	5	H
	105100	Brunei	28	0	H
	105365	Thailand	41	0	H
	105376	Thailand	29	3	M
O. latifolia	105139	Guatemala	25	4	H
O. alta	100967	Surinam	19	10	H
	105685	Brazil	29	11	H
O. rhizomatis	103421	Sri Lanka	18	0	-

[a]H = high level of antibiosis, M = moderate level, – = not tested.

Table 5. Accessions originating from selected Asian countries and showing resistance to 6 races of bacterial blight (BB).[a]

Country	Accessions[b] showing resistance											
	PXO61		PXO86		PXO79		PXO71		PXO112		PXO99	
	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Laos	25	2	14	1	29	3	9	1	81	8	0	0
Cambodia	4	7	19	3	2	0	0	0	34	5	2	0
Vietnam	15	1	37	4	8	1	13	2	82	8	1	0
Total	44		70		39		22		197		3	

[a]Isolates were PXO61 (race 1), PXO86 (race 2), PXO79 (race 3), PXO71 (race 4), PXO112 (race 5), PXO99 (race 6). [b]Percentage of resistant accessions based on total screened.

Therefore, this necrosis is considered to be a specific indicator only in *O. glaberrima* and *O. barthii*. We have been trying to introduce this characteristic into the susceptible check variety TN1 by backcrossing. To date our most advanced generation is BC_3F_1. To clarify the inheritance of this necrosis, we crossed *O. glaberrima* accessions with and without necrosis.

Screening for resistance to bacterial blight

During the past few years, IRRI has conducted an extensive collaborative research program with Asian countries particularly Laos, Cambodia, and Vietnam. Since no information is available on BB resistance of traditional cultivars originating from those areas, germplasm evaluation was carried out at IRRI. Among the 2,847 entries screened, 1,060 were from Laos, 724 from Cambodia, and 1,063 from Vietnam. The entries were sown in food keepers and transplanted on plastic trays with 12 hills per entry. IR8, IR20, IR1545-339, DV85, and Cas 209 served as checks. Plants were inoculated at maximum tillering stage using six Philippine races of *Xanthomonas oryzae* pv. *oryzae*. Percentage of leaf area infected was taken 14 d after inoculation. Most of the cultivars identified as resistant were resistant to race 5, followed by races 2 and 1 (Table 5). Testing of selected cultivars with resistance to BB will be carried out in the collaborating countries through their NARS.

Blast resistance of wild *Oryza* species

To evaluate the potential of wild relatives of rice as sources of Bl resistance genes, 14 wild species of *Oryza* were tested under artificial and field conditions. Accessions from eight of the species screened showed high levels of resistance or immunity to

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isolate PO6-6, while accessions from seven species showed resistance to the inocula preser ; the IRRI Bl nursery (Table 6). The accessions that showed resistance to race PO6-6 were not always the same as those found resistant in the Bl nursery, suggesting that some of the resistance genes are race-specific.

The frequency of resistance among accessions of the different species varied widely. While all 42 tested accessions of *O. minuta* were resistant to both race PO6-6 and the inocula in the IRRI Bl nursery, only one of the 18 tested accessions of *O. rufipogon* was found to be resistant. Further, the scores of individual plants of some accessions of *O. nivara* and *O. ridleyi* varied from highly susceptible to highly resistant, suggesting that segregation for a major resistance gene was occurring within the subpopulation represented by those accessions.

Prioritizing germplasm screening

IRRI has 44 morphological tests and 37 tests for genetic evaluation and utilization (GEU) traits, all of which potentially could be applied in the germplasm bank of some 85,000 accessions. Thus, the potential work load is a matrix of 6,885,000 tests and observations to be made on each accession. Therefore, a system must be developed for prioritizing germplasm evaluation.

Priorities for screening are set in consonance with activities of scientists specializing in individual traits, and in consideration of broader foci, such as cultural rice types and national needs.

Priorities will be based on recommendations for scheduling which are determined by the suitable combinations of germplasm to be screened, tests to be used, and countries to be emphasized. Demand for screening results may be trait-driven, trait- or cultural type-driven, or country-driven.

To set proper priorities, the following should be assessed:

- traits and germplasm already screened,
- interest in screening results by country,
- trait-based needs and screening methods available,
- cultural type(s) of accessions in the germplasm bank,
- hot spots of the problem of interest,
- screening needs for special purpose collections, and
- logistics.

In 1991, we conducted a study of priority setting using the first three items on the list.

Traits and germplasm screened in 1991. We started to construct a table listing IRGC screening results averaged by country and trait. This allowed us to identify several parameters.

- The proportion of materials screened by trait (Table 7). The coverage of traits is a result of past priorities and, presumably, level of difficulty and cost of the test. Soil-related stresses are covered in a relatively shallow manner, while disease and insect resistance have been searched extensively.

Table 6. Levels of wild rice resistance to blast.

Species	Accessions tested (no.)	Accessions (no.) with given reaction[a]							
		Isolate PO6-6				Blast Nursery			
		R	S	MR/MS	Seg	R	S	MR/MS	Seg
O. alta	1		1						1
O. australiensis	4		4				4		
O. barthii	4	2	2			3	1		
O. brachyantha	1	1				1			
O. grandiglumis	1			1				1	
O. latifolia	3	2	1			1			
O. longistaminata	1		1				1		
O. minuta	42	42				42			
O. nivara	9	5	2	1	1	3	2		3
O. officinalis	1	1				1			
O. perennis	6	1	2	2	1	3		2	1
O. ridleyi	2	1			1				
O. rufipogon	18	1	4	1		1	14	3	

[a]R = resistant, S = susceptible, MR/MS = moderately resistant or moderately susceptible, Seg = segregating.

Table 7. Germplasm bank entries tested for genetic evaluation and utilization (GEU) traits.

Trait[a]	Sample size[b]	Tested	
		no.	%
BL	78,228	36,634	47
BB	78,367	49,752	63
SHB	78,128	23,088	30
RTD	76,928	15,795	21
RTD SS	74,798	4,473	6
RGSV1	77,437	8,376	11
RGSV2	32,623	366	1
RRSV	76,802	13,759	18
BPH1	78,226	44,335	57
BPH2	76,697	10,053	13
BPH3	77,461	13,021	17
WBPH	78,344	52,042	66
GLH	78,350	50,137	64
ZLH	73,347	2,756	4
SBYD	76,416	15,656	20
SBSD	75,037	6,881	9
RLF	76,397	8,115	11
RWM	77,775	22,949	30
PRTD	78,146	17,587	23
PRTW	77,700	13,631	18
AMY	78,124	32,691	42
GEL	78,037	29,904	38
ALK	73,049	2,693	4
SAL	73,734	8,095	11
ZNC1	75,185	964	1
ZNC2	55,604	120	0
CT	76,511	6,671	9
DRT1	78,223	34,500	44
DRT2	78,222	24,432	31
DRT3	78,141	16,738	21
DRT4	78,222	28,319	36
DRT5	78,155	22,873	29
DRT6	77,825	11,648	15
DRT7	77,750	7,250	9
DRT8	77,710	6,742	9
DRT9	77,710	6,742	9
ELON	75,185	1,221	2
FLOD	77,257	18,216	24

[a]BL = blast, BB = bacterial blight, SHB = sheath blight, RTD = tungro, RTD SS = tungro severity score, RGSV1 and 2 = rice grassy stunt virus 1 and 2, RRSV = rice ragged stunt virus, BPH 1-3 = brown planthopper biotypes 1-3, WBPH = whitebacked planthopper, GLH = green leafhopper, ZLH = zigzag leafhopper, SBYD = yellow stem borer, SBSD = striped stem borer, RLF = rice leaffolder, RWM = rice whorl maggot, PRTD = protein dry season; PRTW = protein, wet season; AMY = amylose, GEL = gelatinization temperature, ALK = alkalinity, SAL = salinity, ZNC1 = zinc deficiency (field test), ZNC2 = zinc deficiency (greenhouse screening), CT = cold tolerance, DRT1-DRT9 = drought score 1-9, ELON = elongation, FLOD = flooding. [b]Some sample sizes not wholly reported.

Table 8. Average number of GEU tests done per entry for major contributing countries.[a]

Country	Tests (no.)	Country	Tests (no.)
India	10	Japan	8
Indonesia	10	Myanmar	8
Bangladesh	10	Malaysia	7
Pakistan	10	Vietnam	7
Philippines	9	Nepal	6
Liberia	9	Thailand	5
Laos	9	Taiwan, China	5
USA	9	China	4
Sri Lanka	9		

[a]Those which contributed more than 1,000 entries to the germplasm bank.

- The degree of "coverage" by country, expressed as average number of screening results per accession (Table 8). Clearly, materials from countries such as Bangladesh and India have been more thoroughly searched for traits of interest than materials from China and Thailand. A major challenge is to achieve wider coverage of some important potential donors of favorable traits.
- Some countries with a high proportion of accessions with favorable expression of each trait (Table 9). Clearly, Bangladesh and India are the two single most "rich" countries in terms of their high proportion of favorable scores. Fuller and more systematic exploration of germplasm from these countries appears justified.

Next steps

Since the initiation of this project, personnel changes have affected the scope and range of activities. We have undertaken a review of the project to determine research priorities for the next couple of years. Specifically, the research effort in Los Baños for screening resistance to rice Bl will be reduced. We shall seek ways of increasing screening for Bl and other biotic stresses in collaboration with the NARS at "hot spot" sites. We intend to allocate more resources to germplasm data base development, and to expand activities related to the study of germplasm diversity.

Subprogram II: Genome manipulation

During 1991, research in genome manipulation focused on 1) saturating the genetic map, 2) developing and characterizing novel aneuploid stocks,

Table 9. Two major countries with the highest percentage of favorable[a] entries for each trait.

Trait[b]	Countries
BL	Ivory Coast, Liberia
BB	Bangladesh, Philippines
SHB	Senegal, Liberia
BPH1	Sri Lanka, Senegal
BPH2	Sri Lanka, India
BPH3	Indonesia, Sri Lanka
WBPH	Pakistan, Nepal
GLH	Bangladesh, Senegal
RLF	Sri Lanka, Bangladesh
RWM	Vietnam, Senegal
ALK	Bangladesh, India
SAL	China, Vietnam
CT	USSR, Brazil
DRT2	Myanmar, Sierra Leone
DRT3	Thailand, Cambodia
DRT4	Ivory Coast, Bangladesh
DRT5	USA; Taiwan, China
DRT6	Brazil, Bangladesh
DRT7	USA; Taiwan, China
DRT8	USA; Vietnam
DRT9	Bangladesh, India
ELON	Bangladesh, China
FLOD	Nepal, India

[a]With scores of 1-3. [b]For legend, see Table 7.

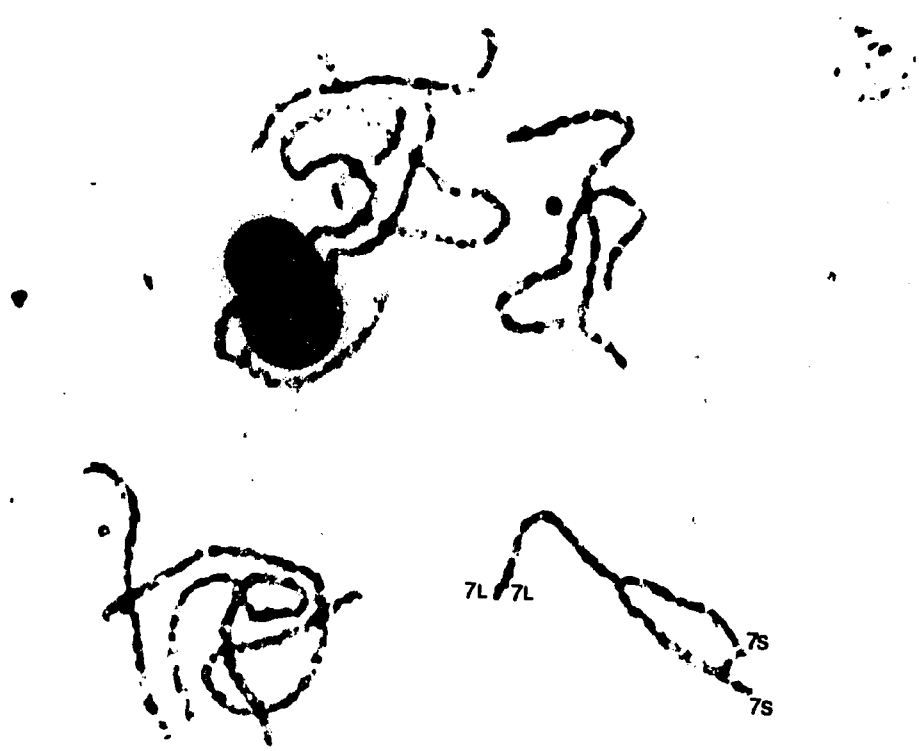
3) finding isozyme loci, 4) tagging genes with molecular markers, 5) widening the gene pool by developing new interspecific hybrids and alien gene transfer, 6) evaluating homozygous lines developed through anther culture from segregating populations, and 7) regenerating plants from protoplasts of both japonica and indica rices.

Saturated genetic maps

To facilitate marker-based selection, we aim to saturate the genetic map and to tag genes governing economic traits. Research in 1991 involved developing and characterizing novel aneuploid stocks, mapping isozyme loci, tagging genes for BB resistance with molecular markers, and RFLP survey of parents to develop populations for tagging genes governing economic traits.

Development and characterization of novel aneuploid stocks

We continued our efforts to complete the novel aneuploid stock (secondary trisomic) series. On the



2. Pachytene chromosome configuration in a secondary trisomic plant (2n + 7s.7s).

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basis of morphological and cytological characteristics, 18 secondary trisomics have been identified. Of these, 14 have been characterized based on pachytene chromosome configurations (Fig. 2).

The F_1, F_2, and BC populations derived from crosses of secondary trisomics with 25 mutant markers and isozyme tester stocks representing 15 loci are being analyzed to locate genes on specific arms of rice chromosomes.

Chromosomal location of isozyme loci

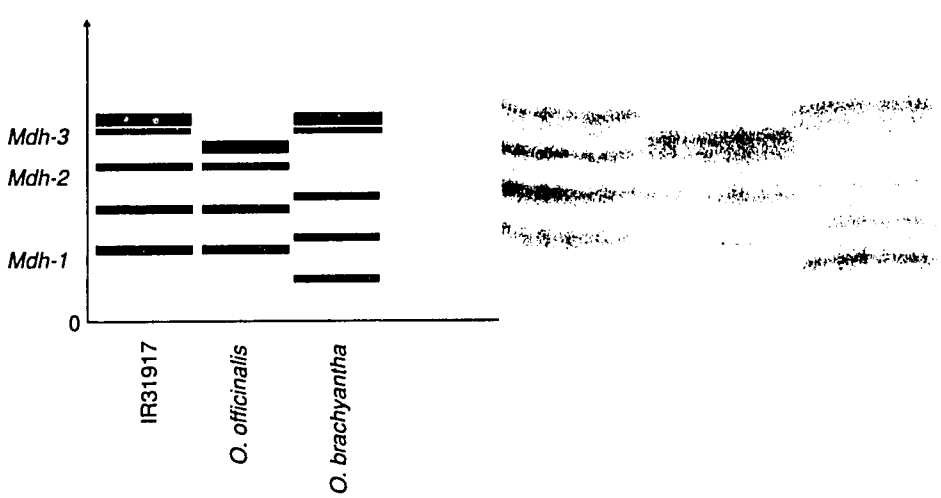
We continued our efforts to identify new isozyme loci and their sites on rice chromosomes. Two enzymes, malate dehydrogenase (MDH) and phosphogluconate dehydrogenase (PGD), were analyzed. Three Mdh isozyme banding patterns were found in *O. sativa* (*Mdh-1*, *Mdh-2*[(1)], and *Mdh-3*); however, none showed allozymic variability in 30 representative isozyme tester stocks of rice. We therefore surveyed wild species for allozymic variations using starch gel electrophoretic procedures. Polymorphism was detected between rice and wild species for three loci: *Mdh-1*, *Mdh-2*[(1)], *Mdh-3* (Table 10). Three mobility patterns for *Mdh-1* and two each for *Mdh-2* and *Mdh-3* were identified among cultivated and wild species (Fig. 3). Contrasting alleles between cultivated rice and wild species were identified for *Mdh-1* in *O. nivara*, *O. brachyantha*, and *O. minuta*. *Mdh-2* was polymorphic only in *O. brachyantha*, and *Mdh-3* in four wild species. Polymorphism was also detected for *G6pd-1* in IR36 and Ma Hae. *G6pd-1* was found to be independent of 10 previously mapped isozyme loci (*Cat-1*, *Pgi-1*, *Pgi-2*, *Amp-1*, *Amp-2*, *Amp-3*, *Est-2*, *Pgd-1*, *Adh-1*, *Fdp-1*) representing chromosomes 2, 3, 6, 8, and 11.

The *Mdh-3* pattern was studied in 10 monosomic alien addition lines (MAALs) of *O. officinalis* and 11 of *O. latifolia* (Table 11). The allozyme pattern for *Mdh-3* in the wild species was detected only in MAAL-5 (Fig. 4), indicating the possible location of *Mdh-3* on chromosome 5 of the two species. Disomic plants homozygous for *Mdh-3* have been crossed with primary trisomic 5 to further confirm the chromosome location.

Table 10. Polymorphism for malate dehydrogenase in cultivated and wild rices.

Isozyme locus	Allele	Marker[a]
Mdh-1	Fast	IR31917-45-3-2, IR56
		O. latifolia (100914)
		O. officinalis (100896)
		O. australiensis (100882)
	Intermediate	*O. brachyantha* (101232)
	Slow	*O. minuta* (101141)
Mdh-2[(1)]	Fast	IR31917-45-3-2, IR56
		O. australiensis (100882)
		O. latifolia (100914)
		O. officinalis (100896)
	Slow	*O. brachyantha* (101232)
Mdh-3	Fast	IR31917-45-3-2, IR56
		O. brachyantha (101232)
	Slow	*O. minuta* (101141)
		O. officinalis (100896)
		O. latifolia (100914)
		O. australiensis (100882)

[a]Accession no. is in parentheses.



3. Zymogram showing malate dehydrogenase (MDH) polymorphism in cultivated and wild species of rice.

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Similarly, analysis of MAALs of *O. officinalis*, *O. latifolia*, and *O. brachyantha* for *Pgd-2* showed an allozyme of wild species only in MAAL-6 (Table 11, Fig. 5). Thus, *Pgd-2* is located on chromosome 6. We have initiated experiments to use isoelectric focusing technique to map additional isozyme loci on rice chromosomes.

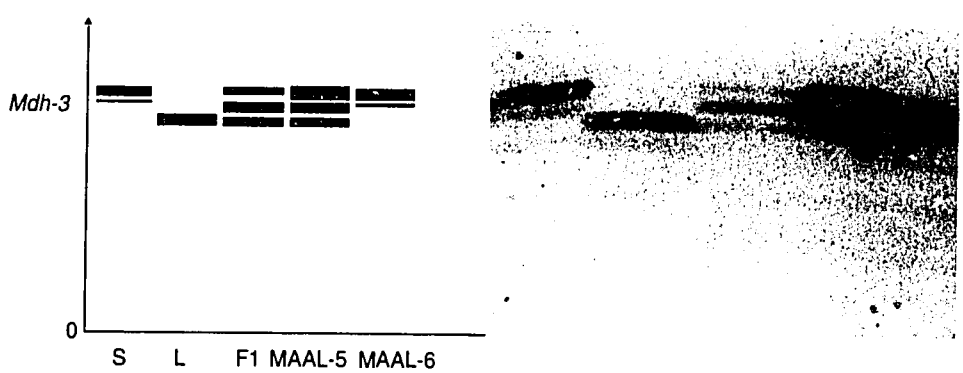
RFLP MAPPING POPULATION

The interspecific RFLP mapping population (120 plants of *O. sativa*/*O. longistaminata* BC_1) was received from Cornell University and is being maintained at IRRI. This population was originally tested for 200 RFLP markers by the Institut Français de la Recherche Scientifique pour le Développement en Coopération (ORSTOM), in collaboration with Cornell University where a total of about 500 markers have been mapped.

The mapping population will allow us to verify the location of markers, especially for multiple copy clones, and facilitate the location of RAPD markers. Fresh or dried leaves will be distributed to interested collaborators for use in genetic mapping. We are using both non-radioactive (digoxigenin) and radioactive (^{32}P) labeling techniques for RFLP analysis.

DNA LIBRARY

A library of more than 300 DNA markers is maintained for use in genome mapping and for distribution to collaborators in rice-growing Asian countries. All clones are originally received as plasmid and are transformed into *Escherichia coli* for long-term storage at –80 °C. Clones are amplified either in the bacterial host or via polymerase chain reaction for Southern hybridization. The plasmids are multiplied for distribution to collaborators in NARS.



4. Gene dosage for *Mdh-3* in a critical MAAL-5 of *O. latifolia*. S = *O. sativa* (IR31917-45-3-2), L = *O. latifolia*.

Table 11. Chromosomal location of *Mdh-3* and *Pgd-2* using MAALs[a] of wild species.

	Mdh-3		*Pgd-2*		
MAAL	*O. officinalis* (Acc. 100896)	*O. latifolia* (Acc. 100914)	*O. officinalis* (Acc. 100896)	*O. latifolia* (Acc. 100914)	*O. brachyantha* (Acc. 101232)
1	na	–	na	–	na
2	–	–	–	–	na
3	na	na	na	na	na
4	–	–	–	–	–
5	+	+	–	–	na
6	–	–	+	+	+
7	–	–	–	–	–
8	–	–	–	–	na
9	–	–	–	–	–
10	–	–	–	–	–
11	–	–	–	–	–
12	–	–	–	–	–

[a]Monosomic alien addition lines. + = critical, – = noncritical, na = not available.

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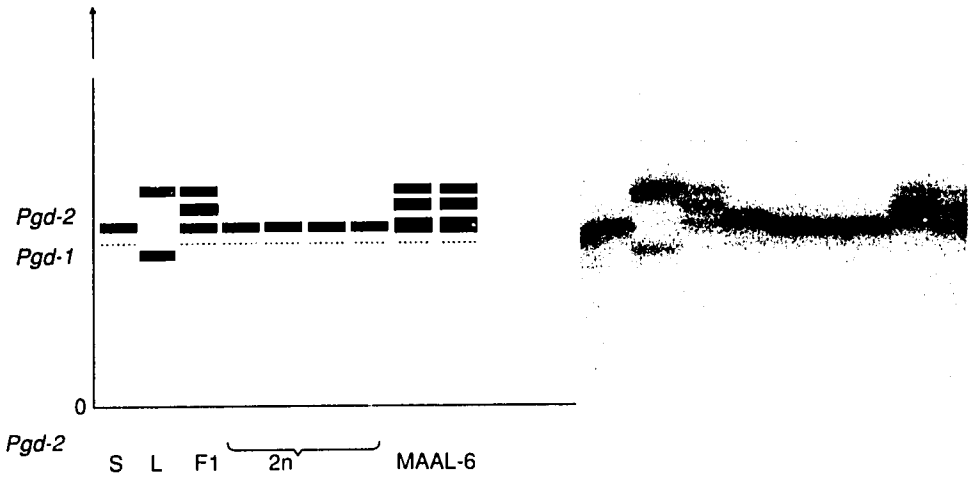


5. Gene dosage for *Pgd-2* in a critical MAAL-6 of *O. latifolia*. *S* = *O. sativa* (IR31917-45-3-2), L = *O. latifolia*.

During 1991, 108 clones were distributed to laboratories in Asia.

Tagging genes for bacterial blight resistance

The availability of a molecular genetic map of rice paves the way for research to detect linkage between molecular markers and genes that govern agronomically important characters. Tagging genes for BB resistance with molecular markers such as RFLPs will facilitate breeding efforts aimed at developing more durable forms of resistance.

We have identified molecular markers linked to two genes for resistance to BB. The recessive gene *xa-5* was tagged with three RFLP markers and *Xa-10* was linked to two RFLP markers and two RAPD markers. Figure 6 shows linkage of RFLP markers (RG207) with *xa-5*. This work was conducted in collaboration with Cornell University, USA, and Kyushu University, Japan.

A subset of 100 mapped RFLP markers was used to survey the genomes of the resistant isoline (IRBB-5), the resistant donor (IR1545-339), and the susceptible recurrent parent (IR24). Eight independent chromosomal segments were detected that had been introgressed from the donor variety into the background of IR24 during isoline construction.

An F_2 population was developed from a cross between IR24 and IRBB-5. F_2 individuals were evaluated phenotypically for resistance or susceptibility to BB. The disease reaction was determined by evaluation of lesion length following inoculation with race 1 using the clipping method. We performed RFLP analysis on 36 individuals from this F_2 population. Markers in all eight regions that showed donor introgression in the IRBB-5 isoline were tested for cosegregation with resistant and susceptible phenotypes. Tight linkage was detected between *xa-5* and three RFLP markers (RG207, RG556, and RZ390) located at the top of linkage group 5 (Fig. 6).

6. Autoradiogram showing confirmation of linkage between RG207 and *xa-5*-resistant phenotype. Lanes 1 and 24 = Lambda/*Hind* III size marker; lane 2 = IR24, the susceptible recurrent parent; lane 3 = IRBB-5, the resistant isoline containing *xa-5*; lane 4 = IR1545-339, the resistant donor; lanes 5-14 = resistant phenotypes; lanes 15-23 = susceptible phenotypes from F_2 population derived from a cross between IR24 and IRBB-5.

Previous studies based on trisomic analysis had shown that *xa-5* belonged to linkage group 5 and was also linked to the morphological marker, *spl-7*. This suggests that the three molecular markers and *spl-7* are linked, clarifying the relative orientation of the classical genetic map and the RFLP map with regard to this linkage group.

Larger F_2 populations are being examined to establish accurately the map distance between the marker and the resistance gene. Markers in introgressed segments unlinked to the resistance gene will be used to eliminate extraneous donor-derived chromosomal segments from the IRBB-5 differential line. Breeding efforts are being initiated using marker-aided selection for this recessive gene. The markers save a generation of progeny testing by allowing detection of heterozygotes containing *xa-5* (which cannot be accomplished by phenotypic screening). Further, in an effort to increase the durability of resistance, *xa-5* can be combined with broad-spectrum BB resistance genes because the tightly linked markers allow accurate assessment of genotype even when phenotypes are not distinguishable. To increase the selection efficiency for breeding disease-resistant cultivars, we are continuing our research to tag additional genes with the molecular markers.

RFLP SURVEY OF *O. LONGISTAMINATA* GERMPLASM

A dominant gene (*Xa-21*) for resistance to BB was initially identified in an *O. longistaminata* accession (#12156-1) in the collection maintained at the Central Rice Research Institute in Cuttack, India. This gene provides broad-spectrum resistance to six Philippine races of *Xanthomonas oryzae* and all known races of the pathogen in India. Earlier, *Xa-21* was introgressed into IR24 background, and derivatives were used to locate the gene via linkage to RFLP markers.

In an effort to identify an accession that did not contain *Xa-21*, 12 *O. longistaminata* accessions were planted in the screenhouse and inoculated with race 6 of *X. oryzae*. An *O. longistaminata* accession susceptible to *X. oryzae* would allow the development of a population segregating for the character, and could be used in efforts to construct a physical map of the region. Such a cross would be more likely to embody high levels of recombination around *Xa-21* than crosses with cultivated rice. Results showed that all 12 accessions examined were highly resistant to race 6, suggesting that *Xa-21* is common in *O. longistaminata* germplasm. After hybridizing the probes mapped to chromosome 11, RFLP analysis showed polymorphism between *O. sativa* and *O. longistaminata*. Similarly, polymorphism was detected among different accessions of *O. longistaminata*.

RFLP SURVEY OF TUNGRO-RESISTANT GERMPLASM

Six RTD-resistant varieties and two susceptible varieties were evaluated for polymorphism using RFLPs to select a parental combination for gene tagging. Thirty-seven RFLP markers were selected, considering their distribution throughout the genome.

The parental combinations showing the most polymorphisms were ARC11554 and Pankhari 203 in combination with either of the susceptible varieties (Table 12). These combinations showed 70-87% polymorphism with probes tested, while the other populations showed 13.6-54.5% polymorphism.

TN1 was selected as the susceptible parent of choice because the susceptible reaction is clearer than with IR22. ARC11554 was selected as the resistant parent of choice because it has resistance to both RTSV and RTBV as well as a moderate level of resistance to the GLH vector. Pankhari 203 contains

Table 12. Polymorphism between tungro-susceptible varieties TN1 and IR22, and 6 resistant varieties, based on a survey of 37 RFLP[a] markers.

Variety	Polymorphism (%)					
	ARC11554	Balimao Putih	Pankhari 203	Kataribhog	Utri Merah	Utri Rajapan
TN1	87.5	16.6	75.0	36.0	13.6	16.6
IR22	70.0	54.0	75.6	54.5	51.7	35.0

[a]Restriction fragment length polymorphism.

only one major gene (*Glh-1*) for resistance to the vector.

Near-isogenic lines as well as segregating populations are being developed for subsequent RFLP analysis. Both RFLPs and RAPDs will be used to locate the genes that confer RTD resistance.

RFLP survey of doubled haploid (DH) lines

Pureline seed was produced from a population of DH lines for genetic mapping. The population was derived from a cross between the indica variety IR64 and the tropical japonica variety Azucena. A large amount of transgressive variation was observed for a range of characters such as plant height, leaf width, leaf color, presence of awns, etc. Future work will be aimed at identifying genes associated with transgression for different characters.

To recover the original DH genotypes, seed derived from the original tissue-cultured plants was obtained and multiplied under controlled conditions in the phytotron. Observations on base color, leaf aroma, leaf width, plant height, stem growth habit, grain shape and color, sterility, and presence of awns were recorded to rapidly identify original genotypes in heterogeneous lines. The observations will be complemented by genetic fingerprint data provided by isozyme, RFLP, and RAPD analyses.

Some of the DH lines were highly sterile. Of 189 lines that were bagged, 76 produced more than 100 seeds, 96 produced 15-100 seeds, 9 lines produced less than 10 seeds, and 8 lines did not have any filled grain. Lines that produced no seed or had low seed set were ratooned and bagged to harvest more seeds.

As a basis for genetic mapping of this population, 74 RFLP markers were surveyed in the parents. Polymorphism was detected for 70% of the probes, using the enzymes *Dra* I, *Eco*RV, *Xba*I, *Sca*I, and *Hind*III. Three different libraries are represented in the clones surveyed and the percent polymorphism for each group of clones is summarized in Table 13.

The results suggest that the library of rice genomic clones is more effective in detecting polymorphism between varieties of cultivated rice than are the libraries of rice cDNA and oat cDNA clones (Table 13). One explanation for this is that the rice genomic clones were mapped based on polymorphism detected in an intraspecific (indica/japonica) cross, while the rice cDNA and oat cDNA clones were mapped based on an interspecific cross (*O. sativa*/*O. longistaminata*). Therefore, most of the rice genomic clones lie in regions that are polymorphic in cultivated rice, while many of the rice cDNA and oat cDNA clones lie in regions that are monomorphic in cultivated rice but demonstrate polymorphism between AA genome species.

Preliminary field studies of the DH populations based on upland drought screening trials showed clear segregation for terminal, seedling-stage drought stress. These populations are being screened using an aeroponic system to tag genes for root traits.

Novel genetic variation

The project objectives are to widen the rice gene pool by creating novel genetic variation through wide hybridization and to develop true breeding homozygous lines through anther culture from segregating populations generated for various ecosystems. In 1991, we produced hybrids between cultivated and wild species of rice, transferred BB resistance from wild species, diversified cytoplasm by developing a new cytoplasmic male sterile (CMS) line, characterized introgression through isozyme and RFLP analyses, evaluated anther culture-derived lines, and regenerated from protoplasts of japonica and indica rice plants for use in transformation research.

Genomic relationship

To understand the homology between different species and to determine the possibility of recombination and alien gene transfer, it is important to know the genomic relationship. Wild species of *Oryza* have 2n = 24 or 48 chromosomes and represent different genomes; AA, BB, BBCC, CC, CCDD, EE, and FF. The genomic constitution of species such as *O. granulata*, *O. meyeriana*, *O. ridleyi*, and *O. longiglumis* is

Table 13. Percent polymorphism between indica variety IR64 and tropical japonica variety Azucena for rice clones derived from 3 libraries.

Library[a]	Clones showing polymorphism		
	Total	no.	%
RG	36	27	81
RZ	28	15	54
CDO	10	6	60

[a]RG = rice genomic, RZ = rice cDNA, CDO = oat cDNA.

unknown. We studied the genomic relationship of *O. ridleyi* and *O. longiglumis* on the basis of chromosome pairing in the F_1 hybrid. Both *O. ridleyi* and *O. longiglumis* are tetraploid species (2n = 48).

The F_1 hybrid was produced between *O. longiglumis* (Acc. no. 100974) and *O. ridleyi* (Acc. no. 101453) following embryo rescue. Meiotic analysis of *O. longiglumis* showed 61.5% of the cells with 24 II and 5.2% of cells with a ring of four chromosomes. Similar behavior was observed in *O. ridleyi* (Table 14). The ring of four chromosomes indicates the presence of a reciprocal translocation. The F_1 hybrid showed predominantly 24 II (74.2% of cells) and one or two rings of four chromosomes in 3.7 and 3.3% of cells, respectively. The presence of two rings of four chromosomes in the hybrid indicates that the chromosomes involved in the translocations in two parents are different.

The occurrence of 24 II in the hybrid shows that the genomes of *O. ridleyi* and *O. longiglumis* are identical. Meiotic analysis of F_1 (*O. sativa*/*O. ridleyi*) showed 36 I indicating that *sativa* and *ridleyi* genomes are different. Additional crosses of *O. ridleyi* have been made with other species to determine the genomic relationship.

Interspecific hybrids through embryo rescue

To widen the rice gene pool and for transfer of useful alien genes, we have produced hybrids of rice varieties with five wild species (Table 15). In these cross-combinations, 14,173 rice florets pollinated by five wild species gave 1,226 seeds. The average seed set was 8.6%. From the cross-combinations, 172 hybrid plants were produced through embryo rescue (Fig. 7). The hybrids were produced specifically to transfer genes for RTD tolerance from *O. officinalis* (Acc. no. 105220) and *O. latifolia* (Acc. no. 105141, Acc. no. 105142), YSB and RTD tolerance from *O. ridleyi* (Acc. no. 100821), and BB resistance from *O. eichingeri*; and to determine the genomic constitution of *O. ridleyi* and *O. granulata*.

Immature embryos from different cross-combinations were excised 10-14 d after pollination. They were cultured on 1/4 Murashige and Skoog (MS) medium and incubated in the dark (25 + 1 °C) until germination. The seedlings were kept in the light-incubated room up to three-leaf stage and transferred to soil after growing in liquid culture medium for 10 d. The hybrid nature of some of the plants was confirmed from pollen mother cell analysis. In general, the hybrids were morphologically intermediate between the parents and were male sterile. The hybrids are being maintained and multiplied through tiller propagation. We have produced BC_1 plants through embryo rescue from crosses of IR42/*O. eichingeri*, IR31917-45-3-2/*O. rhizomatis*, and IR31917-45-3-2/*O. granulata*. We now have interspecific hybrids involving rice elite breeding lines or varieties with 12 wild species representing genomes other than AA.

Alien gene transfer

The genes for resistance to race 6 of BB have successfully been transferred from *O. australiensis* (2n = 24 EE) into an elite breeding line (IR31917-45-3-2) of rice. Of the 8 MAALs examined, only MAAL 12 showed resistance to race 6, indicating the gene for resistance may have been introgressed from chromosome 12 of *O. australiensis*.

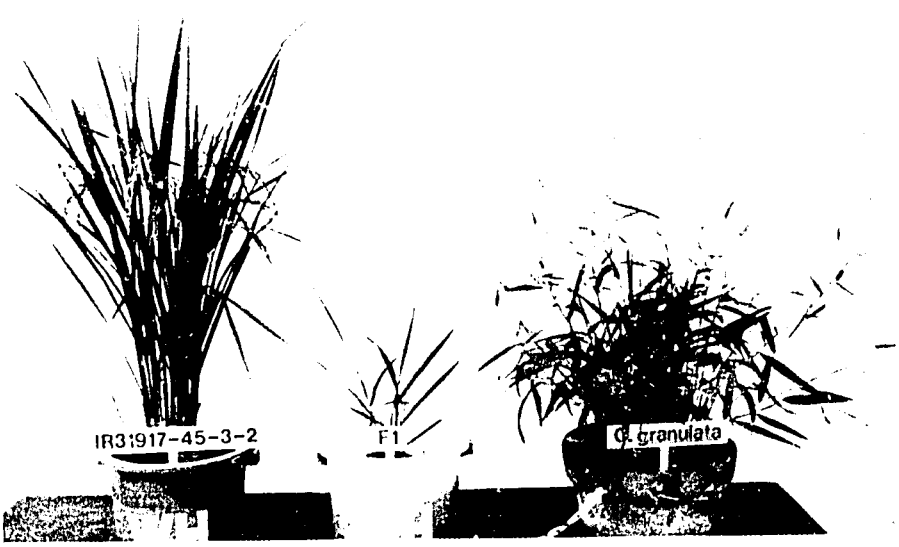
The starch gel electrophoresis technique was used to detect introgression in the wide cross-derived progenies. Introgression was detected for seven isozyme loci (*Pgi-1*, *Pgi-2*, *Pgd-2*, *Mdh-3*, *Amp-1*,

Table 14. Meiotic chromosome configurations in *O. longiglumis*, *O. ridleyi*, and *O. longiglumis*/*O. ridleyi* hybrid.

Species or F_1 hybrid	Chromosome number (2n)	Cells with given chromosome configuration										Total cells (no.)
		24 II		II + I		III + I		1IV		2IV		
		no.	%	no.	%	no.	%	no.	%	no.	%	
O. longiglumis/ (Acc. no. 100974)	48	60	61.5	30	30.9	2	2.1	5	5.2	0	0.0	97
O. ridleyi (Acc. no. 101453)	48	62	50.0	57	46.0	0	0.0	5	4.0	0	0.0	124
O. longiglumis/ *O. ridleyi* (F_1)	48	141	74.2	36	18.9	0	0.0	7	3.7	6	3.1	190

Table 15. Interspecific hybrids produced through embryo rescue between cultivated rice *O. sativa* and 5 wild *Oryza*, spp.

Hybrid-combination							
	Wild species (male)						
O. sativa (female)	Species	Genome	Accession no.	Florets pollinated (no.)	Seed set (no.)	Embryos cultured (no.)	Hybrid plants (no.)
IR64 (4n)	*O. eichingeri*	CC	105181	12	6	1	1
IR54	*O. eichingeri*	CC	101422	112	12	0	0
IR64	*O. eichingeri*	CC	101422	106	12	4	1
IR20	*O. officinalis*	CC	105220	90	30	6	1
IR22	*O. officinalis*	CC	105220	238	2	0	0
IR24	*O. officinalis*	CC	105220	416	6	0	0
IR31917-45-3-2	*O. officinalis*	CC	105220	452	10	1	0
IR70	*O. officinalis*	CC	100878	105	1	1	1
IR20	*O. latifolia*	CCDD	105141	441	64	39	25
IR22	*O. latifolia*	CCDD	105141	786	185	44	33
IR24	*O. latifolia*	CCDD	105141	1,264	173	79	36
IR31917-45-3-2	*O. latifolia*	CCDD	105141	1,745	131	49	6
IR64 (4n)	*O. latifolia*	CCDD	105141	122	2	0	0
IR20	*O. latifolia*	CCDD	105142	384	32	8	6
IR22	*O. latifolia*	CCDD	105142	294	27	5	2
IR24	*O. latifolia*	CCDD	105142	932	40	19	15
IR31917-45-3-2	*O. latifolia*	CCDD	105142	407	37	17	13
IR36 (4n)	*O. latifolia*	CCDD	105142	103	11	18	0
IR72	*O. ridleyi*	Unknown	100821	1,263	3	1	1
IR74	*O. ridleyi*	Unknown	100821	2,091	224	40	27
IR31917-45-3-2	*O. ridleyi*	Unknown	100821	1,259	128	12	1
IR56	*O. granulata*	Unknown	100879	372	42	2	0
IR31917-45-3-2	*O. granulata*	Unknown	100879	537	45	14	3
IR36 (4n)	*O. granulata*	Unknown	100879	642	3	0	0
Total				14,173	1,226	350	172



7. F_1 hybrid (center) produced from a cross of *O. sativa* IR31917-45-3-2 with *O. granulata*.

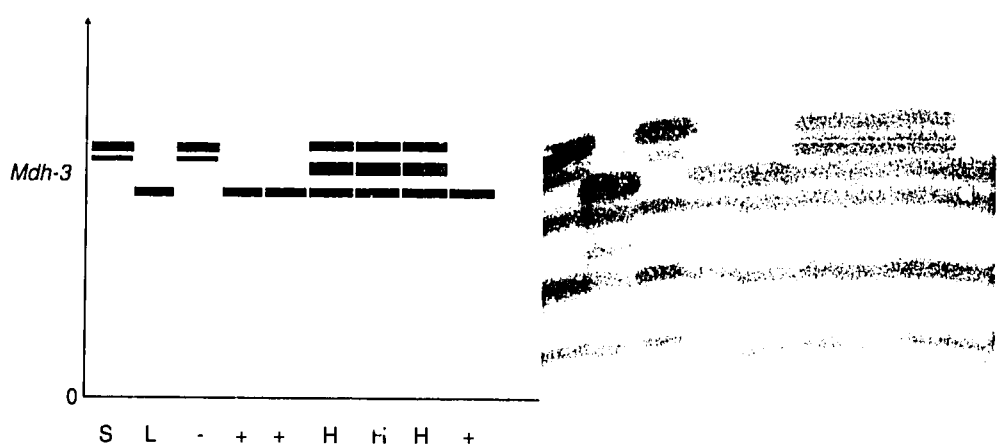
Amp-2, and *Est-5*) in the advanced generation disomic (2n = 24) progenies derived from *O. sativa*/*O. latifolia* (Fig. 8,9). Similar introgression was detected for *Sdh-1*, *Pgd-1*, *Pgd-2*, *Pgi-1*, and *Pgi-2* in disomic derivatives of *O. sativa*/*O. minuta*.

RFLP analysis of BC_2 aneuploid plants derived from the cross *O. sativa*/*O. brachyantha* showed evidence of recombination between chromosomes of AA (*O. sativa*) and FF (*O. brachyantha*) genomes, further indicating the possibility of transferring resistance to YSB from *O. brachyantha*.

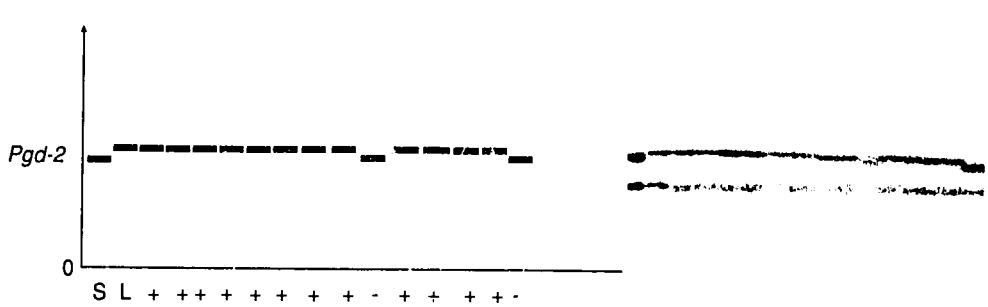
In the BPH-resistant line IR65482-4-136, derived from *O. australiensis*, RFLP analysis showed introgression for RG457 probe located on chromosome 12. We are analyzing the F_2 population to tag the BPH resistance gene introgressed from *O. australiensis*.

A NEW MALE STERILE LINE

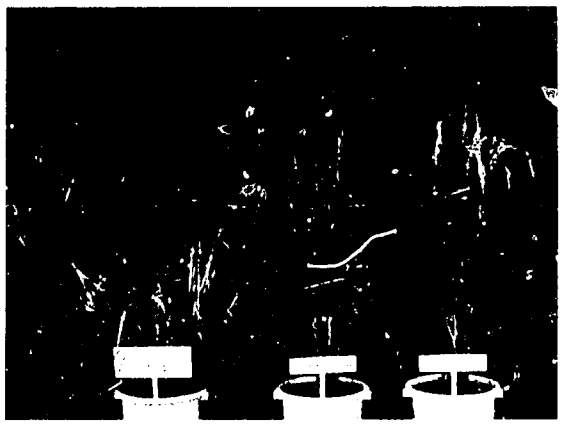
Most commercial indica hybrid rices now being cultivated have the wild abortive (WA) male sterility source. Such genetic uniformity makes hybrid rice vulnerable to diseases and insect pests. To increase the cytoplasmic diversity for male sterility, we crossed two restorers (IR54 R and IR64 R) of WA type cytoplasm with 45 accessions of *O. perennis* and 4 accessions of *O. rufipogon*. From these crosses, we have developed a new male sterile line, with the cytoplasm of *O. perennis* (Acc. no. 104823) and the nuclear background of IR64 R (Fig. 10). This line is in the BC_6 and is stable for complete male sterility (Table 16). The newly developed CMS line has been designated IR66707 A. Genetic tests show that the cytoplasm of IR66707 A is different from that of WA. After hybridization with mitochondrial DNA-specific probes, RFLP analysis indicated that the cytoplasm of *O. perennis* (donor parent) and IR66707 A show identical hybridization patterns. We are searching for restorers of this CMS line to utilize in developing hybrids.



8. Introgression for *Mdh-3* allozyme in disomic progenies derived from the cross *O. sativa*/*O. latifolia*. S = *O. sativa* (IR31917-45-3-2), L = *O. latifolia*, + = introgression, – = no introgression, H = heterozygote.



9. Introgression for *Pgd-2* allozyme in disomic progenies derived from the cross *O. sativa*/*O. latifolia*. S = *O. sativa* (IR31917-45-3-2), L = *O. latifolia*, + = introgression, – = no introgression.



10. Newly developed cytoplasmic male sterile line IR66707 A having the cytoplasm of *O. perennis* (Acc. no. 104823) and the nuclear background of IR64.

Evaluation of lines derived from anther culture

The 15th International Rice Salinity Tolerance Observational Nursery (IRSTON) was conducted in 1990 at 16 sites in East, Southeast, South, and West Asia, and the Latin American region. Results showed that anther culture lines outperformed salt-tolerant varieties and other breeding lines.

The anther culture line IR51500-AC11-1 from the cross IR5657/IR4630 has improved plant type and very good salinity tolerance at maturity stage, with an average rating of 5.7 in three locations: Hwasong and Kyehwa in Korea, and Panvel in India (Table 17). The salt-tolerant check varieties Nona Bokra and Pokkali have average salinity ratings of 6.0 and 6.5, respectively.

Anther culture lines IR51500-AC11-1, IR51500-AC11-3, and IR51500-AC9-7 have very good phenotypic acceptability; they have an average score of 4.0 in saline soils in Hwasong and Kyehwa in Korea, where the electrical conductivity is 10 dS/m.

The anther culture line IR51500-AC11-1 has a very good phenotypic acceptability score of 5.0 in alkaline soils in Dalip Nagar in India. In saline-alkaline soils in Karnal in India and in Kala Shah Kaku in Pakistan, the average phenotypic acceptability score of IR51500-AC11-1 is 6.0 compared

Table 16. Pollen fertility in different generations of a newly developed cytoplasmic male sterile (CMS) line derived by crossing *O. perennis* (Acc. no. 104823) with IR64 R.

Generation	Plants (no.)	Plants (%) with indicated pollen fertility[a]				
		CS (0%)	S (1-10%)	PS (11-30%)	PF (31-60%)	F (61-100%)
BC_6	24	100	0	0	0	0
BC_5	600	100	0	0	0	0
BC_4	29	100	0	0	0	0
BC_3	291	99	1	0	0	0
BC_2	237	84	11	3	2	0
BC_1	76	46	12	21	10	10
F_1	6	0	17	17	0	67

[a]Pollen fertility classes: CS = completely sterile, S = sterile, PS = partially sterile, PF = partially fertile, F = fertile.

Table 17. Performance of anther culture lines in saline soils, 15th International Rice Salinity Tolerance Observational Nursery (IRSTON), 1990.

Country and location	EC[a] (dS/m)	Salinity scores at maturity stage[b]			
		IR51500-AC11-1	IR51491-AC4-6	Nona Bokra	Pokkali
Korea					
Hwasong	10.0	5	5	5	6
Kyehwa, Chonbuk	10.0	5	-	-	-
India					
Panvel, Maharashtra	14.0	7	7	7	7
Average	11.3	5.7	6.0	6.0	6.5

[a]Electrical conductivity. [b]Lower numerical values indicate higher degree of tolerance for salinity.

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Table 18. Phenotypic acceptability scores of anther culture lines in saline, alkaline, and saline-alkaline soils, 15th IRSTON, 1990.

Anther culture line and check variety	Phenotypic acceptability at specified trials[a]						
	Salinity			Alkalinity (3)	Salinity-alkalinity		
	(1)	(2)	Av		(4)	(5)	Av
IR51500-AC9-7	5	3	4	7	7	7	7
IR51500-AC11-1	5	3	4	5	5	7	6
IR51500-AC11-3	5	3	4	9	5	7	6
Nona Bokra	7	7	7	5	9	9	9
Pokkali	7	7	7	5	7	7	7

[a]Lower numerical values indicate higher degree of tolerance for salinity. (1) Hwasong, Korea; (2) Kyehwa, Chonbuk, Korea; (3) Dalip Nagar, India; (4) Karnal, Haryana, India; (5) Kala Shah Kaku, Pakistan.

Table 19. Phenotypic acceptability scores of anther culture lines in acid lowland soils, 8th International Rice Acid Lowland Observational Nursery (IRALON), 1990.

Country and test location	Soil pH	Phenotypic acceptability[a]					
		0 P/ha			60 kg P/ha		
		IR51500-AC9-7	IR53649-AC3	Check variety	IR51500-AC9-7	IR53649-AC3	Check variety
Myanmar							
Myaung Mya	3.5	3	3	3	2	2	2
Indonesia							
Unit Tatas	3.8	1	3	3	1	3	3
India							
Port Blair	4.8	7	7	5	7	7	7
Average	4.0	3.7	4.3	3.7	3.3	4.0	4.0

[a]Lower numerical values indicate higher degree of tolerance for acid lowland soil.

with 9.0 for Nona Bokra and 7.0 for Pokkali (Table 18).

The anther culture lines IR51500-AC9-7 and IR53649-AC3, which were also evaluated in the 8th International Rice Acid Lowland Observational Nursery (IRALON) in 1990, performed as well as or better than the acid soil-tolerant varieties in locations in Myanmar, India, and Indonesia (Table 19). The anther culture line IR51500-AC9-7 has a phenotypic rating of 1 with two levels of P (0 and 60 kg/ha) in Unit Tatas in Indonesia.

Five anther culture lines were utilized as donor parents for breeding programs in five countries (Table 20). In Egypt, anther culture line IR51500-AC11-1 was used as a parent because of tolerance for salinity, excellent phenotypic acceptability, high yield potential, and resistance to Bl. In Thailand, two anther culture lines, IR51491 from IR4630/Pokkali and IR51500 from IR5657/IR4630, had very good phenotypic acceptability and were utilized as parents in the breeding program. For acid-lowland conditions, anther culture lines IR51500-AC9-7 and IR53649-AC3 were used as parents in the breeding program in Myanmar.

Protoplast culture and plant regeneration

Regeneration from primary callus of japonica rice. A reproducible plant regeneration system from rice protoplasts isolated from primary calli has been established for four japonica varieties: Zhonghua No. 6, Zhonghua No. 9, line 02428, and Giza 3030-21-2-3. Embryogenic calli were induced from immature embryos within 1 mo. Exposure of emerging calli to light intensity of 3000 lx for 10 d was beneficial for the formation of globular structures. Careful selection of embryogenic callus was important for the isolation of sufficient protoplasts and

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Table 20. Use of anther culture-derived lines as parents in hybridization programs in 5 countries, 15th IRSTON, 1990.

Country	Anther culture line (donor parent)	Characters selected for breeding[a]			
		Blast resistance	Phenotypic acceptability	Salinity	Yield
Bangladesh	IR51491-AC4-6	-	-	x	x
	IR51491-AC4-7	-	-	x	x
	IR51500-AC11-1	-	-	x	x
Egypt	IR51500-AC11-1	x	x	x	x
Mexico	IR51500-AC9-7	-	x	x	x
Thailand	IR51491-AC4-6	-	x	-	-
	IR51491-AC4-7	-	x	-	-
	IR51500-AC11-1	-	x	-	x
	IR51500-AC11-3	-	x	-	-
	IR51500-AC9-7	-	x	-	-
Dominican Republic	IR51500-AC11-1	-	-	-	x
	IR51500-AC11-3	-	-	-	x
	IR51500-AC9-7	-	-	-	x

[a]x refers to the parent selected for a specific character.

Table 21. Plant regeneration from protoplasts isolated from primary calli in japonica rices.

Variety	Calli (no.) transferred to regeneration medium	Calli producing plants		Regenerated plants (no.)
		no.	%	
Zhonghua no. 6	452	393	86.9	839
Zhonghua no. 9	294	158	53.7	351
02428	180	150	83.3	258
Giza 3030-21-2-3	315	306	97.1	662
Total, av	1241	1007	81.1	2110

subsequent plant regeneration. Nurse cells had to be used to sustain protoplast division and colony formation. High-frequency regeneration of protoplast-derived calli was achieved for the four varieties tested. More than 2,000 plants were regenerated (Table 21). Those grown in the screenhouse set seeds.

Regeneration from protoplasts of indica rice. *Establishment of cell suspension in IR58.* Seed-derived calli with globular embryos that were friable and off-white to pale yellow were selected for inoculation. The embryos either proliferated atop nonembryogenic calli or on the basal part of the scutellum-derived calli and grew on the callus induction medium.

Embryogenic calli inoculated in R_2 medium containing 1 g casein hydrolysate/liter (MR2) were suitable for initiation of cell suspension. Although some calli turned brown, many retained their original color after prolonged subculture. After a month in MR2, the calli became more friable. A portion of the developed, whitish friable colonies were transferred to MS medium, each liter supplemented with 2 mg 2,4-D and 1 g casein hydrolysate (MSCH2) 6 wk after initiation and were cultured thereon for 1 mo. Prolonged subculture in MSCH2 resulted in whitish and compact colonies, so part of the cell line was subcultured in medium supplemented with amino acids. After a month of subculture, the cell line became very fine and creamy yellow in color, and the cells were small (about 30 µm in diameter), round, and had active cytoplasm, typical of the embryogenic cell suspension ideal for protoplast isolation (Fig. 11a).

Protoplast isolation and culture. After incubating the suspension cells for 4-5 h in the enzyme solution, protoplasts (Fig. 11b) were collected and purified and plated onto the regeneration medium. The protoplasts started to divide 4-5 d after culture, and multicellular colonies (Fig. 11c) appeared within 2 wk. The colonies developed into microcalli and could be seen with the naked eye after 4 wk.

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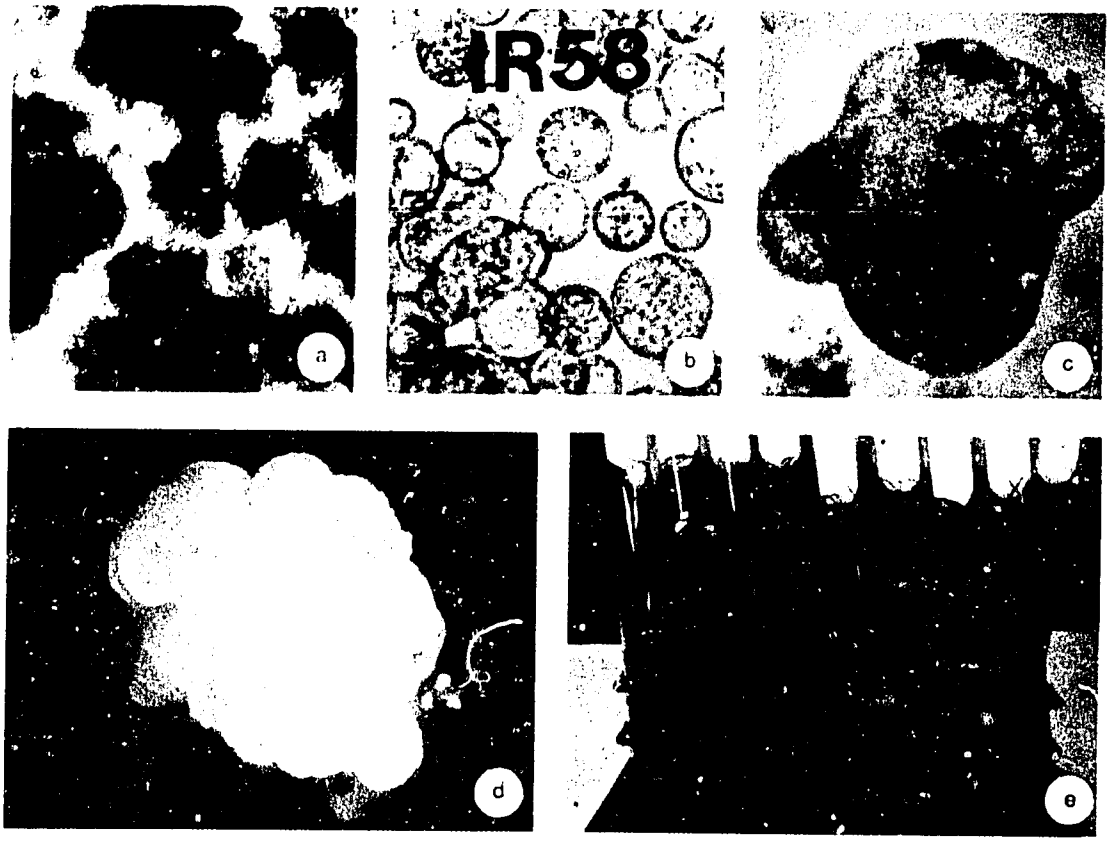

11. Plant regeneration from IR58 protoplasts. a) embryogenic cell suspension used for protoplast isolation, b) freshly isolated IR58 protoplasts, c) multicellular colonies 2 wk after plating, d) embryogenic protoplast-derived calli selected for regeneration, e) protoplast-regenerated plants.

Nurse cells increased plating efficiency, especially when using suspension cells rather than protoplasts, as nurse culture.

Plant regeneration. The protoplast-derived colonies of IR58, which proliferated in N_6 medium having 8 mg kinetin/liter, resulted in the formation of embryogenic calli (Fig. 11d). The calli were selected and plated on MS medium, each liter supplemented with 1 mg naphthalene acetic acid (NAA), 8 mg kinetin, and 30 g sucrose (M_6Ag), or in a medium (M_6MAg) similar in composition to M_6Ag, but having maltose instead of sucrose. The M_6MAg proved to be the best regeneration medium as all of the plated calli turned green in some cases. Hence, in subsequent regeneration studies, the calli were plated only on M_6MAg. More than 900 green plants have been regenerated from these experiments, with an average of 6 plants produced per responding callus.

With IR43, regeneration frequency was higher when maltose rather than sucrose was used as a carbohydrate source (Table 22). Moreover, a higher response was observed in IR43 with R_2 as the basal medium (Table 23). IR43 was more amenable to tissue culture than IR58. Selection of embryogenic protoplast-derived calli was an important step for high frequency plant regeneration in IR58. We have regenerated 3,000 plants from protoplasts of IR43 and 900 plants from IR58 protoplasts. Of these, 750 regenerated IR43 and 506 IR58 plants were grown to maturity.

Plant regeneration from protoplasts is a key factor in genetic transformation of rice. With the success in regeneration from protoplast culture of indica and japonica rices, we have intensified our efforts on protoplast-mediated DNA transformation. Preliminary experiments on transformation show transient expression for reporter genes.

Next steps

Ongoing research to develop a saturated genetic map of rice will continue. We will emphasize use of the isoelectric focusing technique to map additional

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Table 22. Effect of carbohydrate source on plant regeneration in IR43 protoplast-derived calli.[a]

Experiment	Carbohydrate source in regeneration medium[b]	Calli (no.) transferred to regeneration medium	Calli (%) showing plant regeneration	Plants (no.) per regenerating callus	Plants regenerated (no.)
Replication 1	Maltose	166	74.5	2.8	178.5
Replication 2	Sucrose	166	7.5	1.6	10.5

[a]Av of 2 replications. [b]A liter of R_2 medium was supplemented with 5 mg kinetin, 1 mg naphthalene acetic acid (NAA), 6 g agarose type 1, and 30 g of either maltose or sucrose.

Table 23. Effect of basal media on plant regeneration from IR43 protoplast-derived calli.

Basal medium[a]	Calli (no.) transferred to regeneration medium	Calli (%) showing plant generation	Plants (no.) per regenerating callus	Plants regenerated (no.)
R_2	84	70	2.8	165
N_6	84	21	2.0	37
MS	84	35	2.5	75

[a]A liter of regeneration medium was supplemented with 30 g maltose, 5 mg kinetin, 1 mg NAA, and 8 g agarose type I.

isozyme loci on rice chromosomes. We will locate centromeres on the linkage map of rice through RFLP analysis of the characterized secondary trisomics. Populations derived from crosses of secondary trisomics with mutant markers and isozyme testers will be analyzed to locate genes on specific arms of rice chromosomes. We will continue to generate and analyze plant materials for tagging genes that govern various economic traits.

To widen the rice gene pool and develop useful materials for various ecosystems, research on wide hybridization will continue. We will continue efforts to identify new cytoplasmic sources of male sterility for use in hybrid rice improvement. We will intensify use of molecular markers for monitoring alien genetic variation and tagging of alien genes introgressed from wild species into the elite breeding lines of rice. Germplasm of wild species will be screened for apomixis. Anther culture of selected materials generated for various ecosystems will be used to develop homozygous lines possessing useful traits. We will expand our research work on genetic transformation and production of transgenic rices with enhanced resistance to pests, diseases, and abiotic stresses.

Subprogram III: Ecosystem characterization and impact analysis

Biophysical and socioeconomic characterization

Rice-growing environments in Bahraich, Uttar Pradesh, India

To better understand the farming circumstances, which include important production problems and their causes, and to design appropriate solutions to the problems, we undertook a detailed study of the environmental conditions in Bahraich district at the meso level. The study was conducted in five rice-growing blocks of the district—Gilaula, Payagpur, Bisheshwar Ganj, Risia, and Fakharpur—selected by the Uttar Pradesh State Department of Agriculture. (A block is an administrative subunit of the district, covering several gram samajs. A gram samaj is a cluster of four to five villages forming one local administrative unit of a block.) Information on rice and rice environments was collected from about 10% of the gram samajs. This comprised 10-15% of the rice area in each block. Hydrological information was also collected from other parts of the district.

The study was conducted by teams of researchers from Narendra Deva University of Agriculture and

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Technology and IRRI; personnel of the Department of Agriculture at the district, block, and village levels; and groups of farmers in each village.

The teams used various Rapid Rural Appraisal, diagnostic survey, site characterization, and farming systems analytical tools and techniques in the study. The methods also included systems diagnosis (problem diagnosis), which involved key farmer informants, interviews of individuals and of farmers' groups, direct field observations and measurements, and use of secondary information. From the analysis, the following were prepared:

- At the village level:
  - agroecosystem maps (topography, hydrology, social, and enterprise maps);
  - cropping calendars and crop management practices; and
  - a list of important problems and possible solutions.
- At the district level:
  - consolidated maps of agroecological zones (hydrology, landforms, and rice culture types);
  - general rice crop management practices for each rice culture type; and
  - a list of important problems and research issues.

Site description. Bahraich district lies between 27°4' and 28°24' N and 81°3' and 82°13' E. It is bounded by Nepal in the north, Barabanki district in the south, Sitapur and Khiri in the west, and Gonda in the east (Fig. 12). Rice is the main kharif (wet season [WS]) crop and wheat the main rabi (dry season [DS]) crop. Almost all the riceland in Bahraich district is rainfed. The rice areas in the district are located in the central plateau and in the river basins and valleys.

Upland rice areas, located mainly in the central plateau, have both bunded and unbunded fields. These areas are cultivated to dryland rice because they cannot be irrigated or hold water and do not experience floods or waterlogging. The crop often suffers from drought during dry spells in WS.

Lowland rice areas are usually bunded and have variable surface and subsurface hydrology. Ricefields in the central plateau have shallower surface water depth (0-10 cm) and a deeper ground water table than fields in the river basins and valleys. Some areas, especially along riverbanks, are subject to flash floods. River valleys and depressions are prone to waterlogging of varying depths and durations.

Land characteristics. The major landforms in Bahraich are plateaus, river basins, and valleys (Fig. 12). Lowland rice is cultivated mostly in the river basins and valleys, and upland rice in the central plateau. The central plateau is an almost level plain broken only by slight undulations and small drainage channels or by depressions planted to a late crop of rice. The Ghaghra Basin extends from the western edge of the high bank to the river. Its width varies from 15 km in the north to 60 km in the south. The plain is crossed in every direction by numerous channels.

The physiography of Bahraich varies markedly within short distances. Of the area cultivated to rice, about 6% is convex, 61% flat, 17% gently sloping, 5% steeply sloping, and 11% low-lying or swampy (Table 24). Most of the sloping lands are in the Ghaghra Basin and Rapti Valley. The landform

Table 24. Physiography[a] and soil type in blocks of Bahraich, Uttar Pradesh, India.

Block	Physiography (% of rice area)					Soil type
	Convex	Flat	Gentle slope (<3%)	Steep slope (>3%)	Low lying	
Risia	17.7 (0-50)	48.2 (10-100)	12.7 (0-30)	13.4 (0-20)	8.0 (0.50)	Loam, sandy loam
Gilaula	3.8 (0-40)	55.9 (30-90)	28.4 (10-60)	6.6 (0-20)	5.3 (0-15)	Loam, clay loam, sandy loam
Payagpur	1.7 (0-20)	60.6 (40-100)	21.6 (0-40)	4.2 (0-20)	11.9 (0-30)	Loam, clay loam, sandy loam
Fakharpur	6.4 (0-20)	74.3 (40-80)	5.0 (0-30)	1.0 (0-10)	12.8 (0-20)	Loam, clay loam, sandy loam
Bisheshwar Ganj	0.0 (0-0)	66.8 (20-100)	15.7 (0-40)	2.1 (0-20)	15.8 (0-50)	Loam, clay loam, sandy loam

[a]Mean of 10 village clusters in each block. Values in parentheses are ranges within each block.

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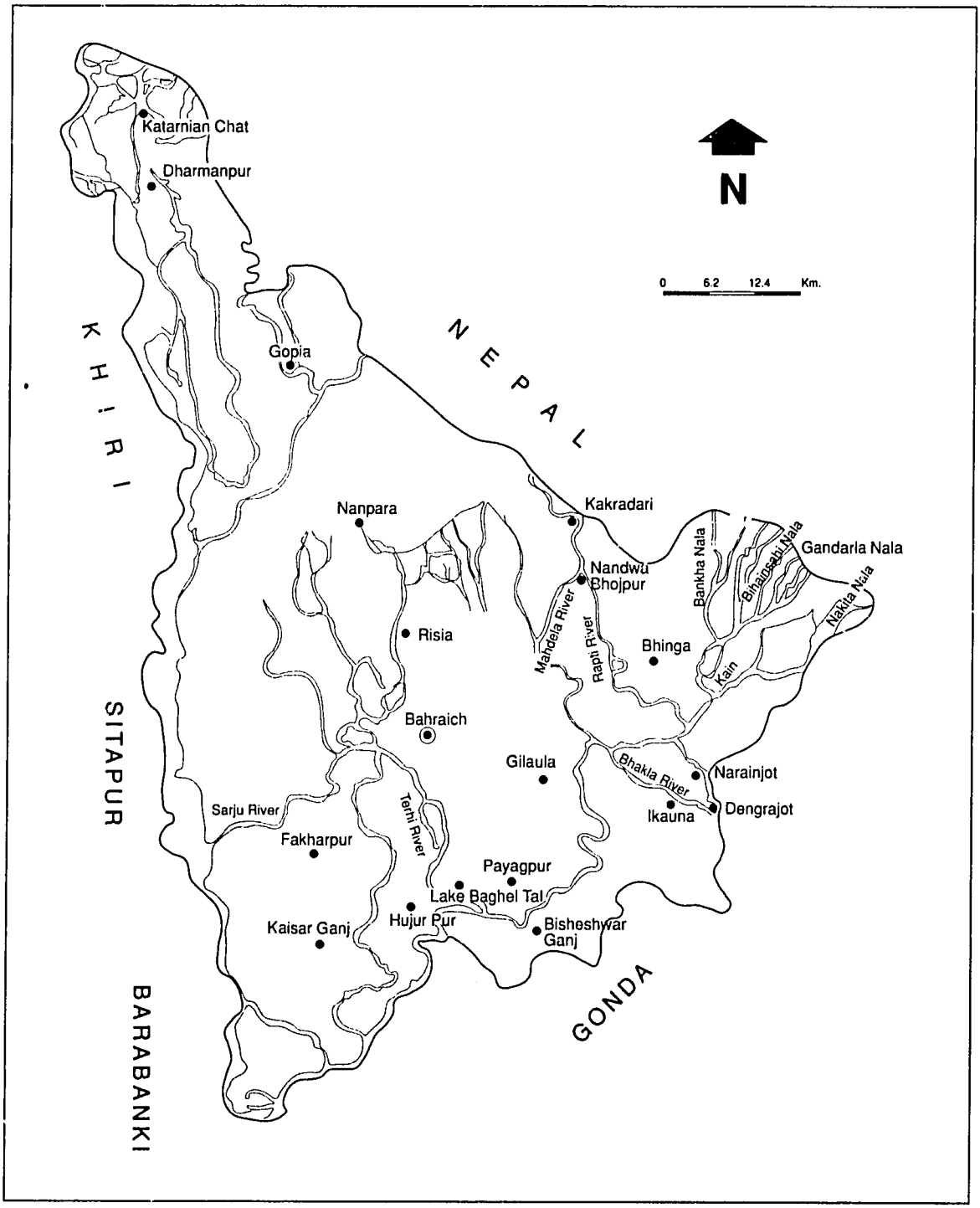

12. Bahraich district, Uttar Pradesh, India.

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varies within the political boundaries of the blocks and village clusters, but is more regular when grouped according to slope contours or viewed as a district. Hydrological patterns follow the physiography of the landscape.

Soil types are fairly uniform throughout Bahraich district. Loam and clay loam soils predominate in all blocks studied. The dominant soil types are given in Table 24. Fakharpur block showed loam, clay loam, and silty loam soils. The soil texture along the Ghaghra and Rapti Rivers is generally light and varies from year to year.

Rapti Valley is one of the most fertile parts of the district. Deposits left by floods of the Rapti River have fertilizing effects. In most areas, alluvial crust overlays the substratum sand, which, in land adjoining the Sarju River, is constantly enriched with fertile deposits.

The dominant soil types in the valley are loam and sandy loam, with distinct alluvial characteristics except where the deposits are thinly spaced over sandy subsoil.

The soil in the Ghaghra Basin resembles that of Rapti Valley but with more variable characteristics. The floodwaters of Ghaghra River leave large deposits of sand. However, sandy soil in the immediate vicinity of the river forms only a small portion of the cultivable area in Bahraich district.

The soil of the central plateau is medium-texture fertile loam on which excellent crops of wheat, upland rice, and other staples grow.

Use of the nutrient index adopted by the National Soil Testing Scheme, Indian Agricultural Research Institute shows that most areas in Bahraich have low organic matter (N reserve), medium levels of P, and low levels of K. Zn deficiency in rice has become widespread because of inherently low Zn levels in the soil and continuous submergence. Some published reports indicate an excellent response of rice to Zn application.

In Bahraich, unlike nearby areas, salinity or other soil-related problems are almost nonexistent; the few patches of saline soils cover less than 0.5% of the total agricultural area. This is attributed mainly to the continued use of numerous deep and shallow wells. As a result, any salinity buildup in the upper horizons of the profile is leached to deeper layers during WS and the entire profile is recharged with fresh water. In effect, any salt present is recycled seasonally within the profile, and does not build up in the soil. In the adjoining areas irrigated mostly by canal water, subsurface salts build up on the surface and salinity is increasing with time.

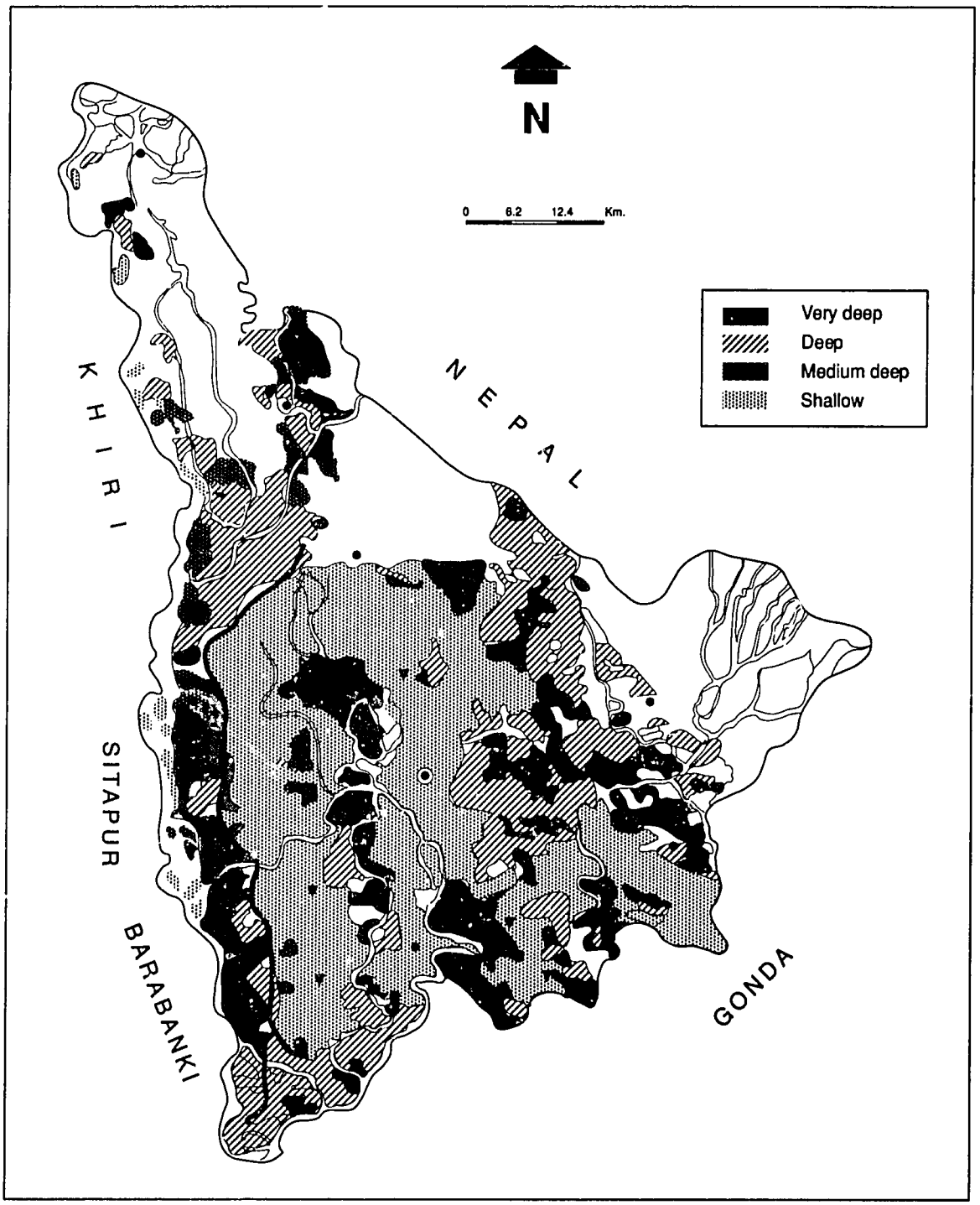
Hydrology. The hydrology of Bahraich ricefields is highly variable and complicated (Fig. 13).

- Some areas experience numerous floods of different depths. These areas may appear permanently inundated during rainy season as flash floods occur successively and before waters from previous floods have fully receded. The depth and duration of surface water vary considerably during the season.
- Low-lying areas away from rivers or streams also are flooded with runoff from higher areas.
- Areas flooded by flash floods, rain, or runoff where the floodwater recedes very gradually appear to have several water depths in a growing season.
- Some areas that are flooded gradually also show several water depths in a growing season.

These situations, which are especially pronounced in some parts of the Bisheshwar Ganj and Fakharpur blocks, complicate the measurement and classification of water depths and necessitate frequent monitoring of the surface hydrology. The sources of flooding (runoff, rains, or rivers) also should be identified as they have different influences on rice productivity.

The Bahraich hydrology is further complicated by recent construction of roads and canals. The Sarju main canal passes through Risia and Payagpur blocks, and causes extensive flooding and very slow water recession. Consequently, rice areas that were typically upland are now being flooded to different depths for several months and areas that were prone to shallow flooding are now experiencing deeper floods. The changes have substantially increased the extent of flooded areas during the rainy season. As a result rice production has been abandoned in Lakhiapur Jadid village clusters in Risia, Lakhan Gonda and Raniapur Goverahi in Bisheshwar Ganj, and Talab Baghel in Payagpur blocks. In other areas, farmers reduced input use because of the risk of flooding. Where water depths exceed 50 cm, average rice production varies from none in the worst years to 1.04 t/ha.

The district is crisscrossed by numerous rivers and streams and their tributaries. Except in the cen-



13. Water depths in actual ricefields in Bahraich, UP, India.

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tral plateau, most ricelands are found in river basins and valleys. Areas along the riverbanks are flooded seasonally to various depths. Some large tracts are submerged perennially. Numerous lakes and ponds retain 2.1-2.8 m water for 7 to 9 mo (July-March), and provide water for irrigation in DS. Lake Baghel Tal is an important water source of this type.

Numerous ponds and pools in the district were formed during excavations for clay and silt for domestic construction. Village clusters in the study area have 6-30 ponds, averaging 14 per village cluster (Table 25). The pond size (average 0.46 ha) and water depth (average 2.5 m) are nearly uniform. The ponds contain 7.2 to 307.6 ha m water (1 ha m = 10,000 m^3) for more than 8 mo/yr. Pond water is used primarily to irrigate DS crops (mainly wheat), to provide drinking water for livestock, and for raising fish.

The main sources of irrigation water in Bahraich district (Table 26) are deep tubewells, either government or privately owned; shallow tubewells, mostly privately owned; and low-lift portable pumps, mostly privately owned.

The number and density of the irrigation sources vary markedly within and among blocks. The variation among blocks is largely due to diverse physiography and surface hydrology. The variation among villages within blocks is related to the resourcefulness of farmers and their political influence. The number of irrigation units, mainly shallow tubewells and pumps, is not proportional to the extent of the cultivable area but to the capacity (social and economic status and political influence) of individual farm households, villages, or village clusters to serve them.

Table 25. Attributes of ponds and pools (average per village cluster) in blocks[a] of Bahraich, Uttar Pradesh, India.

Block	Ponds and pools			Period[b] with water (mo)	Volume of water[c] (ha m)
	no.	Average size (ha)	Average water depth (m)		
Risia	6	0.52	2.3	7.2	7.18
Gilaula	16	0.38	2.8	9.2	14.59
Payagpur	9	0.40[d]	2.1	8.3	307.56
Fakharpur	7	0.60	2.8	8.3	11.76
Bisheshwar Ganj	30	0.40	2.5	8.0	30.00

[a]Mean of 10 village clusters in each block. [b]About 25% ponds have water throughout the year. [c]One ha m is equivalent to 10,000 m^3 water. [d]One pond in this block is 2,000 ha in size, and is not included in this mean.

Table 26. Irrigation sources[a] in blocks of Bahraich, Uttar Pradesh, India.

Block	Irrigation source (no./village cluster)			Pond water		
	Deep tubewells	Shallow tubewells	Pumps	Volume (ha m)	Depth[b] (cm/ha)	Cultivated area (ha/village cluster)
Risia	1.0	21	12	7.18	2.8	256
Gilaula	2.5	59	36	14.59	3.8	385
Payagpur	4.4	21	14	307.56	103.5	297
Fakharpur	0.3	29	8	11.76	2.5	468
Bisheshwar Ganj	2.3	31	16	30.00	10.6	282

[a]Mean of 10 village clusters per block. [b]Field water depth if available pond water is used to irrigate cultivated area in each block.

The irrigation service area per irrigation source also varies among blocks and village clusters (Table 27). On average, there is one deepwell for every 300 ha, varying from 61 ha in Payagpur block to 937 ha in Fakharpur block. The uneven distribution of deepwells has caused a large variation within and among blocks. The analysis indicates that the irrigation sources are more evenly distributed in Risia block, followed by Payagpur, Fakharpur, Gilaula, and Bisheshwar Ganj.

The average depths of the water table in the five blocks are 1.96 m in WS and 5.52 m in DS. This varies from less than 2 m to over 6 m in WS and from 4 to over 8 m in DS (Table 28). The average fluctuation between seasons is about 3.6 m. About 60% of the cultivated land has a shallow ground water table (1-2 m deep). This greatly influences the flooding and submergence pattern especially in low-lying areas with poor drainage and poor soil permeability. Water table depth is also influenced by the level of water in the rivers.

The district has no drainage canals. Rivers and streams provide natural drainage. During rainy season, their catchment areas exceed their drainage capacities and hence they become a source of floodwater. Only in the DS do they serve as drainage sinks

Table 27. Irrigation service area[a] (ha per unit of irrigation source and per ha m water[b] in ponds) in 5 blocks of Bahraich, Uttar Pradesh, India.

Block	Irrigation service area (ha/unit irrigation source and /ha m pond water)							
	Deep tubewells		Shallow tubewells		Portable pumps		Ponds	
Risia	255.7	(390.4)	12.2	(18.5)	21.3	(29.7)	35.6	(140.3)
Gilaula	154.1	(309.7)	6.6	(17.1)	10.6	(32.5)	26.3	(71.8)
Payagpur	60.8	(177.9)	14.0	(15.0)	22.0	(24.1)	0.1	(18.5)
Fakharpur	936.7	(1277.5)	16.0	(20.8)	55.8	(60.4)	41.6	(176.2)
Bisheshwar Ganj	98.1	(313.2)	9.0	(14.4)	17.2	(37.5)	9.3	(45.9)
Mean	301.1	(493.7)	11.5	(17.2)	25.4	(36.8)	22.6	(90.5)

[a]Average of 10 village clusters in each block. [b]One ha m equals 10,000 m^3 water. Values in parentheses are cumulative means computed separately for all units of irrigation sources in each village cluster and averaged for the block.

Table 28. Cultivated area[a] by water table depth (m) in 5 blocks of Bahraich, Uttar Pradesh, India.

Depth to water table (m)	Cultivated area (%)									
	Risia		Gilaula		Payagpur		Fakharpur		Bisheshwar Ganj	
	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS
1	22	-	30	-	22	-	50	-	62	-
> 1- 2	33	-	40	-	12	-	17	-	13	-
> 2- 3	-	-	20	-	22	12	33	17	13	-
> 3- 4	12	12	10	10	33	-	-	17	13	25
> 4- 5	-	-	-	20	11	22	-	17	-	38
> 5- 6	22	11	-	50	-	22	-	33	-	12
> 6- 7	11	44	-	20	-	33	-	16	-	25
> 7- 8	-	11	-	-	-	-	-	-	-	-
> 8- 9	-	11	-	-	-	11	-	-	-	-
> 9-10	-	-	-	-	-	-	-	-	-	-
>10-11	-	11	-	-	-	-	-	-	-	-
Average depth (m)	3.2	6.9	1.2	5.0	2.7	5.9	1.3	4.8	1.4	5.0

[a]Mean of 10 village clusters in each block having an average cultivated area of 337 ha. WS = wet season, DS = dry season.

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because of lower water level. This is undesirable for agriculture because of the lack of moisture in DS.

The district has only one large flood control dike, a 105-km-long dike located along the Ghaghra River and extending from Nanpara to Kaisar Ganj block. The dike protects large areas along the riverbanks from flash floods. However, areas between the dike and national roads become flooded for long periods because of the slow surface drainage. The situation is serious in areas of Nanpara on the west side of Risia block and near Ghagharaghat in Kaisar Ganj block.

Rice-growing environments. About 71% (23,000 ha) of the average agricultural cultivated land in each block is used for rice cultivation. However, Payagpur block has less riceland (57.8%) because of extensive deep flooding in Talab Baghel and Mohanpur Mafi village clusters.

Rice areas under different water regimes have highly variable conditions within and among blocks as well as within village clusters. Lowland rice areas in the plateau and river basins or valleys are affected by flash floods. Some flash floods result from river overflows, others from runoff from higher areas.

The duration and frequency of flash floods vary within blocks and village clusters. In general, lowland rice areas (with 0-10 cm water depth) in the plateau are inundated for 3-5 d per flash flood and low-lying areas of the river basins and valleys flood for 10-15 d or longer. Floodwaters in areas along the river banks drain in 4-5 d, while those in low-lying patches receiving runoff take 10-15 d or longer to drain.

Water regimes. Table 29 gives the rice areas and percentages of those areas cultivated under different water regimes in the study area. The shallow (0-10 cm) riceland in rainfed bunded fields is generally called upland in Uttar Pradesh. These areas accumulate up to 10-cm-deep water during most of the growing season. Only 3% of these areas receive supplemental irrigation when needed. Most areas with supplemental irrigation are in Bisheshwar Ganj and Fakharpur blocks. Growing conditions in the shallow rainfed areas and in areas with supplemental irrigation are similar during most of the season.

In rice areas with different water regimes, water depths depend on the water-holding capacity of the soils, height of the bunds, rainfall pattern and intensity, and other related hydrological conditions.

Floods. Bahraich experiences at least two flash floods almost every year. Water accumulates at variable depths in low-lying areas with poor drainage. Flood affects about 67% of the rice area in the district (Table 30): 39.4% once, 11.8% twice, and 15.7% thrice per WS. In midlands and uplands, floodwaters remain for 3-4 d with one flood and 10 d if flooded twice in succession. In low-lying areas, flooding lasts for 60-120 d. The shallow (0-10 cm depth) category of rainfed lowland is flooded twice per WS, and all other categories three times.

Table 29. Rice area under different water regimes in 5 blocks[a] of Bahraich, Uttar Pradesh, India.

Block	Total rice area (ha)	Rice area (%)						
		Irrigated	Rainfed lowland					
			Shallow		Medium	Deep	Very deep	Flash flooded
			0-10 cm	10-30 cm	(30-50 cm)	(50-100 cm)	(>100 cm)	
Risia	16,241	-	84.3 (75-100)	0.6 (0-5)	0.6 (0-5)	2.3 (0-10)	12.2 (5-50)	55.7 (0-100)
Gilaula	20,125	-	24.3 (10-98)	28.3 (2-75)	17.5 (10-30)	15.1 (20-50)	10.3 (10-40)	50.0 (5-100)
Payagpur	12,268	-	71.0 (5-100)	15.7 (4-44)	10.1 (4-40)	1.9 (2-30)	1.3 (0-6)	52.9 (0-100)
Fakharpur	19,878	7.7 (0-30)	16.7 (10-50)	43.2 (10-50)	12.8 (10-200)	9.0 (10-50)	7.1 (10-20)	49.3 (10-100)
Bisheshwar Ganj	14,957	7.5 (0-30)	59.5 (25-100)	6.4 (2-25)	8.7 (2-25)	8.3 (3-25)	7.8 (10-25)	27.3 (2-100)
Mean	16,694	3.0	51.2	18.8	9.9	7.3	7.7	47.0

[a]Average of 10 village clusters in each block. Values in parentheses are ranges.

Table 30. Rice area under different water regimes and frequency and duration[a] of flood per season in Bahraich, Uttar Pradesh, India.[b]

Water regime (depth in cm)	No flood area (%)	1 flood		2 floods		3 floods		Total area (%)
		Area (%)	Duration (d)	Area (%)	Duration (d)	Area (%)	Duration (d)	
Irrigated	3.0	0	-	0	-	0	–	3.0
Rainfed lowland								
Shallow								
0-10	29.3	18.8	3 – 4	3.1	10	0	–	51.2
10-30	0.1	8.8	60 – 90	1.4	60 – 90	8.5	90 – 120	18.8
Medium deep								
30-50	0.0	5.7	60 – 90	1.8	60 – 90	2.4	90 – 120	9.9
Deep								
50-100	0.0	2.7	90 – 120	3.0	90 –120	1.6	90 – 120	7.3
Very deep								
100	0.0	3.4	90 – 120	2.5	90 –120	1.8	90 – 120	7.7
Only flashflooded	0.0	0	–	0	–	1.4	3 – 4	1.4

[a]Some areas (about 20%) in "Deep" and "Very deep" water category remain flooded for more than 6 mo. [b]Mean of 5 blocks, each with 10 village clusters. [c]Percent of total rice area.

Of the shallow areas, 18.8% is flooded once and 3.1% twice per WS. Risia and Payagpur blocks have the greatest flooded area in this category.

In the area with 10-30 cm water depth, 8.8% is flooded once, 1.4% twice, and 8.5 thrice per WS. Risia block has the least (0.6%) area under this category, and Fakharpur block (43.2%) has the most.

Flooding patterns in medium deepwater (30-50 cm) areas are similar to those of shallow (10-30 cm depth) areas. Gilaula block has the largest area in this category and Risia block the least.

A greater part of the deepwater areas experiences two floods per WS, with Risia block having a larger flooded area than other blocks in the district.

Drought. In general, two droughts occur per WS in the area surveyed (Table 31). Drought most severely affects the 0-10 cm shallow lowland rice areas. In most places, drought lasts 15-20 d per occurrence.

In the rainfed lowlands with 0-10 cm water depth, all blocks except Fakharpur are subject to two droughts per WS (Table 31). Most of the Fakharpur block rice areas are in the lower plains of the Ghaghra Basin and experience drought early or toward crop maturity, but rarely in the middle of the growing season.

Risia block has the largest area with the 0-10 cm water depth regime, the least number of irrigation sources, the deepest water table, the greatest area of steep slopes, and coarse-textured soils. The irrigation sources in Risia are hampered by lack of electricity, and by aged and unevenly distributed wells. Therefore, even short-duration droughts severely affect crops in this block.

In the 10-30 cm rainfed lowland rice areas, Risia block is least affected by drought and Fakharpur block most. Only Gilaula block experiences two droughts per WS, primarily due to its uneven physiography. In the medium deepwater areas, Payagpur and Fakharpur blocks are affected by one drought whereas Gilaula is affected twice per WS. In deep and very deepwater areas, only small areas in Gilaula are affected by drought prior to the monsoon (Table 32).

Rice cultivation and associated agronomic practices. Farmers establish rice by direct seeding (broadcast or drilled) or transplanting with or without fixed spacing. They select the method most appropriate for the soil and hydrological conditions. Early and long-duration rices are cultivated throughout Bahraich. Early rice is sown in June or early July and harvested in November. Long-duration rice is transplanted in July to early August and harvested in late December to early January. In low-lying areas, transplanting in WS is delayed to avoid floods at the early stage of growth.

About 58% of the rice is transplanted with or without fixed spacing and 42% is direct seeded: broadcast and drilled in rows. Of the direct seeded area, about 36% is dry seeded (from 22% in Payagpur to 50% in Risia). Wet seeded rice covers 64% of the rice area (from 50% in Risia to 78% in Payagpur).

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Table 31. Rice area[a] with different frequencies of drought in 5 blocks of Bahraich, Uttar Pradesh, India.

Block	Rice area (%) at given drought frequency			Area[b]
	0	1	2	
Shallow water (0-10 cm) rice area				
Risia	0	75.8	8.5	84.3
Gilaula	0	1.0	23.3	24.3
Payagpur	0	52.6	18.4	72.0
Fakharpur	0	16.7	0	16.7
Bisheshwar Ganj	0	20.4	39.1	59.5
Average	0	33.3	17.9	51.4
Shallow water (10-30 cm) rice area				
Risia	0.6	0	0	0.6
Gilaula	4.8	3.7	19.8	28.3
Payagpur	11.0	4.7	0	15.7
Fakharpur	13.3	29.9	0	43.2
Bisheshwar Ganj	3.1	1.7	1.6	6.4
Average	6.6	8.0	4.3	18.8
Medium deepwater (30-50 cm) rice area				
Risia	0.6	0	0	0.6
Gilaula	5.9	5.5	6.1	17.5
Payagpur	5.4	4.7	0	10.1
Fakharpur	5.2	7.6	0	12.8
Bisheshwar Ganj	8.7	0	0	8.7
Average	5.2	3.6	1.1	9.9

[a]Mean of 10 village clusters in each block. [b]Percent of total rice area.

Table 32. Rice area under different water regimes and frequency and duration[a] of drought during WS in 5 blocks[b] of Bahraich, Uttar Pradesh, India.

Water regime (depth in cm)	Rice area (%) at given drought frequency			Area[c]
	0	1	2	
Irrigated	3.0	0.0	0.0	3.0
Rainfed lowland				
Shallow				
0-10	0.0	33.3	17.9	51.2
10-30	6.4	8.1	4.3	18.8
Medium deep				
30-50	5.0	3.6	1.3	9.9
Deep				
50-100	5.5	1.8	0.0	7.3
Very deep				
>100	6.3	1.4	0.0	7.7
Only flashflooded	0.0	1.4	0.0	1.4

[a]Duration of drought is reported to be 15-20 d per occurrence; once in 7 yr, drought exceeds 2 mo. [b]Mean of 5 blocks, each having 10 village clusters. [c]Percent of total rice area.

Rice yields. Table 33 shows yields under different water regimes. Irrigated rice produced the highest average yields (3.12 t/ha) on the smallest land area (3%). Rainfed shallow (0-10 cm) lowland areas yielded an average of 2.42 t/ha.

The average yields in rainfed areas of 10-30, 30-50, 50-100, and >100 cm water depths are low (1.07 to 1.8 t/ha) and very unstable because of 1) highly variable hydrological conditions from year to year, and 2) the low levels of input use because farmers are averse to losing expensive inputs during floods.

Fertilizer and other inputs. Most farmers use organic manure as well as inorganic fertilizers. However, green manuring is not practiced because of lack of water in DS (before the beginning of the rice season) and because stray and wild animals destroy green crops during summer. Farmers build bunds to conserve soil and water.

Inputs, except herbicides, are generally applied in shallow lowland (0-10 and 10-30 cm) and irrigated areas only. Table 34 presents the levels of input use in the district. Because of the inadequacy of manure, its application is rotated among fields every 3-4 yr.

Various insecticides are commonly used in Bahraich, primarily during crop growing and grain-filling stages, to protect the crop from grain-sucking insects. The average rate of insecticide application in the district is high: 12.9-25.4 kg/ha. Even in Risia and Fakharpur blocks, where farmers reported that light traps effectively control insects, insecticide application averaged 13.0 kg/ha. Such practices may have serious environmental, health, and economic consequences.

Problems and suggestions. Groups of farmers and key farmer-informants in all the blocks studied enumerated their common problems in rice cultivation (Table 35). The problems were grouped in two classes: problems that existed 10 yr ago, and problems that arose within the last 10 yr. Many problems are common to both periods, but their extent has changed with time.

Lack of irrigation and drainage facilities, flash flooding, and unavailability of fertilizers are common in both periods. New weed species, labor shortage, bureaucratic difficulties in the Integrated Rural Development program, late-maturing modern varieties, and wild and stray animals are new problems.

Drainage and flood problems, common to both periods, increased significantly in all blocks because of the construction of new roads and canals. That

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Table 33. Rice yields under different water regimes in 5 blocks[a] of Bahraich, Uttar Pradesh, India.

Block	Rice yield (t/ha)						
	Irrigated	Rainfed lowland					
		Shallow		Medium (30-50 cm)	Deep[b] (50-100 cm)	Very deep[b] (>100 cm)	Flash flooded[b]
		(0-10 cm)	(10-30 cm)				
Risia	0	2.1	0.8	0.8	0.7	0.6	0.7
Gilaula	0	2.9	2.4	2.5	2.1	0.9	2.5
Payagpur	0	2.3	2.0	2.1	3.0	0	0
Fakharpur	4.50	3.0	1.8	1.3	1.6	1.3	1.8
Bisheshwar Ganj	1.8	1.9	1.8	1.6	1.5	1.6	1.8
Average	3.1	2.4	1.8	1.7	1.8	1.1	1.7

[a]Average of 10 village clusters in each block. [b]In deep and very deep areas, most farmers reported no production because of repeated heavy rains, with flood depth and duration of more than 1 m and 20 d, respectively, especially at later stages of growth.

Table 34. Uses of fertilizer and other inputs in 5 blocks[a] of Bahraich, Uttar Pradesh, India.

Block	Input use (kg/ha)						
	Organic manure[b]	N	P_2O_5	K_2O	Zn	Insecticides	Herbicides
Risia	8,700	40.0	3.9	0.6	0.6	12.9	0.0
Gilaula	7,100	34.1	5.5	0.9	6.7	25.4	1.6
Payagpur	8,500	36.7	13.2	1.1	8.3	21.8	0.0
Fakharpur	11,400	32.3	11.5	0.0	1.2	13.5	0.0
Bisheshwar Ganj	8,800	27.0	0.6	0.0	1.6	17.7	0.0

[a]Mean of 10 village clusters in each block. [b]Generally applied only in about 15-20% of the shallow lowland areas and remaining area scheduled for future years. Other than in Gilaula and Fakharpur, the medium lowland and deepwater areas did not receive organic or inorganic fertilizers. In other blocks, the quantity, if applied, is reduced by 50%.

fertilizer unavailability has been a constant problem over time indicates that some farmers have long been receptive to fertilizer use. Problems with stray animals possibly indicate the continuing fragmentation of farms, lack of grazing lands, and shortage of fodder.

Most farmers in all village clusters of each block suggested the following for raising farm productivity in Bahraich:

- for the lowlands, modern rice varieties that are early maturing and tolerant of submergence and drought,
- improving irrigation and drainage facilities,
- effective weed and insect pest control measures that reduce pesticide use,
- forage and multipurpose crops to increase fodder supply,
- controlling wild and stray animals, and
- removing subsidy on inputs and reducing their prices.

Conclusion and recommendations. Of the rice area in Bahraich district, 3% is irrigated, 80% rainfed lowland, and 15% deepwater. The remaining 2% has mixed hydrology. Of the rainfed lowland, 51.2% has 0-10 cm water depth, 18.8% has 10-30 cm, and 9.9% has 30-50 cm. Most of the rainfed lowland rice area is drought- and submergence-prone, generally with two droughts and two floods in WS.

Among the various constraints to rice production, unfavorable hydrological conditions and lack of seeds of modern varieties appear to be the most important. About 67% of the rice in the district is affected by floods and 72% by drought.

This analysis indicates that different agroecological zones need different sets of research and development priorities. Because of its large area, the number

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Table 35. Some problems of rice production in 5 blocks[a] of Bahraich, Uttar Pradesh, India.

Problem	Type[b]	Farmers (%)				
		Risia	Gilaula	Payagpur	Fakharpur	Bisheshwar Ganj
Lack of high-yielding varieties	Old	100	25	62	67	38
	New	-	-	-	-	35
Lack of irrigation	Old	30	30	37	30	37
	New	78	40	29	67	30
Problem of flood and drainage	Old	25	50	10	50	20
	New	55	80	62	90	62
Fertilizer unavailability	Old	30	10	10	-	20
	New	30	10	5	20	20
Weeds	Old	-	10	-	-	-
	New	-	-	-	38	68
Lack of labor	Old	-	-	-	-	-
	New	44	30	11	-	37
Bureaucratic difficulty in rural development program	Old	-	-	-	-	-
	New	20	30	30	25	25
Late-maturing varieties	Old	-	-	-	-	-
	New	25	30	30	-	-
Drought	Old	-	-	-	-	-
	New	20	20	20	20	20
Stray and wild animals	Old	-	-	-	-	-
	New	-	50	78	-	62

[a]Mean of 10 village clusters in each block. [b]Old problems refer to those existing since 10 yr ago; new problems are those that became problems in the last 10 yr.

of affected households, and the high potential for improving yields, top priority should be given to rainfed lowland.

The available technology packages should be assessed against the problems and biophysical and socioeconomic conditions in each block to determine their applicability. Further, there is a need to prioritize the thrust of research in each block so as to develop technologies that will have the greatest impact on rice farming systems' productivity.

Integrated pest survey in Central Luzon

A survey on pest management practices and pest status in irrigated rice was conducted during four consecutive cropping seasons, from the 1987 WS to the 1988-89 DS. The survey encompassed various components of the system and addressed cropping practices (including pest management practices), levels of pests, and yield. The surveyed population was 90 fields chosen at random in four provinces of Central Luzon: Pangasinan, Nueva Ecija, Pampanga, and Bulacan. The fields were visited three times per cropping season. At each visit, we observed cropping practices, crop status, and pest levels.

Each field during each cropping season was considered as unique, represented by attributes as diverse as the rice variety, method of crop establishment, amount of fertilizer applied, water status, proportion of tillers with deadhearts, proportion of leaves with whorl maggot (RWM) damage, proportion of tiller area with sheath blight (ShB) symptoms, and yield.

Categorization of the information. This data set probably represents some of the most detailed, comprehensive information available on a multiple-pest system affecting a tropical crop. It was analyzed to 1) produce an overall view of the relations between the cropping practices, pest levels, and variation in yield in a given area and over a limited period of time; and 2) delineate a general procedure that could be followed to analyze data sets on rice productivity constraints that may become available in the future.

The variables involved were of differing types; some were essentially ordinal (e.g., the rice variety), and some were cardinal (i.e., quantitative, e.g., the yield); some were time-dependent (e.g., the level of a given pest), and some were time-independent (e.g., the planting method). One aim of categorizing the information was to unify the variables in a single, compatible format, so that all the information available could be mobilized. The very large amount of

information had to be compacted to make an overview of the data possible, to forward interpretations of the data, and to generate hypotheses. The information was compacted in three phases.

Compaction over time. Some of the variables involved (e.g., water status, pest levels) were time-dependent. They were represented by a set of three values accounting for the three visits. This set was replaced by a single value, representing the overall status of the crop with respect to the considered attribute throughout the cropping season. Some of the pest damages (e.g., deadhearts, ShB) were represented by the highest level observed; others (e.g., RWM, brown spot) were represented by the area

Table 36. List of variables.

Symbol	Variable	Classes
Y	Yield	Y_1 (very low) to Y_6 (very high)
		Cropping practices
Pltg*	Planting method	Transplanted (T) or direct seeded (S)
CS*	Cropping season	Wet (WS) or dry (DS) season
FAP*	Fertilizer application	Combinations of amounts and dates, from none or minimal (F1) to very high (F4)
IUF*	Insecticide use frequency	Frequency of insecticide application, in 5 classes, from none (IO) to very high (I4)
WCP*	Weed control practices	None, hand weeding, herbicide, and combinations (7 classes)
PLD*	Planting date	Very early to very late (5 classes)
VG*	Variety groups	7 types of varieties: IR36, IR42, IR64, IR66, R10, and other R- and IR-varieties
EW*	Excess of water	Water submergence stress in 3 classes (absent to strong)
DS*	Drought stress	Water shortage stress in 3 classes (absent to strong)
		Diseases, insect pests, and weeds
ShB*	Sheath blight	Maximum sheath blight severity, in 5 classes, from none to very high
SR*	Stem rot	Maximum stem rot incidence, in 3 classes
ShR*	Sheath rot	Maximum sheath rot incidence, in 2 classes
BB*	Bacterial blight	Area under bacterial blight severity progress curve (SPC), in 3 classes
NBS*	Narrow brown spot	Area under narrow brown spot SPC, in 3 classes
LM	Leaf smut	Area under leaf smut SPC, in 2 classes
LS	Leaf scald	Area under leaf scald SPC, in 2 classes
BS	Brown spot	Area under brown spot SPC, in 2 classes
BLS*	Bacterial leaf streak	Area under bacterial leaf streak SPC, in 3 classes
BPH*	Brown planthopper	Area under population progress curve (PPC), in 4 classes
WBP	Whitebacked planthopper	Area under PPC, in 4 classes
ZLH	Zigzag leafhopper	Area under PPC, in 4 classes
GLH*	Green leafhopper (*N. virescens*)	Area under PPC, in 4 classes
NN	*Nephotettix nigropictus*	Area under PPC, in 4 classes
RWM*	Rice whorl maggot	Area under percent damage progress curve (DPC), in 5 classes
CW	Caseworm	Area under percent DPC, in 2 classes
LF*	Leaffolder	Area under percent DPC, in 4 classes
OTH	Other defoliators	Area under percent DPC, in 4 classes
DH*	Deadhearts	Maximum proportion of damaged tillers
WH*	Whiteheads	Maximum proportion of damaged panicles
WB*	Weeds below the rice canopy	Area under weed infestation (below the rice canopy) index progress curve (IPC), in 4 classes
WA*	Weeds above the rice canopy	Area under weed infestation (above the rice canopy) IPC, in 4 classes

*Variable involved in the cluster analyses.

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under the injury progress curve using the development of the crop as a time frame.

Compaction of ranges: categorization of the information. The frequency distribution of each quantitative variable was analyzed, and a series of classes, limited by boundaries, were defined. The variation of yield (Y), for instance, was represented by six classes: Y1 (0.5 t/ha ≤ Y < 2.75), Y2 (2.75 ≤ Y < 3.75), Y3 (3.75 ≤ Y < 4.5), Y4 (4.5 ≤ Y < 5.0), Y5 (5.0 ≤ Y < 5.75), and Y6 (5.75 ≤ Y < 7.5 t/ha). The classes are defined in such a way that they contain equivalent numbers of fields. Categorization of the quantitative information therefore is a means to normalize the data; it also allows us to take into account the intrinsic error made in measurements, such as in disease assessment or yield estimate.

Compaction over individuals: buildup of classes and cluster analyses. Aside from the yield output of the system, two broad groups of variables were distinguished (Table 36). Through cluster analyses, subpopulations of fields were thus characterized according to their 1) patterns of cropping practices, and 2) pest profiles.

Characterization of cropping practices and pest profiles: cluster analyses. The characteristics of seven types of cropping practices (PR) and six pest profiles (PE) are summarized in Tables 37 and 38.

Some emerging types of cropping practices are described (Table 37). The first type (PR1) was represented by WS crops where water management is adequate, fertilizer input usually high, and some insecticide usually applied. The fields did not, however, receive adequate weed control measures. In many of them, weed management was minimal, the only measure being some hand weeding. This may be related to the relatively late establishment of the crop. PR3 was characterized as DS crops, predominantly direct seeded, with high fertilizer inputs, a combination of weed control practices (use of preemergence herbicides and hand weeding), and moderate insecticide inputs. PR4 was represented by predominantly transplanted, WS crops, with low fertilizer inputs.

Similarly, a series of pest variables were used to define categories of pest profiles (Table 38). The first (PE1) was represented by low weed infestation and absence of significant pest problem except ShB. PE3 corresponded to high weed infestation above the rice canopy, variable insect pest levels, and no or little diseases. PE4 was represented by fields with high weed infestation (above and below the canopy), variable insect pest levels, some sheath rot (ShR), and high bacterial leaf streak (BLS). PE5 corresponded to high weed infestation below the canopy, and high stem borer (whitehead) damage.

The representational value of the two classifications was assessed by measuring their association with an independent attribute—categorized yield levels. This categorized variable, which represented one output of the considered system (irrigated rice),

Table 37. Patterns of cropping practices (PR1 to PR7).

Component[a]	Characteristics[b]						
	PR1	PR2	PR3	PR4	PR5	PR6	PR7
VG	B, C, D	Diverse	B, C, D	B, C, D	A, B, C, D	A, B, C, D	B, C, D, G
Pltg	T	S&T	S predom.	T predom.	T predom.	T predom.	T predom.
FAP	High	High	High	Low	High	Variable	Variable
IUF	Medium	Low	Medium	Medium	High	Medium	Medium
WCP	No or hand weeding	Variable	PEH and hand weeding	PEH and hand weeding	PEH and hand weeding	PEH and/or hand weeding	Variable
EW	No	No	No	No	No	No	Yes
DS	Infrequent	Frequent, slight	No	Infrequent	Frequent, slight	Frequent, strong	Frequent, slight
PLD	Intermediate	Intermediate	Intermediate	Late	Early	Inter-mediate	Inter-mediate
CS	WS (3)	Predomi-nantly DS	DS	WS	WS or DS	WS or DS	WS or DS

[a]VG = variety group, Pltg = planting, FAP = fertilizer application, IUF = insecticide use frequency, WCP = weed control practices, EW = excess of water, DS = drought stress, PLD = planting date, CS = cropping season. [b]Variety groups: A = IR36; B = IR42; C = IR64; D = IR66; E = IR58, IR60, IR65, IR72; F = IR20, IR22, IR32, IR44, IR68, IR70; G = R4, R32, R34, R92, R98; H = R10. T = transplanted, S = direct seeded, predom. = predominant, PEH = preemergence herbicide, WS = wet season, DS = dry season.

Table 38. Types of pest profiles (PE1 to PE6).

Pest[a]	Characteristics					
	PE1	PE2	PE3	PE4	PE5	PE6
ShB	High	Variable	Low	Variable	Variable	Variable
BLB	No	No	No	No	Low	Some
NBS	Variable	Variable	Low	High	Variable	Variable
SR	Very low	Very low	No	Variable	Variable	High
ShR	No	No	No	Some	No	No
BLS	Low	Low	Low	High	Low	Variable
BPH	Variable	Variable	Variable	Variable	Variable	Variable
GLH	Low	High	Variable	Variable	Variable	Variable
RWM	Variable	Variable	Variable	Variable	Variable	Variable
LF	Variable	Low	Variable	Variable	Variable	Variable
DH	Low	Variable	Variable	Variable	Variable	Variable
WH	Variable	Variable	Variable	Variable	High	Variable
WA	Variable	Low	High	High	Low	High
WB	Variable	High	Variable	High	High	Variable

[a]ShB = sheath blight, BLB = bacterial leaf blight, NBS = narrow brown spot, SR = stem rot, ShR = sheath rot, BLS = bacterial leaf streak, BPH = brown planthopper, GLH = green leafhopper, RWM = rice whorl maggot, LF = leaffolder, DH = deadhearts, WH = whiteheads, WA = weeds above the rice canopy, WB = weeds below the rice canopy.

was then used to build contingency tables and compute chi-square tests. The tabulated results demonstrated a strong variation in yield distribution among the patterns of cropping practices (Table 39), as well as among the types of pest profiles (Table 40). The chi-square values [χ^2(Y,PR) = 46.6 and χ^2(Y,PE) = 50.5] were both significant at $P<0.05$. The two classifications were therefore considered to capture a significant proportion of yield variation.

Correspondence analysis. Correspondence analysis is a multivariate statistical technique that allows pictorial representation of a series of contingency tables. Axes and the corresponding eigenvectors are defined, each of them accounting for a given fraction of the total information (inertia) represented by the contingency tables. The variables are the classes of these tables, and the coordinate of each of them on the axes is computed, so that the classes can be plotted against the resulting axes.

The two contingency tables (Table 39,40) were jointly submitted to a correspondence analysis. The considered variables were the seven patterns of cropping practices, six types of pest profiles, and six yield categories. The two first axes generated in the analysis accounted for 50.3 and 26.6% of total inertia (i.e., the two first axes accounted for 76.9% of the information contained in the contingency tables). The various classes were thus plotted on a two-dimensional diagram (Fig. 14), and their relations interpreted. As a succession of yield classes represented a logical series, the corresponding points were linked together, producing a path of increasing yield, from very low (Y1) to very high (Y6). This path of increasing yield was interpreted in relation with the axes, and with the various patterns of cropping practices and types of pest profiles that were plotted on the same graph.

Figure 14 indicates an overall increase of yield along the horizontal axis in the negative direction; the horizontal axis may therefore be considered as representing a gradient of increasingly unfavorable production situations. The path of increasing yield shows strong movements along the vertical axis, which are associated with various pest profiles and patterns of cropping practices. For instance, close associations (correspondences) are indicated between very low yield (Y1) and PR1, PE4, and PE5; between Y2 and P3; and between Y6 and PR3, and PE1. The associations are summarized in Figure 14. The graph indicates the overall major effect of 1) fertilizer inputs, 2) weed control, and 3) cropping season (wet or dry) on yield variation. It also indicates specific yield-pest relations at varying production situations. The only pest associated with very high yield is ShB. The association can be interpreted in two ways: 1) the conditions that are conducive to very high yield are favorable to the disease, and 2) even higher yield might be achieved when this disease is controlled in this production situation. In contrast, the pest profile that affects very low yielding fields (Y1)

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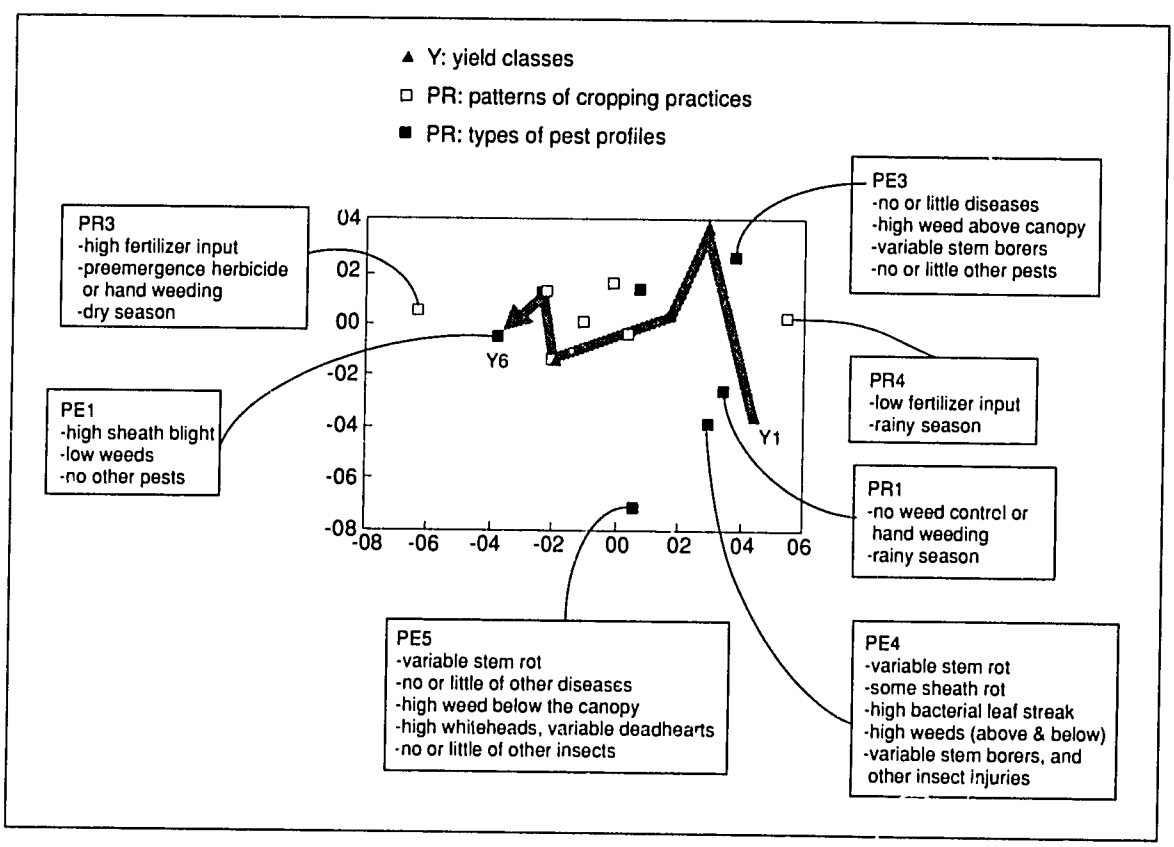
Table 39. Contingency table for yield classes and patterns of cropping practices: Y x PR.

Cropping practice	Y1	Y2	Y3	Y4	Y5	Y6
PR1	2	1	6	3	0	1
PR2	4	8	7	5	8	7
PR3	0	3	2	7	6	9
PR4	12	12	8	2	6	4
PR5	2	2	3	5	3	4
PR6	8	8	13	11	11	7
PR7	9	11	19	19	22	11

Table 40. Contingency table for yield classes and types of pest profiles: Y x PE.

Pest profile	Y1	Y2	Y3	Y4	Y5	Y6
PE1	4	4	10	11	16	14
PE2	4	8	7	9	15	9
PE3	7	16	15	7	7	4
PE4	7	2	5	4	4	2
PE5	8	0	4	7	2	5
PE6	7	15	17	14	12	9



14. Two-dimensional diagram of classes of variables in Tables 39 and 40.

is very diverse, including, aside from weeds, stem rot (SR), ShR, and BLS (PE4), or stem borers and SR (PE5).

The analysis provided an overall picture of the relationships between cropping practices, pest profiles, and yield. It indicated that the concept of "key pest" should be used with due consideration of the overall production situation. More generally, the use of categorized information allows us to handle large data sets, incorporating information that reflects the diversity of rice ecosystems, in a way that is compatible with decisionmaking in agriculture.

Characterization and simulation for riceland management and productivity

To guide the design of new technology, comprehensive characterization of rice-growing environments and quantitative understanding of the growth of the rice crop in relation to its environment are needed to help determine extrapolation domains for research findings and to indicate future targets for research. Ongoing research activities focus on improving rice growth models, including pest effects in the models, and applying models to studies of environmental characterization and improved N management. Methods to characterize rice-growing environments are being developed by combining GIS with rice crop simulation models. Special attention is paid to characterization of soil properties in relation to water management. As simulation models can be an important tool in rice research, this subprogram emphasizes the training of scientists from various disciplines at Asian NARS.

Application and improvement of simulation models

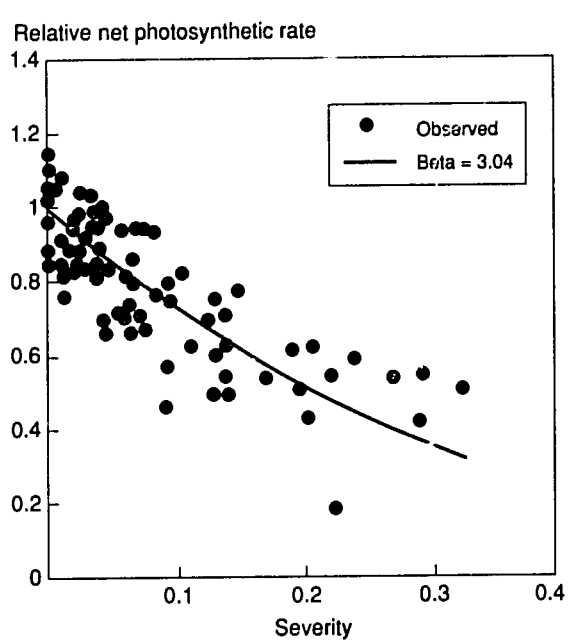
The existing models simulate currently measured yields accurately, but yields have been declining in the past 20 yr. The models thus cannot simulate real potential yields in an optimal environment. To select parameters for simulation of real potential yields (determined only by radiation, temperature, and varietal characteristics), we conducted new detailed experiments. Using literature studies, we hypothesized that the yield decline could be reversed by increasing N supply during grain filling and by a higher planting density. An experiment that gave 15-20% higher yields with increased late N treatment is reported on p. 6 of the Irrigated rice ecosystem report. Most of the late-supplied N was taken up by the crop.

Several aspects of the model need improvement. Major improvements are needed on the simulation of leaf area development, source-sink relationships and tillering, and especially the role of N in rice physiology.

Quantifying the effect of blast on rice growth and production

Rice Bl constrains rice production in temperate lowland, tropical upland, and rainfed lowland areas. Rice Bl comprises leaf infections, occurring mainly before flowering, and infections of the neck node or the panicle. Leaf Bl indirectly affects yield by reducing crop growth before flowering. This study concentrates on construction of damage relations for leaf Bl. For this purpose the physiological processes that underlie damage are quantified and combined using crop growth modeling. Results of such studies are highly applicable across years, locations, and varieties.

Gas exchange measurements were used to analyze the effect of *Pyricularia oryzae* on leaf photosynthesis and respiration. The photosynthetic rate of infected leaves was lowered through a reduction in both green leaf area and photosynthesis of remain-



15. Relative net photosynthetic rate of leaves infected with *Pyricularia oryzae* in relation to disease severity as measured in a field experiment.

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ing green leaf tissue. The relative reduction in leaf photosynthetic rate thus surpassed disease severity (Fig. 15).

A function was derived to relate net photosynthetic rate of infected leaves (P_x) to disease severity (x):

$$P_x = P_0(1 - x)^{\beta}$$

In this model, P_0 is the photosynthetic rate of healthy leaves and ß is a proportionality factor characterizing the pathogen's effect on leaf photosynthetic rate. ß can be represented as the ratio between the area of a virtual lesion in which photosynthesis is negligible and the area of the visual lesion. For cultivar IR50, a ß-value between 3 and 4 was found. Since ß is independent of disease severity, effects of host resistance are excluded. Therefore this parameter is a pure component of tolerance. Tolerance (the host's ability to endure the presence of the pathogen with reduced disease symptoms and/or damage) may help minimize yield loss.

In a separate experiment, we studied the suitability of ß as a selection criterion in breeding rice with tolerance for leaf Bl. Variations were marginal because of a lack of genetic variation in ß (Table 41). Dark respiration of infected leaves was increased. The ratio between respiration of lesion and healthy tissue ranged from 4 to 5.

To evaluate the effect of the disease on photosynthesis of rice canopies, the effects on leaf photosynthesis and respiration were introduced in an ecophysiological model. Photosynthesis of healthy and diseased canopies was determined in the field, and the experimental data were used to evaluate the performance of the model. Simulated results agreed well with the experimentally obtained data (Fig. 16).

Model analysis revealed that the reduction in photosynthesis of diseased canopies was mainly due to the adverse effect of lesions on leaf photosynthesis and the dead leaf area resulting from the disease. A sensitivity analysis demonstrated the significance of the vertical distribution of the disease. Lesions in the top layer of the canopy contributed more to the reduction in canopy photosynthesis than did lesions on lower leaf layers. Thus, disease monitoring for crop loss assessment should account for the vertical distribution.

The time course of dry matter production and yield formation of diseased crops will comprise the last step of this study. Field experiments and modeling will be combined. An analysis must reveal how reduced crop growth before flowering results in reduced kernel filling. If this mechanism is understood, the model can be used to construct damage relations for various situations.

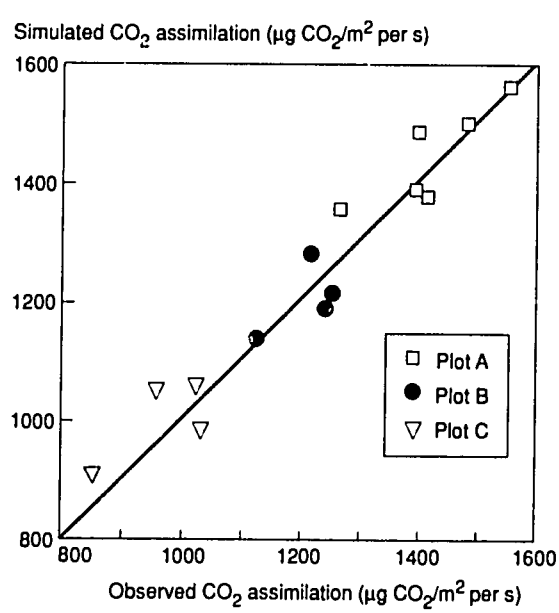
Table 41. Variability in infection frequency and parameter β, for 3 rice cultivars, after inoculation with *Pyricularia oryzae*.

Cultivar	Infection frequency (lesions/cm²)	β
CO 39	3.5	2.8
IR50	1.6	2.9
IR64	0.7	3.2

Influence of soil structure on water relations

To investigate the influence of soil structure on water relations in rainfed rice ecosystems, we quantified the impact of bypass flow in cracking soils and studied the effect of soil tillage practices on bypass flow.

Soil-cracking and internal catchment. The development of soil cracks and the depth of internal catchment (the subsoil infiltration of water that bypasses the topsoil) were studied after draining a puddled ricefield in the 1991 DS at the IRRI experi-



16. Simulated and observed canopy CO_2 assimilation.

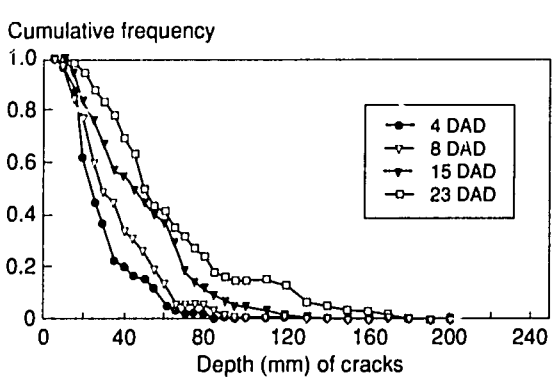
mental farm. The soil was an isohyperthermic, mixed Typic Tropudalf. A thin, flexible steel tape was used to measure depth and width of cracks along a 6-m string stretched across the surface of the soil. At 15 d after drainage (DAD), mean depth of cracks was 4.5 cm and mean width was 0.9 cm (Fig. 17).

Mean soil-water pressure potential at 10 cm (maximum cracking depth at 15 DAD) was about –0.1 MPa. Depths and widths of cracks increased as the soil dried. To determine depth of cracks at 50 DAD, cracks were stained with soluble white paint—they extended between 40 and 60 cm throughout the profile.

The processes of bypass flow and internal catchment differ from the classical concept of surface infiltration and cannot be modeled with standard flow theory. However, models can be formulated if cracking patterns (depth of internal catchment) and the magnitude of bypass flow as a function of pressure potential of the topsoil are known.

For the future, a subroutine simulating bypass flow will be added to the Simulation Algorithm for Water Flow in Aquic Habitats (SAWAH) model. Bypass water will be assumed to infiltrate to that depth where internal catchment occurs, as derived from the morphological analyses described above. The quantity of rain infiltrating at the surface will be decreased by the amount of bypass water. It will be assumed that no bypass water is absorbed laterally by the soil during downward flow.

Reducing water losses from bypass flow. Bypass flow (water that flows into vertically continuous soil macropores or cracks, bypassing a surrounding unsaturated soil matrix) was measured for a previously puddled, cracked clay soil in the 1991 DS. Simulated rainfall was applied to four large undisturbed soil cores of 0.21 m diameter and 0.25 m height, using a needle array (comprising 48 needles) connected to a mariotte buret, timer, and pulsating pump. All cores contained one major crack that extended through the full cylinder height. High bypass ratios (>90%), similar to those reported in the IRRI Program report for 1990, were obtained for low (5 mm/h) and high rain intensities (15 mm/h). At low rain intensities, more water was initially absorbed.



17. Cumulative frequency of depth of cracks at different days after drainage (DAD).

To reduce water losses from bypass flow, the surface of the cracked experimental field was shallow-tilled (0-5 cm) using a rototiller. Tillage left a topsoil of clods with an average diameter of about 20 mm. The clods were collected from the field and placed on top of another set of four cracked soil cores from which the top 50 mm had been removed. Because the clods were loosely stacked, the initial weight of the second set of four soil cores was 10-15% less than that of the first set of four soil cores. Nevertheless, closing the cracks by adding the clods saved 40% (15 mm/h) to 65% (5 mm/h) more water (Table 42). Shallow surface tillage makes cracks discontinuous, and water is therefore better retained in the topsoil.

Where water losses during land preparation for rice are high due to a relatively permeable subsoil, use of pretillage might result in considerable water savings.

The benefits of tillage at the end of a soil-cracking DS prior to rewetting the land for the next rice-growing season will be studied at a site with a cracking, heavy clay topsoil and a permeable subsoil.

Combining GIS and a rice crop simulation model

The combination of a GIS and a crop simulation model offers unique possibilities to interpret extensive data sets derived from various disciplines and from different locations. The interpretation may identify important constraints to rice production. The models can be used to predict potential yield under given weather conditions, conduct risk analysis using long-term weather data for rainfed environments, and optimize crop management strategies. The methodology (Fig. 18) involves the following activities:

1. Agroecological characterization. The geographic distribution of soil, climatic, and administrative units and associated attribute data (e.g., rainfall,

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Table 42. Bypass flow for tilled and nontilled samples at different rain intensities.

Treatment	Rain intensity (mm/h)	Time (min) before start of outflow	Absorbed water (mm) at start of outflow
Nontilled	4.4	282	21
Tilled	4.7	435	34
Nontilled	17.1	47	13
Tilled	15.3	74	1

soil hydraulic properties, actual crop yield) is characterized. Maps are digitized and stored with associated attribute data in a GIS.

2. Identification of land evaluation units. An overlay of input maps (made by the GIS) generates maps of land evaluation units (LEUs). Each LEU is a unique combination of a soil, a climatic, and an administrative unit.

3. Qualitative land evaluation. The suitability of each LEU for a specific land use is assessed, using expert knowledge. Nonsuitable and potentially suitable LEUs are identified.

4. Quantitative land evaluation. Production constraints are evaluated by techniques applied to potentially suitable LEUs.

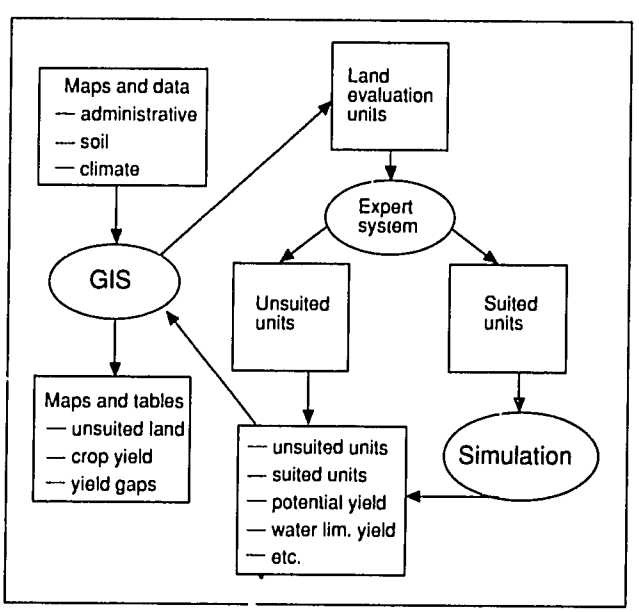
5. Display and interpretation of results. Maps or tables of unsuitable land units, and of crop yields and yield gaps for suitable units can easily be displayed.

This methodology has been applied to Tarlac Province, Philippines, to analyze yield losses due to drought in rainfed rice-growing environments.

Using GIS software, we digitized for Tarlac Province a soil map (1:50,000 scale), provided by the Bureau of Soils and Water Management, Quezon City, Philippines.

Guided by this map, we located 13 representative soil profiles and determined soil water retention and hydraulic conductivity data for the various soil horizons. Soil water retention was measured using the hanging water column, evaporation, and pressure plate methods. The column method and the crust method were used to determine hydraulic conductivity relations. Water retention and hydraulic conductivity functions were derived simultaneously from measurements using a one-step pressure outflow apparatus on 300-ml soil cores.

Soil hydraulic properties were assumed to be represented by Van Genuchten's closed-form equation involving four unknown parameters—coefficients a, n, l and residual moisture content θ_r. Two other parameters—the saturated moisture content (θ_s) and the saturated hydraulic conductivity (K_s)—were set equal to their measured values. Values for the four unknown parameters were determined by nonlinear least-squares fitting using the program MULSTP. MULSTP includes measured



18. Conceptual diagram showing the relationship between geographic information systems, simulation models, and data needs.

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time series of cumulative outflow and measured water retention data. As an example, parameters determined for two contrasting representative profiles are listed in Table 43.

Table 43 is part of a series of soil hydraulic functions being developed for rice-growing areas. The functions relate well-defined horizons in taxonomic units to physical parameters such as soil water retention and hydraulic conductivity, and can be used in numerical simulations of regional soil-water regimes.

The saturated hydraulic conductivities that were measured in the 1991 DS were relatively high because of preferential flow through soil cracks and macropores (Table 43). Such high values are likely to be unrealistic for rice soils in WS. Additional measurements were therefore carried out in the 1991 WS. Saturated conductivities of the least permeable layer (average thickness 4 cm) in puddled topsoils were measured for each soil type where rice is grown. Values ranged from 0.3 to 3.3 mm/d, and were clearly lower than the K_s values measured for the same soils in the 1991 DS.

Data were obtained from 12 rainfall stations and 1 fully equipped agrometeorological station in Tarlac. Three rainfall zones and three elevation zones (0-50, 50-100, and >100 m above sea level) were distinguished.

Using the measured data, 25 yr of synthetic weather data (including data for rainfall, maximum and minimum temperature, and hours of sunshine) were generated for each rainfall zone and each elevation zone. Simulated rainfall was highly variable, ranging from 400 to 1,000 mm in WS. Planting dates were estimated for each year, set to the date by which cumulative rainfall in June-July exceeded 75 mm.

Mountainous and sandy areas of Tarlac were considered unsuitable for rice, but on sandy soils that were frequently flooded by nearby rivers, rice was assumed not to suffer from water shortage and to have fully watered potential yield.

Potential yield (fully watered, assuming optimal nutrition, and no pests) was calculated for each elevation zone for all 25 yr using the LID-MACROS model.

Rice yield was also predicted for 1 yr (1987) when actual weather data were available. To predict yield under nonirrigated conditions as a function of the soil characteristics (assuming DS K_s values and optimal nutrition, and no pests), the SAWAH soil water balance routine was coupled to the model. A constant water table depth of 1.0 m was assumed. The difference between the predictions for irrigated and nonirrigated conditions indicated the prospective benefit that would be derived from irrigation (Fig. 19). The yield gap between irrigated and nonirrigated conditions ranged from 0 to 5.3 t/ha.

We will use this methodology to predict rice yield under nonirrigated conditions, as a function of the soil characteristics (using WS K_s values) and the 25 yr of synthetic weather in each rainfall and elevation zone (assuming optimal nutrition and no pests). Average yield losses and yield losses that have a 10, 25, and 50% probability to be exceeded will be calculated for each LEU.

Knowledge sharing of simulation methodology

Knowledge sharing is essential to increase the application of systems simulation methodology in national systems. The distribution of research teams belonging to the project Systems Analysis and Simulation in Rice Production (SARP) is shown in Figure 20.

Three SARP workshops were organized in 1991. Case study reports of participants in a 1990 SARP training course and reports on future plans of the SARP teams were discussed at the first workshop.

Table 43. Textural properties and Van Genuchten's soil-hydraulic parameters as calculated for major horizons occurring in 2 contrasting representative profiles (nr. 27 and 30)[a] of Tarlac Province.

Major horizon code	Sand (%)	Silt (%)	Clay (%)	K_s (m/d)	θ_s (vol/vol)	a (cm^{-1})	n (-)	l (-)	θr (vol/vol)
27Apg	55	26	19	1.16	0.47	0.0097	1.618	3.34	0.04
27AC	79	9	12	5.43	0.48	0.0096	2.035	1.40	0.05
27C	89	2	9	6.20	0.48	0.0082	1.904	4.39	0.01
30Ap	36	37	27	0.07	0.47	0.0088	1.128	−1.91	0.01
30 Bw	36	22	42	0.21	0.46	0.0091	1.082	13.14	0.03
30Bw2	47	24	24	0.09	0.52	0.012	1.12	31.98	0.001

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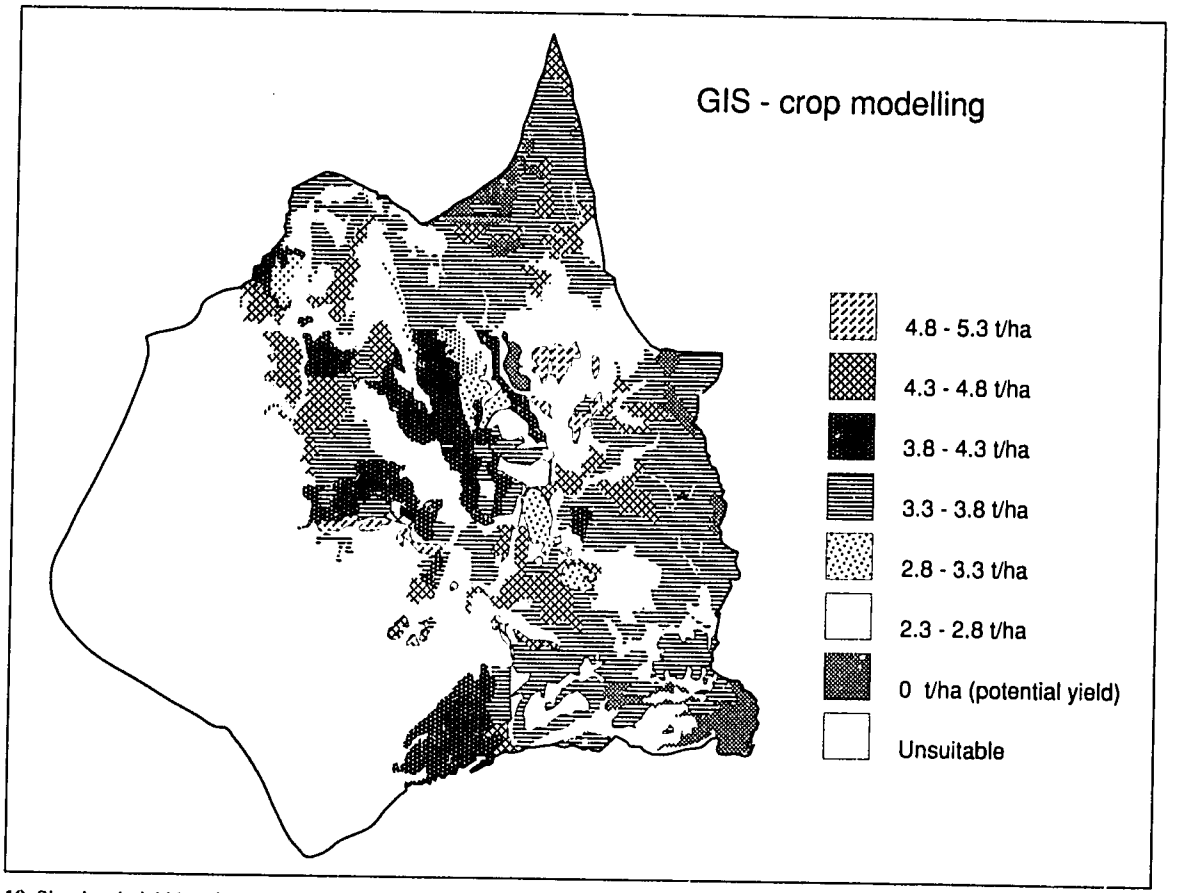
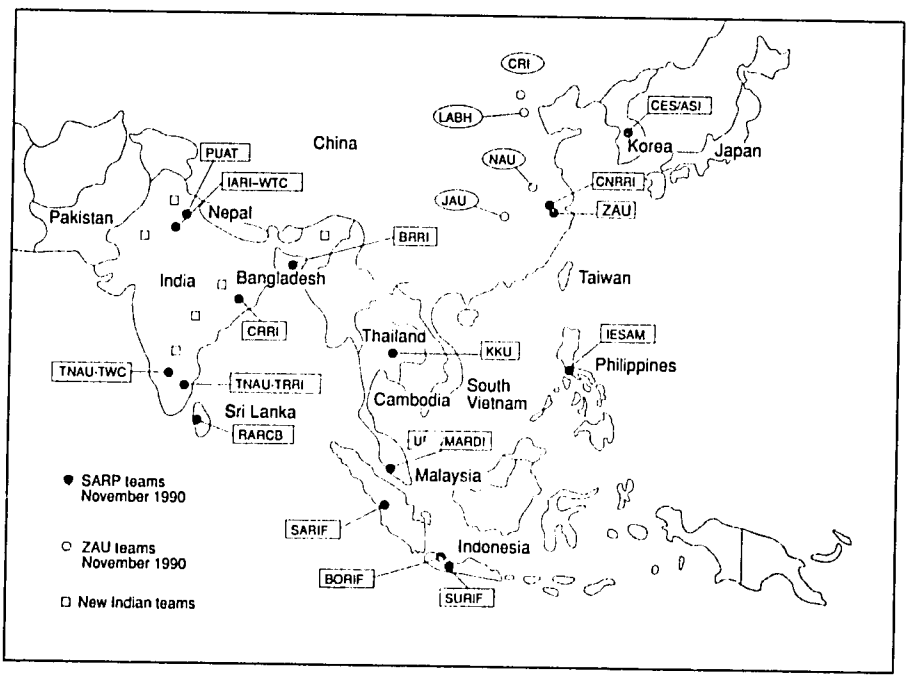


19. Simulated yield loss in wet season caused by drought in Tarlac Province, Philippines.



20. Location of SARP teams in Asia.

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Subsequently, an internal report was issued on plans and themes in the SARP project.

A workshop was held in India on simulation of the impact of pests and diseases on rice. Twenty-five participants of the SARP project attended the workshop, with more than 15 interested local scientists. Research findings were presented, topics of common interest were identified, and possibilities of cooperation between participants from different countries were explored. Participants agreed on the use of standardized models to study the effect of pests and diseases on crop growth and production. These models will be improved by the participants and used to solve local problems.

A workshop on simulation of the effects of water and nutrients on rice in relation to root development was held in Malaysia. Twenty-five participants of the SARP project from nine different countries and several interested local scientists attended the workshop. The group agreed to conduct a joint experiment to elucidate key questions related to N balance processes. The SARP team from the Indian Agricultural Research Institute-Water Technology Center in New Delhi, India, organized a training course on simulation and systems analysis in agricultural production for seven new teams from different agroecological zones in India.

Papers that SARP collaborators presented at the four thematic workshops organized in 1990 and 1991 were published in a book.

An international symposium on Systems Approaches for Agricultural Development was organized in Bangkok. The status of systems research and modeling in agriculture was reviewed with special focus on evaluating their efficacy and efficiency for achieving research goals and on their application in developing countries. In addition, the symposium aimed to promote international collaboration and to increase awareness of systems research and simulation. About 160 scientists attended the symposium. The proceedings will be published as a book and a special edition of *Agricultural systems*.

Socioeconomic impact and rice projections and policy analysis

This project aims to quantify the impact of modern rice technology on productivity, the welfare of producers and consumers, and income distribution. In 1991, we completed international collaborative research on the differential impact of modern rice technology across production environments in seven Asian countries: Bangladesh, China, India, Indonesia, Nepal, Philippines, and Thailand.

Varietal improvements, yield change, and income distribution: a case study of Lampung, Indonesia

Effects of the adoption of modern varieties (MVs) on income distribution are unknown. Diffusion of MVs has been limited to irrigated and favorable areas in South and Southeast Asia. Consequently, concerns have arisen that the widening productivity gap between favorable and unfavorable rice environments will worsen income distribution.

This case study was conducted in Lampung, Indonesia, collaboratively with Gadjah Madah University to analyze the income distributional effects of differential technology adoption across production environments. The study focuses on the effects of returns to land, an issue largely ignored in the Green Revolution literature.

Lampung is a suitable study site for several reasons.

- Its lowland production environments were relatively similar in the late 1960s. Subsequent changes in irrigation and the adoption of MVs provide a rare opportunity to identify the impacts of irrigation and MVs on productivity and returns to land in isolation from other factors.
- Dramatic changes in demographic patterns, land development, and technology adoption generated substantial land market transactions.
- Lampung has relatively large tracts of upland areas where MVs are not raised but where alternative crops can be grown. The presence of these tracts facilitates the investigation of the indirect effect that differential technology adoption has on the farmer's choice of cropping patterns (i.e., product market adjustments).

This study also considers the changing characteristics of MVs in assessing technology impact. Previous studies of technology impact have not distinguished specific variety effects, implicitly assuming that different generations of MVs have had uniform characteristics and, hence, unchanging productivity effects. However, MVs have changed over time from being mainly fertilizer responsive to having

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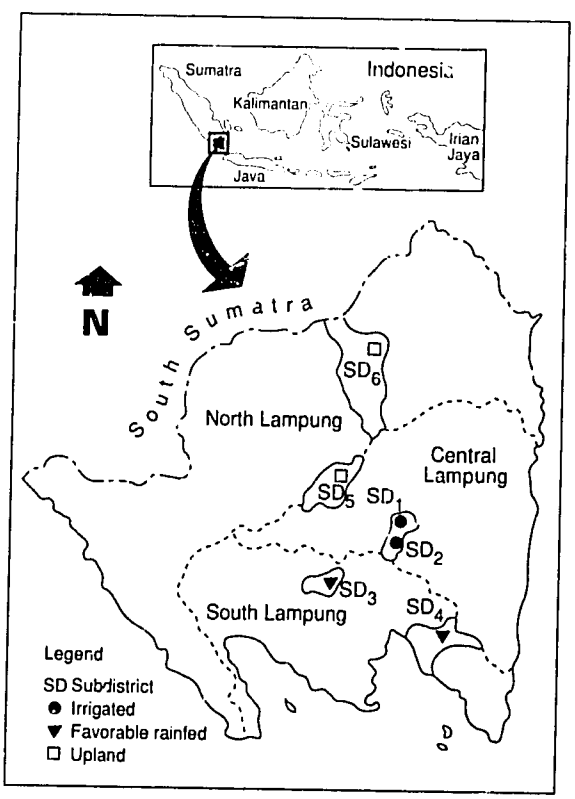
more pest resistance, better grain quality, and shorter growth duration.

Village characteristics. For each Lampung production environment—irrigated, rainfed, and upland—four villages were chosen. In each village, 40 farm households were randomly selected from the population of rice farmers (Fig. 21). Farm households were surveyed twice, during WS (November 1987-April 1988) and during DS (May-October 1988). The survey questionnaire covered detailed information on household characteristics, technology adoption, input use, yields prices, wages and labor contracts, tenure pattern, and income from all sources. A special questionnaire was used for historical data (by recall) on technology adoption, fertilizer use, productivity, and land prices.

Table 44 presents the villages' selected socioeconomic characteristics and cropping patterns by production environment. Land ownership and operational farm size are greater in the less favorable than in irrigated areas. Farmers in irrigated and rainfed villages typically own some upland area. Owner cultivation is the dominant tenure pattern and the proportion of leasehold and share tenancy is highest in the more favorable rice-growing villages.



21. Location of areas for an intensive survey, Lampung, Indonesia, 1987-88.

Rice is grown twice a year in irrigated areas. In the mid-1970s, the introduction of MVs made double cropping of rice possible in some favorable rainfed areas where residual moisture is available after WS. Multiple cropping, including rice, is common in the upland area.

Modern varieties and yield. Current plantings comprise MVs bred at IRRI and in the Indonesian rice research system. However, the first-generation varieties (IR5, IR8, and C4-63) have been completely replaced by second (IR36) and third generation (IR64) MVs from IRRI and by domestically bred varieties.

The Indonesian improved varieties are grouped into IMV1 and IMV2. IMV1 includes crosses of IR5 and the Indonesian improved variety Syntha, which produced Pelita I-1 and Pelita I-2. IMV2 includes crosses between Pelita I-1 and other improved varieties and traditional varieties (TVs), e.g., Cisadane, Cimandiri, Cipunegara, Citarum, Citandui, Krueng Aceh, Semeru, and Sadang.

Current patterns of technology adoption and yields. Table 45 presents adoption rates of MVs and TVs and yields by production environment. TVs are

Table 44. Farm size, tenure, and cropping patterns by production environment. Lampung, Indonesia, 1987-88.

Item	Irrigated	Rainfed	Upland
Sample farm households (no.)	160	160	160
Land ownership (ha)	1.3	1.7	2.2
Lowland	0.9	1.0	-
Upland	0.4	0.7	2.2
Operational farm size (ha)	1.3	1.6	1.9
Rice farm	0.9	0.9	1.5
Other crops	0.4	0.7	0.4
Tenure of rice farm (%)			
Owner	85	89	98
Leasehold	5	4	0
Share-tenancy	10	7	2
Cropping pattern (%)			
Rice - rice	100	27	0
Rice - nonrice food crop[a]	0	61	0
Rice - fallow	0	12	18
Multiple cropping including rice	0	0	82
Rice cropping intensity (%)	200	127	100
Total cropping intensity (%)	200	188	182

[a]Includes maize, peanut, mungbean, soybean, cassava.

Table 45. Modern variety (MV) adoption and rice yield by variety, season, and production environment. Lampung, Indonesia, 1987-88.

Variety[a]	Wet season			Dry season	
	Irrigated	Rainfed	Upland	Irrigated	Rainfed
	MV adoption (% of area)				
Traditional variety	0	0	100	0	0
IMV1	0	16	0	0	22
IR36	6	5	0	27	48
IMV2	92	69	0	70	8
IR64	2	10	0	3	22
	Yield (t/ha)				
Traditional variety	-	-	1.8	-	-
IMV1	-	2.8	-	-	2.5
IR36	4.2	3.4	-	3.6	2.7
IMV2	4.5	3.6	-	4.0	2.6
IR64	4.5	3.5	-	4.2	2.8

[a]IMV1 includes Pelita I-1 and Pelita I-2 — results of crosses between IR5 and the national improved variety Syntha. IMV2 includes crosses between Pelita I-1 (IMV1) and other improved varieties, e.g., Cisadane, Krueng Aceh, etc.

planted solely in the upland areas. Irrigated and rainfed lowland areas are planted only to MVs.

The latest Indonesian-bred MVs (IMV2, particularly Cisadane and Krueng Aceh) dominated rice cultivation in the irrigated lowland villages during both growing seasons. IMV2 is also popular in the rainfed lowland, but only during WS. IR36 was planted in almost half the rainfed rice area, and IMV1 and IR64 each were raised in 22% of the area during DS. The shorter growth duration of IR36 and the higher drought tolerance of IMV1 and IR64 make these varieties more suitable for rainfed areas. IR64 was released in the 1987 DS and is expected to spread more widely.

Average yield was higher in the more favorable environments and generally increased with later generation MVs. Yields of all MVs were about the same in the rainfed lowland during DS and were mostly much lower than WS yields. During WS, the greatest yield attained from TVs grown in upland areas was only half the yield from third-generation MVs.

Yield determinants. To identify the impact of varietal improvement on land productivity, a yield function was estimated by regression where varieties, production environment, and socioeconomic characteristics were specified as independent variables. Because the effects of rice varieties on yield depend on the environment, the production environment and varieties are specified as interaction terms. Thus, each of the three production environments (irrigated [IRG], rainfed [RF], and upland), expressed as a dummy variable, is multiplied with dummy variables indicating variety or group of varieties, e.g., IRGxIR36. In upland areas, a distinction is made between TVs planted as a single crop (UplandxTV) and those cultivated as part of a multiple cropping system (UplandxTV-MCT). The interaction term between rainfed lowland and the first generation of Indonesian MVs (RFxIMV1) served as the control in this set of environmental and technology variables.

Among the socioeconomic characteristics, the variables were rice farm size in hectares, tenure pattern as represented by the ratio of area under leasehold and under share tenancy, age of household head, years of schooling of household head, and the number of workers in the family. Except for the variables expressed as dummies and ratios, all continuous independent and dependent variables are specified in natural logarithms.

The estimated yield functions in Table 46 indicate that production environments and varieties are the important factors determining yields. Moreover, the pattern of the estimated coefficients of the interaction terms between production environment and varieties is consistent with expectations—the adoption of more recent MVs has increased yields more significantly in the irrigated than in the rainfed lowlands. Because of limited water supply, varieties with shorter growth duration, such as IR36 and IR64, had higher yields than longer growth duration varie-

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Table 46. Regression results of paddy yield functions. Lampung, Indonesia, 1987-88 WS and DS.[a]

	Lowland		Lowland + upland
	Wet season (1)	Dry season (2)	Wet season (3)
Intercept	8.02	7.40	7.77
RF × IR36	0.17*	0.11*	0.17**
	(3.61)	(1.85)	(2.36)
RF × IMV2	0.24**	0.07	0.25**
	(8.47)	(0.85)	(5.82)
RF × IR64	0.20**	0.17**	0.21**
	(5.39)	(2.22)	(3.60)
IRG × IR36	0.38**	0.50**	0.39**
	(8.31)	(8.28)	(5.55)
IRG × IMV2	0.46**	0.58**	0.47**
	(16.91)	(10.11)	(11.40)
IRG × IR64	0.47**	0.63**	0.47**
	(6.49)	(4.21)	(4.20)
UPLAND × TV	-	-	−0.58**
			(−10.58)
UPLAND × TV-MCT	-	-	−0.66**
			(−14.56)
TRUSER	0.02	−0.09	0.02
	(0.36)	(−1.20)	(0.31)
Ln RFSIZE	−0.03**	−0.03	−0.02*
	(−2.44)	(−1.32)	(−1.72)
LEASER	−0.05	−0.001	−0.04
	(−0.94)	(−0.01)	(−0.48)
SHARER	0.03	0.03	0.05
	(0.83)	(0.45)	(1.01)
Ln AGE	−0.02	0.09	0.04
	(−0.61)	(1.23)	(0.88)
Ln SCHOOL	0.004*	0.002	0.007*
	(1.77)	(0.28)	(2.03)
Ln WORKER	−0.005	−0.008	−0.008
	(−0.29)	(−0.23)	(−0.33)
R^2	0.62	0.55	0.88
F value	38.31	21.23	228.57
No. of samples	320	240	480

[a]Numbers in parentheses are *t*-statistics. RF = rainfed environment, IRG = irrigated environment, UPLAND = upland environment, MCT = multiple cropping system, TV = traditional variety, TRUSER = tractor user, Ln = natural logarithm, RFSIZE = rice farm size in ha, LEASER = ratio of area under leasehold, SHARER = ratio of area under share-tenancy, AGE = age of household head, SCHOOL = years of schooling of household head, WORKER = number of workers in the family.

ties, such as IMV1 and IMV2, during DS in rainfed areas.

Estimated results do not significantly change when the lowland and upland data are combined. In this equation, the yield of upland rice under monoculture was about 56% of yield from IMV1 grown as rainfed lowland rice and was slightly lower when grown in multiple cropping.

The farm size and schooling coefficients are significant, and have the expected signs in WS, but the magnitudes are comparatively small. Farmer's age, the number of working family members, tenure, and tractor adoption, on the other hand, did not have significant impact.

Varietal improvement and land prices. Although differential technology adoption increases the productivity gap between favorable and unfavorable production environments, potential inequitable effects on income distribution may be mitigated by labor, land, and commodity market adjustments. Earlier program reports have noted that as demand for labor increases in favorable areas where MVs are used, interregional migration from unfavorable and favorable areas occurred, equalizing wages and sharing the benefits of higher labor productivity in the adopting regions with migrants from unfavorable areas. Differential technology adoption across production environments did not significantly exacerbate inequities in labor income. However, land rental prices are expected to become more disparate across production environments.

The relatively similar production environments among the study villages in the late 1960s and subsequent changes in irrigation and adoption of MVs, provide a rare opportunity to identify the impacts these changes had on the return to land. Although historical data on land rent are not available and farmer recall of rents paid was poor, farmers who had purchased land could accurately recall the price and year of transaction.

Therefore, we focus on the impact varietal improvement had on land prices. The main questions for getting related information on land prices were as follows: when did the farmer buy the land, how much did it cost, and what was the parcel size; was it irrigated, rainfed lowland, or upland ricefield, dryland nonricefield, or residential land; what was the soil class; and had the farmer adopted MVs before buying the land? Among the 480 farm households, 160 reported land transactions (142 lowland parcels and 18 upland parcels) from 1969 to 1987.

Changes in land prices. The number of land transactions in irrigated and rainfed villages was about the same, except during 1984-87 (Table 47). The average size of parcels sold tended to decline over time, mainly because of population pressure. Population pressure seems more pronounced in the irrigated and rainfed lowlands than in the upland areas, where some mountainous areas remain unsettled. Some farmers in the rainfed lowland had

adopted MVs by 1970 and almost all sample farmers in the lowland area grew MVs by the mid-1970s.

Data from Table 47 indicate that land prices of irrigated and lowland areas in the early 1970s were about equal. This is as expected because most of the villages that are irrigated now were rainfed or inadequately irrigated at that time. The price of irrigated lowlands increased sharply from the mid-1970s as a consequence of irrigation expansion and MV adoption. Further increases occurred in the 1980s as rice productivity continued to grow, partly because of the adoption of improved MVs.

The particularly rapid growth in real land prices in the irrigated villages since the early 1970s widened the gap in land prices across production environments. Increases in real land prices in the rainfed areas were much less than in irrigated areas. In upland areas, where no technological change took place, real land prices essentially remained constant.

Such rapid growth, particularly in the irrigated villages, can not be explained solely by more favorable price incentives for rice because the fertilizer-to-rough rice price ratios changed significantly only in the early 1980s. It seems more reasonable to attribute the land price growth to the construction of irrigation facilities and the adoption of MVs in these areas.

Determinants of land price. Determination of land rental depends on several factors. On the demand side are variables that affect the profitability of farming, such as input and seed prices, technology, and production environments. On the supply side, man-to-land ratio (village population to cultivated land area) can be a proxy for shifts in the land supply function. Distance from the market center, a proxy for access to urban markets, also affects land price. Although a farmer's decision to sell land may depend on financial pressures arising from family or personal circumstance or occupational and locational mobility, these pressures have to be assumed as occurring randomly. Assuming changes in land rental to be proportional to land prices, a land price determination function in log-linear form was estimated.

Table 48 presents the regression results. In equation 1, types of varieties were not distinguished. Production environment and varieties were specified simply as dummy variables for irrigation and MV adoption, and as an interaction term between irrigation and MVs. These variables were statistically significant with the expected positive coefficients. Adoption of MVs and irrigation appear to contribute equally well to growth in rice productivity as evidenced by the nearly equal estimated coeffi-

Table 47. Number and size of land transactions, MV adoption, and land price by period and production environment. Lampung, Indonesia, 1969-87.

Item	Environment		
	Irrigated	Rainfed	Upland
Transactions (no.)			
1969-73	14	15	0
1974-78	15	14	3
1979-83	16	15	0
1984-87	35	18	15
Average size of transaction (ha)			
1969-73	0.41	0.75	-
1974-78	0.53	0.64	2.00
1979-83	0.42	0.67	-
1984-87	0.26	0.45	1.83
MV adoption (% of area)			
1969-73	0	7	0
1974-78	84	91	0
1979-83	100	100	0
1984-87	100	100	0
Land price (t rice equivalent/ha)			
1969-73	3.9	3.5	-
1974-78	16.3	5.4	4.6
1979-83	23.3	6.9	-
1984-87	30.5	13.5	5.3

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Table 48. Regression of land price determination functions in an intensive survey of Lampung, Indonesia, 1987-88.[a]

	Lowland		Lowland + upland
	Equation 1	Equation 2	Equation 3
Intercept	8.18	8.00	7.99
IRG	0.39**	-	-
	(2.13)		
MV	0.42**	-	-
	(3.77)		
IRG × MV	0.67**	-	-
	(3.40)		
RF × IR5	-	0.28**	0.27**
		(2.81)	(2.86)
RF × IMV1	-	0.74**	0.71**
		(5.09)	(5.57)
RF × IR36	-	1.003**	0.97**
		(5.14)	(5.61)
RF × IMV2	-	1.43**	1.40**
		(9.95)	(11.31)
IRG × TV	-	0.45**	0.44**
		(3.15)	(3.22)
IRG × IR5	-	1.22**	1.21**
		(8.82)	(9.10)
IRG × IMV1	-	1.69**	1.69**
		(15.50)	(16.08)
IRG × IR36	-	1.99**	1.97**
		(12.31)	(13.66)
IRG × IMV2	-	2.19**	2.16**
		(15.62)	(18.13)
UPLAND	-	-	0.48**
			(3.98)
Ln DISTC	0.03	−0.008	−0.002
	(0.70)	(−0.23)	(−0.05)
Ln MLR	0.14*	0.07	0.08
	(1.76)	(1.07)	(1.40)
Ln FPPRICE	−1.002**	0.04	0.007
	(−6.86)	(0.21)	(0.04)
R^2	0.84	0.91	0.91
F value	117.53	108.84	118.54
No. of samples	142	142	160

[a]Numbers in parentheses are *t*-statistics. IRG = irrigated ecosystem, RF = rainfed ecosystem, UPLAND = upland ecosystem, Ln = natural logarithm, DISTC = distance, MLR = man:land ratio, FPRICE = fertilizer : paddy price ratio.

cients of these variables. On the other hand, the coefficient of the interaction term is considerably higher, suggesting a higher rate of increase in the land prices of irrigated areas than in rainfed lowland areas as MVs were adopted.

Because profitability of rice farming will critically depend also on relative prices of rough rice and inputs, the fertilizer-to-rough rice price ratio was inserted. The coefficient was highly significant and negative, as expected. Population pressure, as measured by man-to-land ratio, was also found to drive up land prices. Only the coefficient of the distance variable is not significant, mainly because distances between villages of our sample and town centers do not vary much.

As discussed in the previous section, newer MVs were adopted in recent years. In equation 2, MVs were specified as an interaction term between production environment and specific varieties or variety groups. With this specification, the coefficients of the man-to-land ratio and fertilizer-to-rough rice price ratio became insignificant, as is the distance variable. Most remarkable are the significance and magnitudes of the estimated coefficient of environment-variety interaction terms. The coefficients of RF×IR5, RF×IMV1, RF×IR36, and RF×IMV2 were highly significant and increased from 0.28 to 0.74, 1.00, and further to 1.43. These estimated coefficients imply that the adoption of improved MVs continuously increased land price and, in recent years, the price of rainfed lowlands suitable for MVs increased 4.1 times relative to the land price of rainfed areas planted to TVs. These results indicate that the availability of improved MVs significantly and continuously contributed to the acceleration of productivity growth even in rainfed areas.

The coefficient of IRG×TV is 0.45 and significant, implying that land productivity improved with irrigation even in the absence of MVs. The value of land, however, dramatically increased with the adoption of MVs—the coefficient of IRG×IR5 is significantly larger than that of IRG×TV.

Improvement in the characteristics of MVs further contributed to productivity growth in irrigated lands. The coefficient of IRG×IMV1 is 1.69, whereas the coefficient of IRG×IR36 is 1.99 and that of IRG×IMV2 is 2.19. All are significantly different from the coefficient of IRG×IR5 (0.28). Thus, changing characteristics of MVs over time contributed to the increases in land values in irrigated areas. However, the rate of increase seems to be declining, which may indicate a declining contribution of MVs to productivity growth in the irrigated areas.

The estimated coefficients of the interaction terms between the MV variables and IRG are significantly larger than the corresponding coefficients of those MV variables interacting with RF. Thus, by increasing both rice cropping intensity and rice yields, the adoption of a series of improved MVs brought about greater increases in land prices in the irrigated than in the rainfed area.

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Even when the regression is based on the combined lowland and upland price data, as shown in equation 3, the results are essentially unchanged. Distance, man-to-land ratio, and fertilizer-to-rough rice price ratio remain insignificant, and the coefficients of the interaction terms are only slightly lower than those in equation 2. The coefficient of upland dummy is 0.48, implying that the price of upland areas was 61% higher than the price of rainfed lowlands planted to TVs. This is not unreasonable, because the price of upland areas generally reflects the value of other crops grown in those areas.

Household income distribution. Although differential technology adoption clearly widened returns to land across production environments, effects on income distribution depend on what happens to overall household income. Household income is determined not only by the distribution of rice income but also by the ownership of productive resources such as land, human capital, and capital assets, as well as market and institutional factors such as opportunities for nonrice production, access to nonfarm employment, and land tenure. If labor migration reduces farm size in favorable areas and increases farm size in unfavorable areas, the potentially inequitable impact may be partly mitigated. Potentially adverse effects on rice farm incomes in the unfavorable production environments may also be alleviated by reallocating land to nonrice crops and family labor time to nonfarm employment. Factors affecting differential level of household income are examined in this section.

Sources of household income. Table 49 shows the average annual income of farm households by source and by production environment. In the irrigated villages, rice production accounted for slightly more than half of total household income, and returns to land had by far the highest contribution. In less favorable areas, income from rice cultivation as a whole, as well as returns to land, was relatively small. On the other hand, nonrice income in the less favorable areas was higher absolutely, which suggests that the lower income from rice production in less favorable environments was substantially compensated for by allocating more family resources to production of other crops and livestock, and to nonfarm activities. Total household income in the rainfed villages was about 88% of that in the irrigated villages, and in upland villages it was about 75%. Farm income in the upland villages did not substantially differ from that of the other villages, mainly because upland farms were larger than those in the rainfed and irrigated villages.

Determinants of household income. Table 50 reports income determination functions for rice, nonrice, and nonfarm incomes. Each income com-

Table 49. Average annual income[a] of farm households by production environment. Lampung, Indonesia, 1987-88.[a]

Source of income	Income (thousand $)		
	Irrigated (5.7)	Rainfed (6.3)	Upland (5.0)
Rice production	443	273	154
Labor[b]	104	77	40
Capital[c]	24	20	18
Land[d]	313	176	96
Nonrice farm income	225	314	433
Land rental earnings	61	48	16
Off-farm wage earnings	32	23	11
Nonrice food crops		13	170
Perennial crops and vegetables	76	120	177
Livestock, poultry, and fishery	56	110	59
Farm income	1092	961	959
Nonfarm income[e]	194	169	63
Total income	862	757	650
Income per person	151	120	116

[a]In rupiah, converted into dollars at Rp 1634.8 = $1. Household size is in parentheses. [b]Imputed family labor income in own farm. [c]Imputed return to owned machineries and water buffaloes. [d]Residual for owner-cultivators and residual minus actual rent payments for tenants. [e]Includes labor earnings from nonfarm employment, other assets, pensions, and remittances.

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Table 50. Regression results of annual household income functions by source. Lampung, Indonesia, 1987-88.[a]

	Rice income equation	Nonrice income equation	Nonfarm income equation
Intercept	12.53	13.90	20.57
RF × IMV1-IR36	0.35**	−0.16	−0.19
	(5.12)	(−0.30)	(−0.13)
RF × IMV2-IR36	0.48**	−0.27	−1.84
	(5.88)	(−0.42)	(−1.10)
RF × IMV2-IMV2	0.45**	−0.85	−2.44
	(4.09)	(−0.97)	(−1.08)
IR × IMV2-IR64	0.52**	−0.48	−0.66
	(6.28)	(−0.73)	(−0.39)
IRG × IR36-IR36	0.52**	0.12	−0.17
	(4.58)	(0.14)	(−0.07)
IRG × IMV2-IR36	0.66**	0.32	−1.11
	(11.57)	(0.71)	(−0.94)
IRG × IMV2-IMV2	0.76**	0.43	0.91
	(17.29)	(1.25)	(1.01)
IRG × IMV2-IR64	0.83**	0.11	1.75
	(6.17)	(0.10)	(0.63)
UPLAND × TV	−0.77**	−0.82	−0.68
	(−12.01)	(−1.61)	(−0.51)
UPLAND × TV-MCT	−0.96**	0.52	−1.006
	(−23.06)	(1.57)	(−1.17)
Ln RFSIZE	0.83**	−0.40*	−1.45**
	(34.25)	(−2.09)	(−2.90)
Ln NRFSIZE	0.03*	0.89**	−0.27
	(1.98)	(8.55)	(−0.98)
LEASER	−0.78**	−0.06	4.05
	(−6.57)	(−0.07)	(1.56)
SHARER	−0.78**	0.49	0.47
	(−9.55)	(0.75)	(0.28)
ANOWNER	0.16**	0.80**	−1.55**
	(5.62)	(3.48)	(−2.61)
Ln AGE	0.06	−0.46	−4.02**
	(0.81)	(−0.77)	(−2.57)
Ln SCHOOL	0.004	−0.05	0.08
	(0.75)	(−1.19)	(0.78)
Ln WORKER	0.03	−0.42	2.06**
	(0.79)	(−1.39)	(2.64)
R^2	0.86	0.23	0.12
F value	162.02	7.86	3.35
No. of samples	480	480	480

[a]Numbers in parentheses are *t*-statistics. RF = rainfed environment, IRG = irrigated environment, UPLAND = upland environment, TV = traditional variety, MV = modern variety, MCT = multiple cropping system, Ln = natural logarithm, RFSIZE = rice farm size, NRFSIZE = nonrice land, LEASER = ratio of area under leasehold, SHARER = ratio of area under share-tenancy, ANOWNER = ownership of bullocks, AGE = age of household head, SCHOOL = years of schooling of household head, WORKER = number of workers in the family.

ponent is regressed on the interaction terms between production environments and various MVs and socioeconomic characteristics, i.e., rice farm size, tenure pattern, ownership of draft animals, age and schooling of household head, and number of working family members. The control variable pertains to the rainfed farms growing any MVs during WS and to nonrice crops or fallow during DS.

The rice income equation showed the best statistical fit with an R^2 of 0.86. Except for age, schooling of household head, and the number of working members, all the coefficients were highly significant and had the expected signs. The size of land, its tenure pattern and quality, and ownership of bullocks and water buffaloes significantly explain differences in rice income across farm households. The coefficients of leasehold and share-tenancy are equal despite lower rent payments of leaseholders to landowners because share-tenants devote relatively more family labor to rice farming. The ability to plant a second crop and degree of water control mattered, as evidenced by significant differences in the coefficients across uplands, rainfed lowlands, and irrigated farms. The effect of difference in varieties planted seems most pronounced in the irrigated areas. Moreover, in both the irrigated and the rainfed areas, the choice of IMV2 and IR64 provided the highest income. On the other hand, upland areas clearly provided the lowest income from rice.

While the size of riceland, other land, and ownership of bullocks and water buffaloes explained nonrice farm income, the characteristics of the family labor force, specifically age of the household head and the number of working members, significantly determined the size of nonfarm income. The negative coefficients of age, rice farm size, and bullocks in the nonfarm income equation simply imply that farm households with younger heads, smaller rice area, and fewer other assets devote more family labor time to nonfarm employment. This suggests that income from other sources of employment compensates for the smaller proceeds from rice farming in the less favorable environments.

Determinants of household income distribution. The effects of varietal improvement on household income distribution were examined by a decomposition analysis of the Gini measure of income inequality. The overall Gini ratios based on household income did not show significant difference across production environments, and were slightly lower in more favorable villages (Table 51). On the other hand, the Gini ratios of income components suggest that income generated from nonfarm activities and returns to owned capital in rice farming were most unevenly distributed among farm households in any production environment. The distribution of

Table 51. Income shares, Gini ratios, and contribution of income components by production environment in an intensive survey, Lampung, Indonesia, 1987-88.

Environment	Total income	Rice income			Nonrice income	
		Land	Family labor	Owned capital	Farm	Nonfarm
		Income shares				
Irrigated	1.000	0.333	0.127	0.030	0.274	0.236
Rainfed	1.000	0.191	0.107	0.028	0.439	0.235
Upland	1.000	0.130	0.062	0.028	0.681	0.099
Pooled	1.000	0.227	0.102	0.029	0.447	0.196
		Gini ratios based on household income				
Irrigated	0.347	0.394	0.288	0.725	0.531	0.725
Rainfed	0.363	0.363	0.286	0.664	0.552	0.744
Upland	0.385	0.470	0.306	0.594	0.535	0.681
Pooled	0.369	0.476	0.354	0.675	0.568	0.743
		Contribution of household income components				
Irrigated		0.093	0.014	0.007	0.101	0.132
Rainfed		0.026	0.007	0.003	0.200	0.127
Upland		0.030	−0.003	0.009	0.349	0.000
Pooled		0.059	0.008	0.007	0.204	0.091
		Gini ratios based on per capita income				
Irrigated	0.370	0.435	0.333	0.740	0.539	0.732
Rainfed	0.371	0.394	0.338	0.681	0.567	0.734
Upland	0.425	0.488	0.298	0.622	0.561	0.687
Pooled	0.396	0.507	0.390	0.689	0.592	0.743
		Gini ratios based on individual income				
Irrigated	0.350	0.419	0.309	0.714	0.533	0.713
Rainfed	0.371	0.399	0.328	0.690	0.559	0.720
Upland	0.440	0.497	0.287	0.643	0.590	0.660
Pooled	0.394	0.498	0.367	0.692	0.595	0.726

income from nonrice farming was more skewed than land income and family labor earnings from rice farming.

In the irrigated villages, the most important source contributing to the overall income inequality was nonfarm activities (38%) followed by nonrice farming (29%) and the returns to land in rice farming (27%). In the rainfed villages, it was nonrice farming (55%) followed by nonfarm activities (35%), while in the upland villages it was almost solely nonrice farming (91%).

The pooled data of all households also show that the most important contributions to the overall income inequality came from nonrice farming (55%), the nonfarm sector (25%), and land income from rice farming (16%). The distribution of family labor income was equal while that of capital income was clearly more skewed than the overall income. However, the inequality of capital income did not significantly contribute to the overall income inequality because its share in total income was small.

Gini ratios based on per capita income were also estimated to account for differences in family size. The distribution of overall income, as well as income components, was generally more unequal for per capita income than for household income, indicating that lower income households tended to have larger family size. Income distribution was more uneven in the upland area in which MVs were not grown, and was only slightly worse in the rainfed area than in the irrigated areas. Patterns of contributions of the various income sources to income inequality were similar to those of household income patterns.

Conclusion. Because adoption of newer MVs increased land income from rice farming in the irrigated area more than in the rainfed lowland and upland areas, overall income inequality may increase. Despite the greater disparity in returns to land between favorable and unfavorable rice-growing areas, distribution of household income was not significantly worsened. This is mainly because farms in favorable areas are smaller and profitable nonrice

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income opportunities existed in less favorable areas so that family labor and land were used in nonrice farming and nonfarm work. Thus, MV improvement did not contribute much to the overall income inequality among farm households across rice production environments in Lampung.

The tradeoff between efficiency and equity associated with the diffusion of MVs is not as severe as commonly thought. Therefore, research investment is warranted for the favorable rice-growing areas and to develop modern technologies for the nonrice food and commercial crops grown in the less favorable environments.

Subprogram IV: Pest science and management

This project aims to generate knowledge for management strategies in rice ecosystems by improving our understanding of the biology and ecology of pests and of beneficial organisms. The three specific objectives are to 1) analyze the biology and ecology of pests and beneficial organisms, 2) characterize and quantify the key factors influencing population dynamics and pest-plant coevolution, and 3) quantify yield-loss relationships and determine the mechanisms of plant-pest interactions.

Seed health

Bacterial pathogens associated with seed and sheath discoloration

This activity focuses on determining the bacterial pathogens causing rice seed and sheath discoloration in the tropics. Many bacterial pathogens cause discoloration disease syndromes, which are associated with MVs and known to be seedborne. The discolorations result from complex interactions of biotic and abiotic stresses. As many pseudomonad pathogens are reported to cause panicle and sheath discoloration in temperate environments, this activity aims at generating the information needed to prevent discoloration through crop management and healthy germplasm exchanges.

The collection of pathogens (185 from more than 4,000 isolates collected throughout the Philippines) was taxonomically identified using a series of phenotypic analyses at both IRRI and Rijksuniversiteit Gent, Belgium. Symptoms induced by the groups of pathogens were verified at IRRI.

Three commercially available techniques (API 20NE/API 20E [bioMerieux SA France], BIOLOG [Biolog Inc. of Hayward, California], and Microbial Identification System based on the cellular fatty acid composition [FA-MIS ID, Newark, Delaware]) were used to identify the Philippine rice isolates and reference cultures of the *Pseudomonas*, *Erwinia*, and *Xanthomonas* genera. Results of these tests were numerically analyzed against data bases of known rice pathogenic bacterial isolates. An overview of the results is given in Table 52 and Figure 22.

With BIOLOG, correct identification for all reference strains was obtained for *Pseudomonas avenae*, *P. aeruginosa*, *P. corrugata*, *P. fuscovaginae* (except strain GR2), *P. marginalis*, *P. putida*, *P. syringae*, and *Xanthomonas maltophilia*. During numerical analysis, the Philippine isolates and the reference strains clustered in nine groups. Cluster A5 included the *P. aeruginosa* isolates; cluster B1 comprised *P. fuscovaginae* isolates and reference strains; cluster B2 had isolates and reference strains belonging to *P. marginalis*, *P. corrugata*, *P. fluorescens*, and *P. aureofaciens*; cluster E had *P. avenae* cultures and reference strains; and cluster D1 was formed by the *P. glumae* reference strains and five Philippine cultures. The remaining 62 Philippine fluorescent isolates grouped in cluster A2, A3, A4, and A6 are still for identification because they did not contain reference strains.

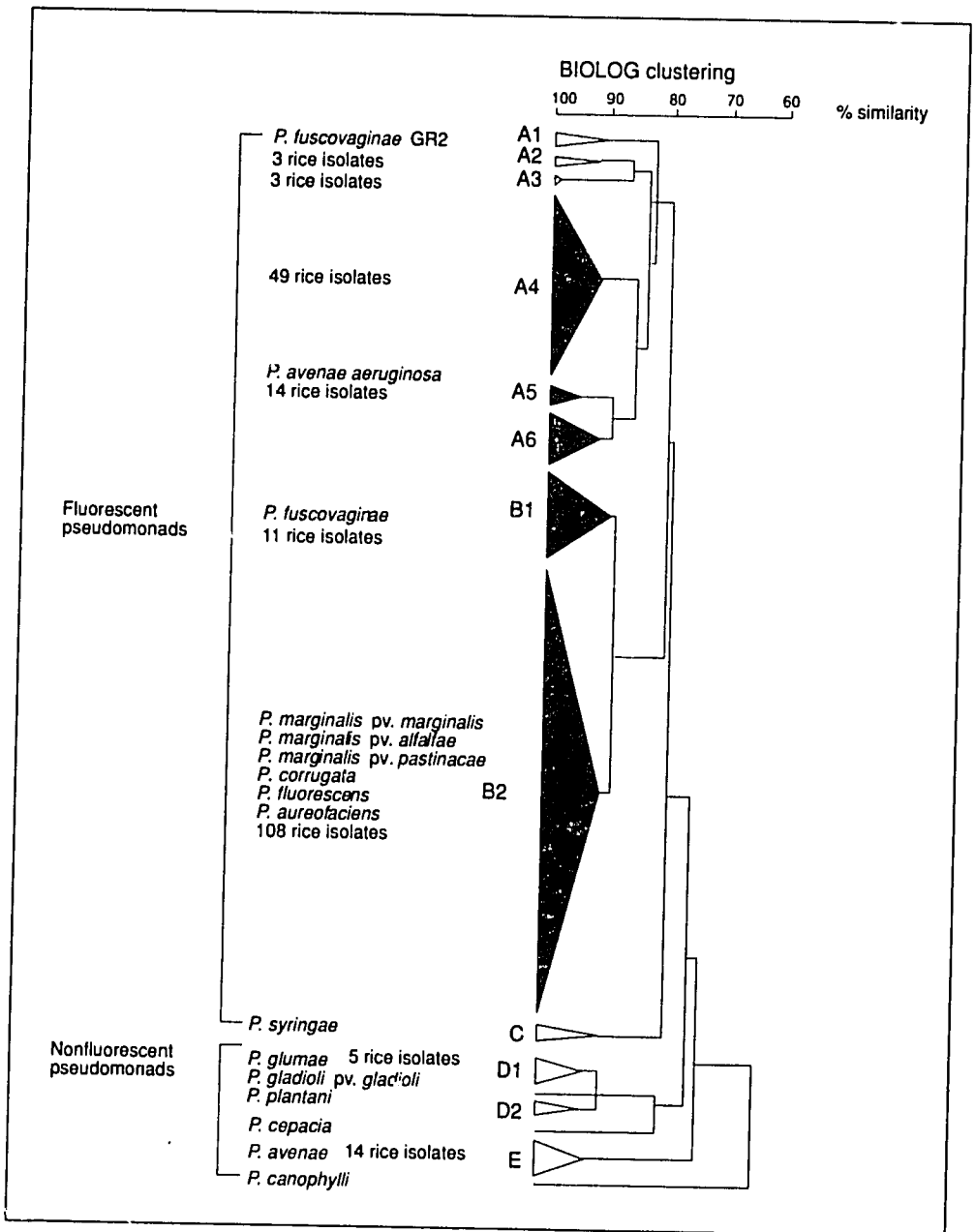
To further confirm the identities of the Philippine isolates, characteristic growth on selective media, growing-on tests, and Ouchterlony double diffusion tests were done. The characteristic colonies on the selective media used for the known rice pathogens revealed the presence of *P. glumae*, *Erwinia* spp., and *P. fuscovaginae* in the collection. However, not all strains identified by BIOLOG, FA-MIS ID, and API as *P. fuscovaginae* showed the characteristic cream-colored colony with greenish center (Fig. 23) on Miyajima's selective medium. All the *P. glumae* colonies that are congruent with the identification in Belgium showed the characteristic colony types "A" and "B" (Fig. 24).

Selective media used for *P. plantarii* did not show the distinctive colony morphologies expected. All other phenotypic tests suggest the absence of this species. As limited selective media are available for plant pathogenic bacteria, especially for fluorescent pseudomonads, few differential media were used.

Table 52. Identification of Philippine rice isolates.

Rice isolates (no.)	BIOLOG		API 20NE/API 20E	FA-MIS ID	
	Cluster	Identification (similarity)[a]	Identification (code[b])	Cluster	Identification (similarity)[a]
3	A2	*P. fluorescens* C. (0.682-0.862)	*Pseudomonas* (0156557)	II	*P. aureofaciens* (0.270-0.527)
3	A3	*P. fluorescens* C (0.638-0.768)	*Pseudomonas* (1152555)	II	*P. putida* A (0.194-0.321)
49	A4	*P. fulva* (0.234-0.451)	No match (0054455)	II	*P. putida* A (0.181-0.755)
		P. putida A (0.137-0.790)	*Pseudomonas* (0056451)		
			Pseudomonas (0056455)		
			Pseudomonas (0154455)		
			P. fluorescens (0156455)		
4	A5	*P. aeruginosa* (0.834-0.826)	*P. aeruginosa* (0154475)	VI	*P. aeruginosa* (0.660-0.739)
			P. aeruginosa (1154475)		
4	A6	*P. fluorescens* C (0.093-0.697)	*Pseudomonas* (0156457)	I	No match
			Pseudomonas (0156557)	II	*P. putida* A (0.198)
11	B1	*P. fuscovaginae* (0.711-0.917)	*P. fluorescens* (0147555)	I	No match
			P. fluorescens (0157455)	IV	*P. putida* A (0.381)
			P. pseudomonas (0157555)		
109	B2	*P. corrugata* (0.334-0.424)	*P. fluorescens* (0147555)	II, IV	*P. aureofaciens* (0.135-0.796)
		P. marginalis (0.090-0.838)	*P. fluorescens* (0156555)		*P. fluorescens* B (0.106-0.802)
		P. fluorescens B (0.747)	*Pseudomonas* (0157555)		*P. putida* A (0.197-0.769)
			No match (0357555)		
3	D1	*P. gladioli* (0.111-0.229)	No match (0477551)	VIII	No match
		P. caryophyli (0.062-0.188)	No match (1077051)		
			No match (1077451)		
			No match (1477551)		
14	E1	*P. avenae* (0.188-0.900)	No match (1205474)	V	*P. facilis* (0.145-0.509)
			No match (1205464)		*H. pseudoflava* (0.123-0.457)
			No match (1205460)		
			No match (1247577)		
4	F	*X. maltophilia* (0.003-0.704)	*X. maltophilia* (0472345)	I	No match
		X. campestris pv. *utica* (0.619)	No match (0473345)		*X. maltophilia* (0.121-0.152)
14	G	*E. agglomerans* A (0.057-0.7358)	*Erwinia* sp. (1245123)	X	
		K. terrigena (0.544-0.735)	*Erwinia* sp. (1245163)		
			Erwinia sp. (1245563)		
			Erwinia sp. (1245573)		
			S. ficaria (1206373)		
			No match (0207773)		
			No match (1204173)		

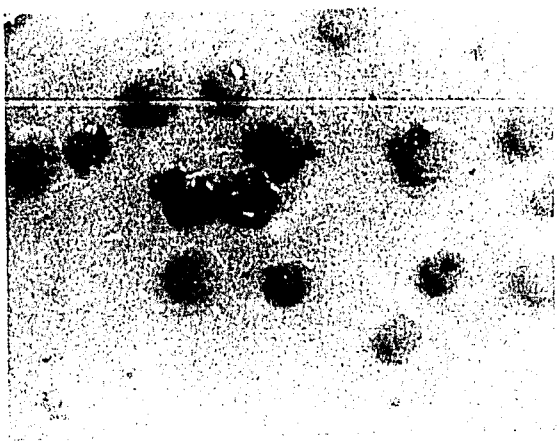
[a]Minimum and maximum similarity are mentioned where two or more isolates give the same identification. [b]API 20NE code is given for oxidative isolates and API 20E code for fermentative isolates.



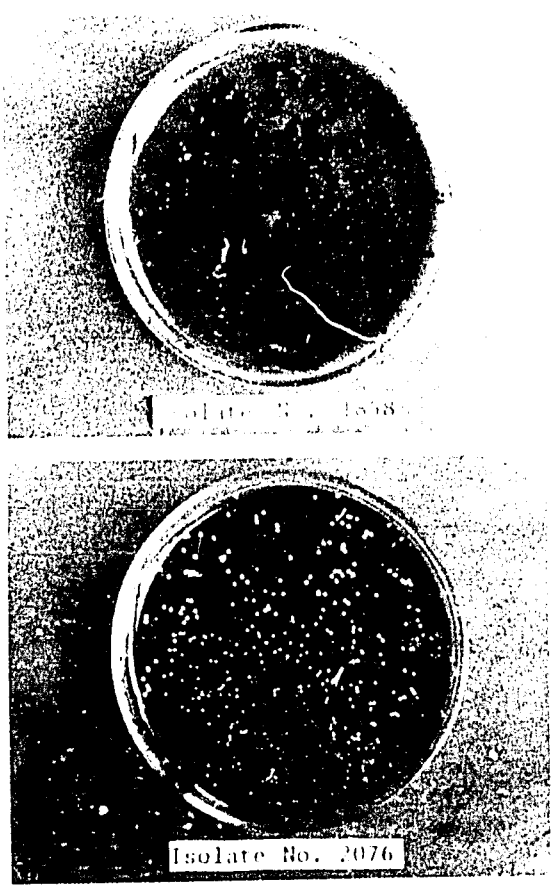
22. Dendrogram of the numerical analysis of the BIOLOG data on isolates and culture collection strains.

The presence of *P. glumae* in the collection was verified by the formation of precipitin bands with its antiserum (*P. glumae* type stain NIAES 1169) using the Ouchterlony double diffusion test. All the strains identified by BIOLOG as *P. glumae* (isolates no. 1857, 1858, 2056, 2076, 2057), regardless of the type of colonies on SPG medium (its selective medium), formed precipitin bands with its antiserum. This confirms the presence of *P. glumae* in the Philippines, as the isolates were collected during the surveys for this project. *P. glumae*-like isolates recently collected from the Bicol Region in southern Luzon were also positively identified by the same test.

The antisera from *P. plantarii* type strain NIAES 1723 and *P. fuscovaginae* "A" did not precipitate with any of the *Pseudomonas* isolates tested. Based on other tests, *P. plantarii* is not present in the collection. Philippine *P. fuscovaginae* strains could vary slightly from the Japanese strain from which the



23. *Pseudomonas fuscovaginae* on Miyajima's medium produces round, smooth, raised, translucent, light brown colonies with green pigments in the center.



24. *Pseudomonas glumae* types A and B on SPG medium. Type A colonies: round, smooth, convex, and reddish brown. Type B colonies: round, smooth, convex, and opalescent purple.

antiserum was produced, in which case the Philippine strains may not produce precipitin bands.

Conclusions and next steps. Not all the isolates identified by the methods described above produced symptoms similar to those caused by the *Pseudomonas* pathogens reported in temperate environments, but clear necrotic and water-soaked lesions were noted. Although the tests clearly indicated the identities of some of the pathogens, their taxonomic relationships remain ambiguous. Other diagnostic tests are needed to elucidate the taxonomic variations of the pseudomonad pathogens that were isolated from rice seeds and sheaths in the tropics.

Biology and physiology of rice pests and beneficial organisms

Rice genotype effect on natural enemies

Increasing evidence points to the important role that an insect pest's host plant plays in guiding natural enemies to the pest. A potentially fruitful approach to rice pest management is to select cultivars that provide some resistance to or tolerance for pests and also attract natural enemies. Plant improvement efforts with such dual objectives could contribute significantly to achieving durable and sustainable systems of plant protection.

This research aims to measure the response of insect predators and parasitoids to different rice genotypes and determine if mechanisms that favor an increased response can be manipulated through plant improvement.

One technique for quantifying response to different rice genotypes involves bioassays in an olfactometer (Fig. 25). The natural enemies are released (at point 3 in the figure) and allowed to choose an odor source from a chamber with a plant or from a blank chamber. Bioassays showed that the predator *Cyrtorhinus lividipennis*, a major natural enemy of BPH *Nilaparvata lugens*, generally preferred the plant odor when allowed to choose between it and pure air in a blank chamber (Table 53). Rice genotypes IR28, IR68, and IR50404 were the most attractive to the predator.

Volatiles from the three most attractive genotypes will be examined in detail. The efficiency of Tenax TA, Carbopack B, and activated C as adsorbents for volatiles has been tested using synthetic mixtures of rice plant volatiles under anhydrous conditions. Integration areas obtained from gas chromatographic analysis of desorbed volatiles from test

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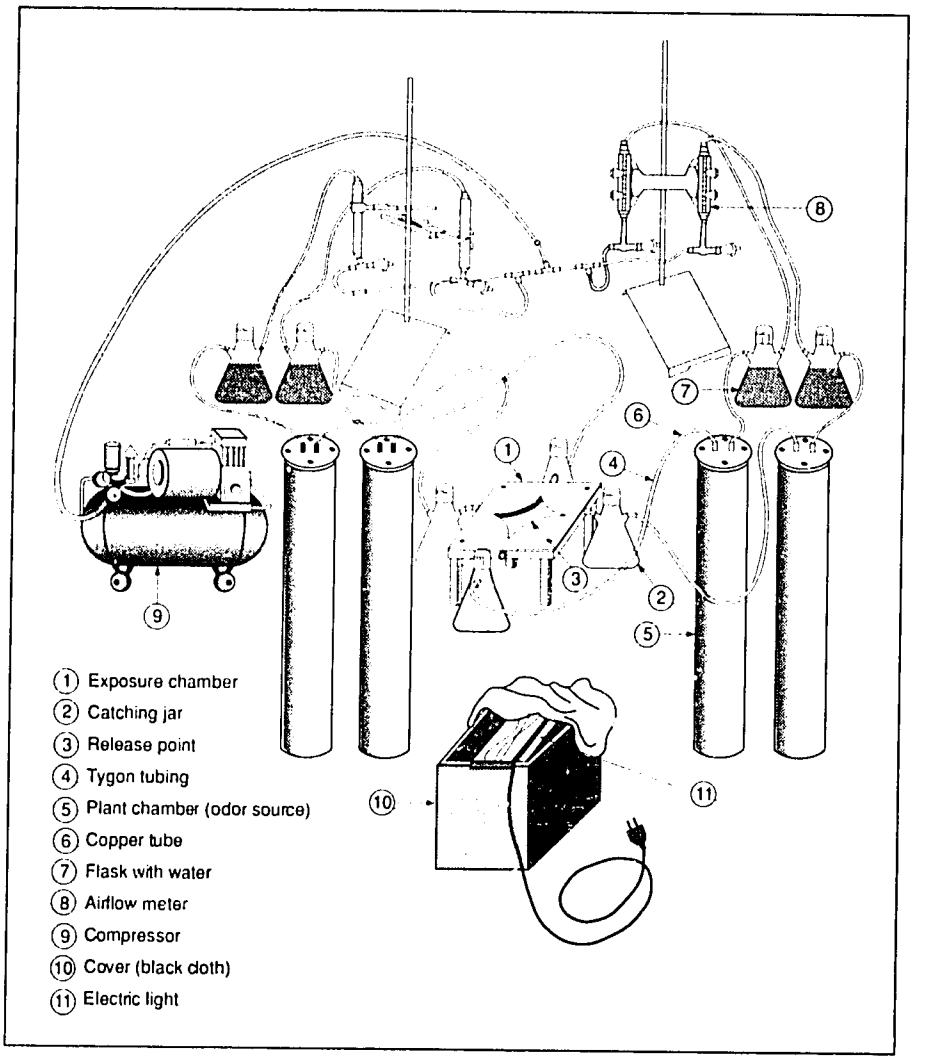


25. Olfactometer for measuring insect predator and parasitoid response to different rice plants.

columns were compared with the integration areas of the control obtained from direct injection of the test mixtures. Carbopack gave the highest total recovery rate and adsorbed consistently at the same proportion as the standard, while Tenax showed preferential adsorption of less oxygenated volatiles. In addition, volatiles adsorbed on a Tenax trap had to be desorbed immediately, since 2-wk storage at –50 °C resulted in only 25% recovery from Tenax, but no decrease in recovery from the Carbopack trap.

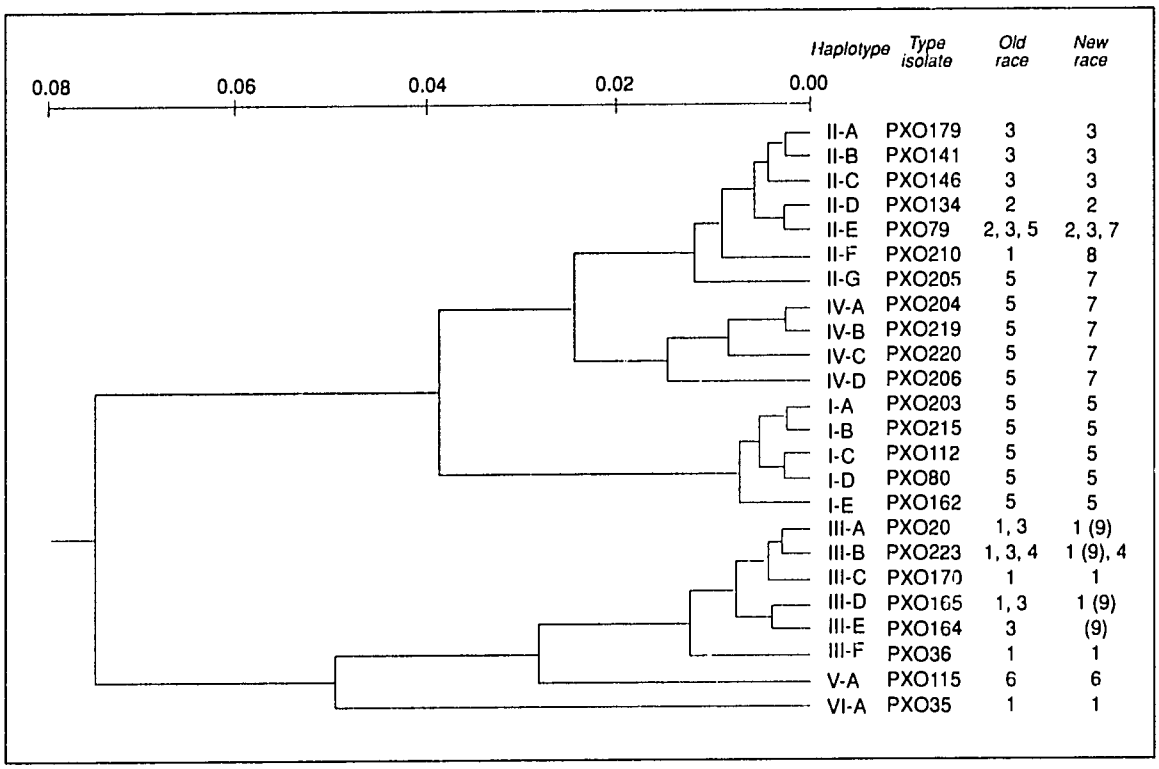
Three new *Xanthomonas oryzae* pv. *oryzae* races

An RFLP survey of 179 strains of *Xanthomonas oryzae* pv. *oryzae* using probe pTNX1 revealed that, of the six previously known Philippine races, two had two distinct lineages each (Fig. 26). Groups of

Table 53. Olfactometer response of *Cyrtorhinus lividipennis* to different rice plants after 10 min.

Rice plant		Number[a] responding to		χ^2
		Plant	Blank	
IR28	a	39	11	14.58**
IR68	a	36	14	8.82**
IR50404	b	34	16	5.78*
IR49491	a	32	18	3.38 ns
IR33059	b	32	18	3.38 ns
IR74	b	31	19	2.42 ns
IR56446	e	31	19	2.42 ns
IR64	c	30	20	1.62 ns
Peta	f	30	20	1.62 ns
IR56455	c	30	20	1.62 ns
TN1	c	29	21	0.98 ns
O. nivara	d	28	22	0.5 ns
IR56382	h	28	22	0.5 ns
IR72	i	25	25	0.02 ns
IR57283	g	23	27	0.18 ns

[a]Of 50 females allowed to choose between a chamber with a plant and a blank chamber.



26. Phylogenetic tree of Philippine strains of *Xanthomonas oryzae* pv. *oryzae*, as determined by numerical analysis of RFLP data based on the probe pTNX1.

strains representing the pairs of lineages from each race were tested on cultivars carrying 10 known resistance genes for BB. Differential reactions were observed and confirmed (Table 54). Thus, two new races (designated 7 and 8) have been detected, corresponding to pathogen lineages detected through DNA typing. Race 7 is differentiated from 5 and 8 from 1. In some inoculation experiments, the two lineages of race 3 could be distinguished, but differences were not always consistent. Races 7 and 8 are differentiated on cultivars carrying the resistance gene *Xa-14*. The new races will be incorporated into the set of strains used for screening rice germplasm for resistance to BB.

Diagnostic techniques for virus disease monitoring

Indicator variety for rice tungro spherical virus

RTSV does not induce distinct symptoms on any rice varieties so far tested at IRRI. RTSV infection is assayed only by serological tests, which are expensive and require special equipment and materials. The use of an indicator variety would be helpful, especially in monitoring RTSV-carrying GLH caught in light traps or in the field.

To identify an accession that would show distinct symptoms of RTSV infection, we tested four accessions of *O. glaberrima* (IRGC 100139, 100153, 102569, and 103437) that are highly susceptible to RTD. To inoculate 7-d-old seedlings of each accession, one GLH that had fed on RTSV-infected rice plants was allowed to feed on each seedling for 24 h. Healthy seedlings exposed to virus-free GLH served as control. Symptoms were observed at weekly intervals. A visual score was taken 3-4 wk after inoculation and compared with ELISA results.

Among the four accessions tested, IRGC 100139 consistently showed distinct symptoms of RTSV infection. Infected plants were severely stunted and had pale green, erect, narrow leaves 3-4 wk after inoculation. Infection rate at one insect/seedling was 60-80%, which is almost the same as that of TN1. The visual scores concurred 100% with ELISA results. This is the first report of a rice accession showing distinct symptoms of RTSV infection under tropical conditions. The accession may be used

Table 54. New races of *Xanthomonas oryzae* pv. *oryzae* detected by testing pairs of lineages defined by RFLP typing on cultivars carrying known resistance genes.[a]

Cultivar	Known gene	LL	SD	LL	SD	Difference in LL	Significance
		Race 1, lin II (race 8) n = 5		Race 1, lin III + VI n = 10		(II, VI-II)	
IRBB-14	*Xa-14*	2.8	1.1	29.6	4.8	26.8	0.000**
TN1	*Xa-14*	11.2	3.9	34.2	6.7	23.0	0.000**
8106-R	*Xa-14* (?)	18.8	2.4	43.9	2.8	25.1	0.000**
Tetep	*Xa-1, 2, 12*	11.4	2.7	37.4	5	26.0	0.000**
IRBB-1	*Xa-1*	32.4	1.52	34.4	1.26	2.0	0.018*
IRBB-2	*Xa-2*	12.4	1.52	34.7	2.91	22.3	0.000**
		Race 5, lin 1 n = 8		Race 5, lin II + IV (race 7) n = 10		(II, IV-I)	
IRBB-14	*Xa-14*	3.9	4.5	30.3	2.8	26.4	0.000**
TN1	*Xa-14*	10.3	4.2	37.5	2.1	27.3	0.000**
8106-R	*Xa-14*(?)	13.9	3.1	43.1	2.1	29.2	0.000**
IRBB-2	*Xa-2*	19.4	3.3	34.4	1.2	15.0	0.000**
Tetep	*Xa-1, 2, 12*	23.0	3.2	36.4	2.3	13.4	0.000**
IR8	*Xa-11*	27.9	4.4	34.8	1.2	6.9	0.000**
IRBB-1	*Xa-1*	26.8	4.6	32.5	0.7	5.8	0.001**
IR24	none	31.0	4.0	34.6	1.9	3.6	0.022*
IR20	*Xa-4*	5.8	0.9	8.5	1.0	2.8	0.000**
DV85	*xa-5, Xa-7,...*	4.0	2.1	2.3	1.1	-1.7	0.038*
		Race 3, lin II n = 5		Race 3, lin III (race 9) n = 4		(II, IV-I)	
CAS209	*Xa-10*	31.8	7.1	53.8	10.7	22.0	0.008**
Tetep	*Xa-1, 2, 12*	36.0	5.5	65.8	2.5	29.8	0.000**
IRBB-3	*Xa-3*	11.2	8.0	23.5	6.5	12.3	0.041*
IRBB-4	*Xa-4*	30.2	4.9	40.3	7.0	10.1	0.038*

[a]Data for cultivars showing statistically significant differences in lesion length (LL) for the lineages tested are shown. SD = standard deviation, lin = lineage.

for monitoring RTSV-carrying GLH without using expensive serological tests.

Assay using antiserum against noncapsid protein of rice grassy stunt virus

Rice grassy stunt virus (RGSV) produces large amounts of noncapsid protein (NCP) in infected rice leaves. The NCP was easily detected in a small quantity of RGSV-infected leaf extract using sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) and was purified by differential precipitation and single ultracentrifugation. We examined its usefulness in serological assay of RGSV.

The antiserum was produced from NCP purified by differential pH precipitation. It reacted strongly with purified RGSV and infected plants, but not with healthy plants in double antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA). As this indicated a slight contamination of viral coat protein in NCP preparation, NCP was further purified by SDS-PAGE. The antiserum produced from this NCP reacted positively with purified NCP and infected plants, and did not react with purified RGSV and healthy plants in DAS-ELISA. The sensitivity was greatly increased by using indirect ELISA. The NCP was detected in the purified NCP preparation at a concentration less than 10 ng/ml, and in sap from infected plants diluted to 10^{-5}. No positive reaction was obtained with sap from healthy rice plants and purified RGSV (Fig. 27).

The results suggest that antiserum produced from a purified NCP obtained from differential pH pre-

cipitation can be applied for routine indexing of RGSV-infected plants. This process is easier than the very laborious preparation of RGSV antibodies. Antiserum produced from a purified NCP obtained from SDS-PAGE can be applied in detecting NCP in infected plants. However, antiserum obtained this way reacted with some healthy BPH vectors in indirect ELISA and cannot be used to detect viruliferous insects.

DNA PROBES TO DETECT RICE YELLOW DWARF (RYD) AGENT

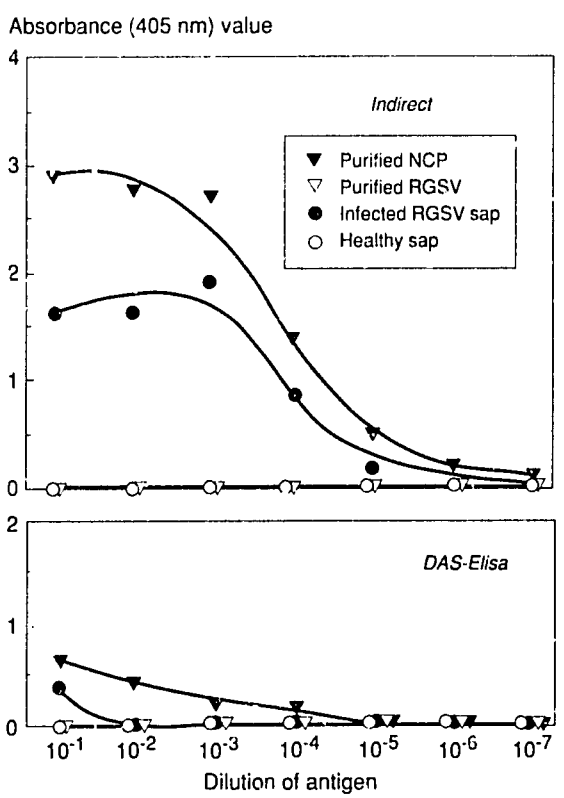
RYD is a serious rice disease caused by a mycoplasma-like organism (MLO). Antiserum for RYD-MLO has not been available so far. Recently, DNA probes pRYD-12 and pRYD-19 for RYD-MLO DNA were developed in Japan to diagnose RYD. In the IRRI-Japan Shuttle Research Project, we tested whether these two probes can detect a Philippine isolate of RYD.

Rice leaves were homogenized in CTAB buffer, incubated at 65 °C for 30 min, and centrifuged. DNA was extracted from the supernatant with chloroform-isoamyl alcohol, recovered by isopropanol precipitation, and dissolved in TE buffer. For comparison, DNA extract of the Japanese RYD isolate was included in the tests.

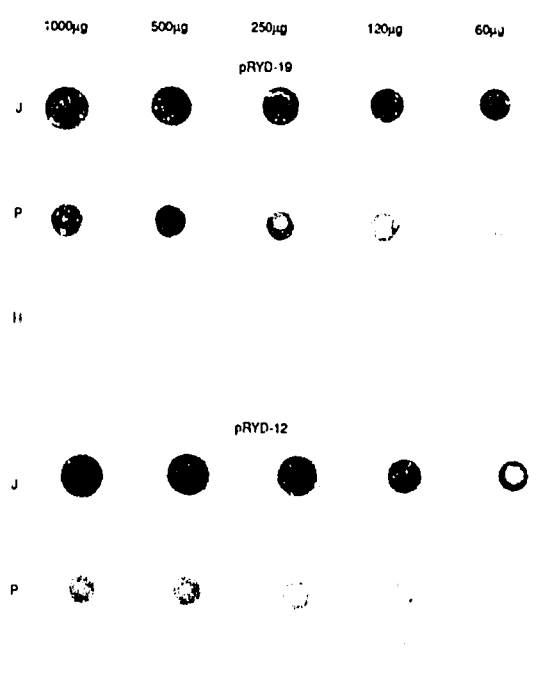
Twofold serial dilutions of the DNA preparations were spotted onto nylon membranes (Hybond N+, Amersham). The enhanced chemiluminescence method (ECL Gene Detection System, Amersham) was used for probe labeling with peroxidase, hybridization, and detection of signal.

Both probes hybridized with Philippine RYD-MLO DNA (Fig. 28). We were able to detect Philippine RYD-MLO DNA in a minimum of 60 µg of rice tissue with these probes. The Philippine isolate gave a slightly weaker signal than the Japanese isolate in both probes. Moreover, pRYD-19 showed a stronger hybridization signal with the Philippine isolate than did pRYD-12. Healthy extracts gave negative reactions.

Results showed that DNA probes developed for Japanese isolates of RYD can be used to detect Philippine RYD isolates.



27. Absorbance (405 nm) values for indirect and DAS-ELISA tests using the 24 kD antiserum purified by SDS-PAGE. The purified NCP was adjusted to an initial concentration of 1 mg/ml, RGSV to A_{260} = 3.0, and plant sap to 1 g tissue/ml.



28. Detection of DNA of RYD-MLO in rice leaves using DNA probes pRYD-19 and pRYD-12. J = Japanese isolate, P = Philippine isolate, H = healthy. Numbers show weight of fresh leaves per dot.

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Pest population dynamics

Systems simulation of leaf blast epidemic in the tropics

Several models that relate real world pathosystems of rice leaf Bl have been developed for temperate environments. These models dynamically predict the polycycle of the fungus using a bottom-up approach in modeling. Realistic forecasting of Bl epidemics in temperate climates was assisted by incorporating stochastic simulation of panicle Bl (PBl) to Bl models.

Few models are available for simulating tropical rice leaf Bl pathosystems. Available models were done mainly for Bl simulation with PBl estimated using only empirical equations. To surmount this limitation, we improved our earlier Bl model and developed a more dynamic program. BLASTSIM.2, version BETA021 (written in FORTRAN) simulates Bl development for a given rice-*Pyricularia oryzae* isolate combination in various tropical situations. State variables in the fungus monocycle, such as spore production, spore release, spore dispersal, spore deposition, latency, and lesion production and expansion, are estimated on the basis of various micro- and macro-climatic parameters of a site and the agronomic characters of a rice cultivar. Receptivity factors quantifying a specific host-pathogen relationship have been added to the model to explain the genetic component of a given pathosystem. BLASTSIM.2 also includes daily dew period estimation and graphic routines.

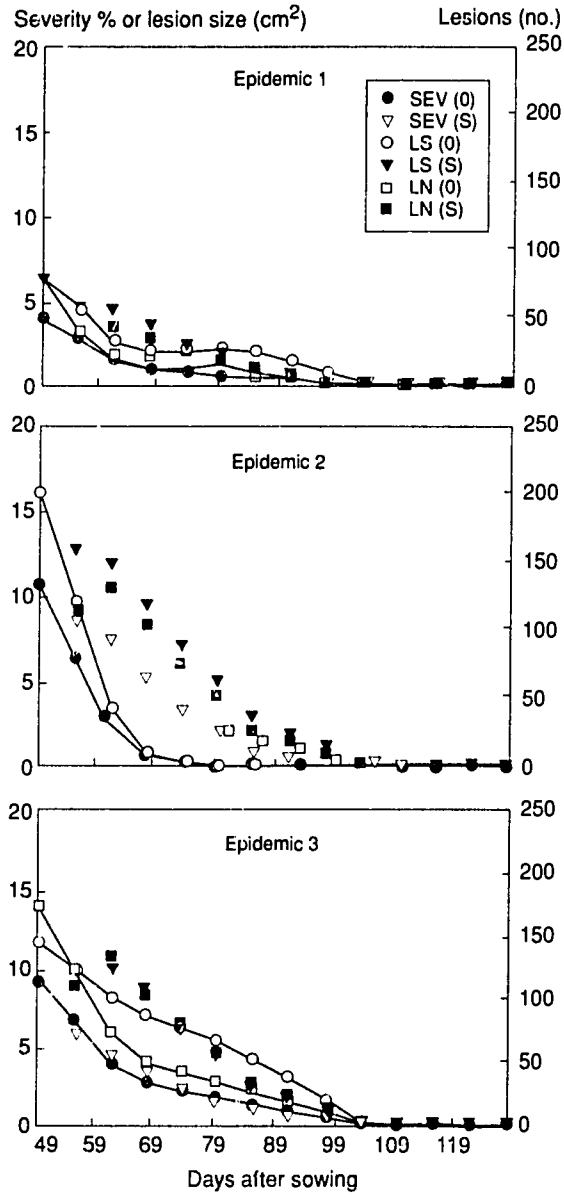
Preliminary validation of the model was done using Bl disease data of UPLRi-5 from 1989 WS in Cavinti, Laguna, and of IR72 from 1991 DS in an IRRI-Bl nursery trial. Minimum data sets on the weather of the sites studied and the characteristics of varieties used were obtained as input to the model. Data on receptivity factors were extracted from a greenhouse experiment using PO6-6 as a test isolate. Results from regression and correlation analyses showed high significance (R^2, r, F-value) of model output vs field-measured data for lesion production and development and disease severity in all experiments (Table 55), suggesting nonsignificant difference. While a pooled variance comparison revealed more distinct differences for one treatment in the Cavinti trial, most treatments were not significantly different from BLASTSIM.2 outputs. Graphically, model-predicted variables produced a trend similar to that of observed data (Fig. 29,30). BLASTSIM.2, with further modifications and validations, will be useful in determining Bl disease management strategy.

Characterization of rice tungro disease incidence

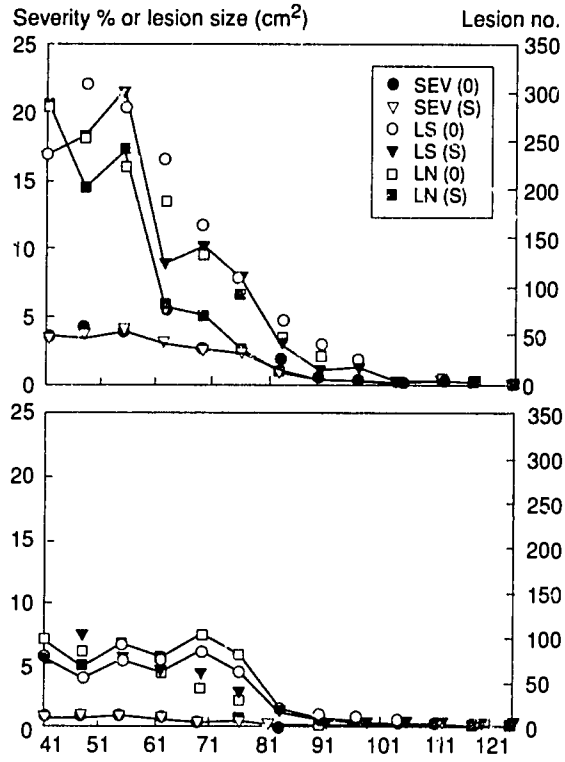
In some Philippine provinces, RTD may be considered epidemic, as it constantly affects crops planted in WS or DS. Such areas are commonly termed "hot

Table 55. Results of regression, correlation, and pooled-variance analyses of observed versus model-predicted lesion number/hill, lesion size/hill, and percent disease severity/hill.

Experiment, treatment	State variables	R^2	r	F	Pooled variance
Cavinti, 1989 WS					
Low-epidemic	Lesion no.	0.77	0.88**	255.08**	301.15^{ns}
	Lesion size	0.86	0.92**	460.96**	3.23^{ns}
	Severity	0.91	0.95**	797.37**	1.17^{ns}
Medium-epidemic	Lesion no.	0.55	0.74**	95.92**	2673.87^{ns}
	Lesion size	0.61	0.78**	122.63**	20.44**
	Severity	0.73	0.86**	215.41**	8.91**
High-epidemic	Lesion no.	0.76	0.87**	251.80**	2426.10*
	Lesion size	0.95	0.97**	1414.71**	15.21^{ns}
	Severity	0.97	0.98**	2628.23**	5.69^{ns}
IRRI, 1991 DS					
10 cm spacing	Lesion no.	0.86	0.93**	516.31**	8669.35^{ns}
	Lesion size	0.94	0.97**	1409.70**	59.44^{ns}
	Severity	0.92	0.96**	990.07**	2.69^{ns}
20 cm spacing	Lesion no.	0.72	0.85**	215.23**	5.82^{ns}
	Lesion size	0.72	0.85**	217.34**	1254.83*
	Severity	0.77	0.88**	276.32**	0.07^{ns}



29. Simulated versus observed lesion no./hill, lesion size/hill, and % severity/hill on three epidemic treatments from 1989 wet season experiment, Cavinti, Laguna. Model used was BLASTSIM.2 v.BETA021. SEV = severity, LS = lesion size, LN = lesion no., S = simulated, O = observed.



30. Simulated versus observed data on lesion no./hill, lesion size/hill, and % disease severity/hill on 10- and 20-cm plant spacing treatments in experiment using IR72, 1991 DS, IRRI BI nursery. Model used was BLASTSIM.2 v. BETA021.

spots," in contrast with other rice-growing areas, where only explosive, sporadic epidemics occur. In order to characterize variation in RTD incidence with a small set of key variables, we conducted a descriptive analysis using survey data of two RTD "hot spots."

The sites are in two rice-growing areas of Mindanao, Philippines: North Cotabato and Sultan Kudarat. The survey was conducted during nine consecutive cropping seasons (from 1983 to 1987). Information was obtained on total populations of 130 fields in North Cotabato and 118 fields in Sultan Kudarat. Data were collected at the tillering stage, and each field was represented by a set of five variables: cropping season (DS or WS), planting date, RTD incidence, total vector population, and proportion of viruliferous vectors. Boundaries and classes for each of the quantitative variables were defined and transformed into qualitative ones (Table 56).

Correspondence analysis is a multivariate method that allows the pictorial analysis of categorized information. A correspondence analysis was conducted for each area. In both correspondence analyses, the two first axes accounted for most of the information involved in the analyses (97.5% in North Cotabato and 92.5% in Sultan Kudarat. The two graphs in Figure 31 share common features, including the pattern of RTD incidence classes from absence (IN0) to increasingly high incidences (IN1 to IN3). The

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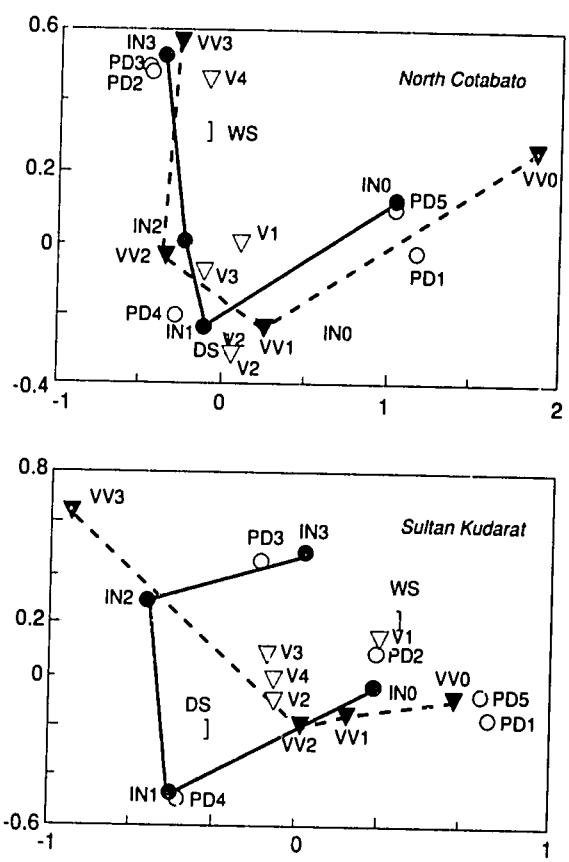
Table 56. Categorization of variables used in the correspondence analyses of (RTD) epidemics.

Variable name	Classes					Unit of initial variable
RTD incidence	IN0	IN1	IN2	IN3		%
Boundaries	0%	0<IN≤2	2<IN≤5	IN>5		
Number of vectors caught in 10 sweeps	V1	V2	V3	V4		N vectors
Boundaries	0≤V≤5	5<V≤10	10<V≤15	V>15		
Percentage of viruliferous vectors	VV0	VV1	VV2	VV3		%
Boundaries	0%	0<VV≤5	5<VV≤15	VV>15		
Planting dates	PD1 Very early	PD2 Early	PD3 Intermediate	PD4 Late	PD5 Very late	—
Cropping season	WS wet	DS dry				

successive classes can be linked in the graphs, and the lines representing paths of increasing RTD incidence may be compared to patterns of other variables. Both paths of increasing RTD incidence show two phases: disease establishment (IN0 to IN1 along the first axis) and disease intensification (IN1 to IN2, and IN3, along the second axis). Off-season plantings (PD1 and PD5 in North Cotabato; and PD1, PD2, and PD5 in Sultan Kudarat) are graphically associated with absence of RTD (IN0), whereas plantings at intermediate (between early and late) periods (PD2 and PD3 in North Cotabato, PD3 in Sultan Kudarat) correspond to high RTD incidence (IN3).

The successive categories of vector population size (from very small V1 to very large V4) and of proportion of viruliferous vectors (from null VV0 to large VV3) can be linked too, and the resulting paths compared to that of incidence levels. The outcome indicates differences in the disease-vector-virus relationships between the two areas.

In North Cotabato, absence of viruliferous vectors (VV0) is associated with absence of disease (IN0), and high proportion of viruliferous vectors (VV3) is associated with high disease incidence (IN3). The path of increasing proportion of viruliferous vectors follows a stepwise pattern in close correspondence with increasing RTD. Disease intensification (from IN1 to IN3) is associated with increasing total vector population.



31. Patterns of RTD incidence in North Cotabato and Sultan Kudarat, Philippines, 1983-87. IN = tungro incidence, VV = % of viruliferous vectors, PD = planting dates, V = no. of vectors caught in 10 sweeps, DS = dry season, WS = wet season.

In Sultan Kudarat, the relationship between RTD incidence and proportion of viruliferous vectors can be seen in two phases. In a first phase, a stepwise increase of the proportion of viruliferous vectors from null (VV0) to medium (VV2) is associated with disease appearance (IN0-IN1). In a second phase, the occurrence of medium to high incidence is associated with a high proportion of viruliferous vectors (VV3). The relationship between RTD incidence and total vector population is represented by an overall trend only: whereas very low vector population (V1) corresponds to absence of disease, disease appearance and further increase are associated with any vector population size, from small (V2) to very large (V4).

RTD prevalence is affected differently by the cropping season in the two areas. In North Cotabato, RTD prevalence is similar in both seasons (WS and DS are equally distant from IN0), incidence being frequently higher in WS. In Sultan Kudarat, RTD prevalence is usually higher in DS; however, when RTD occurs in WS, incidence is higher.

RTD intensity in the tillering stage in the two areas can be characterized as paths of increasing incidence with two phases: disease establishment and disease intensification. In both areas, RTD does not establish during off-season planting. In North Cotabato, RTD establishment is associated with the appearance of viruliferous vectors, regardless of the vector population size or cropping season; whereas in Sultan Kudarat, RTD is associated with an increase of proportion of viruliferous vectors (to V3), any increase in vector population size, and DS. On the other hand, RTD intensification corresponds in both areas to plantings progressively taking place at the peak period. Whereas in North Cotabato RTD intensification is associated with increasing vector population size and percentage of viruliferous vectors, RTD intensification in Sultan Kudarat appears primarily and strongly dependent on the occurrence of a high percentage of viruliferous vectors. Apart from similar effects of planting periods, the two analyses therefore indicate changing patterns in the relationships between the vector population, the proportion of viruliferous vectors, and RTD incidence.

The two analyses indicate that, besides common features, the two areas exhibit differences that may be associated with differing mechanisms influencing the perpetuation of RTD. The North Cotabato sites appear more responsive to RTD than are those in Sultan Kudarat. As the sites are planted to the same varieties, several explanations for the differential response may be considered, including a difference in the amount of alternate hosts, variation in vector ecotypes, or environment-variety interactions.

The analyses successfully produced epidemiological characterizations of two RTD "hot spots." Further analyses should address areas such as the Central Luzon plains, which experience sporadic, large-scale outbreaks with potential for highly damaging effects.

Only a small set of variables were involved in the analyses. They represented historical information collected by plant protection services. This information was processed in a way that was suitable for its precision and the aim of the analysis. Whether this approach could be followed to interpret a range of RTD outbreaks remains to be seen. If so, the variables and the combination of classes that would be associated with definite changes in disease levels could be considered as candidate components of a management system.

Quantifying rice-weed interactions

Although models have been developed to quantify the effects of weeds on crops, they seldom have been used to assess the impact of weeds on rice. Ecophysiological simulation models for crop-weed competition integrate knowledge and help researchers obtain quantitative insights into the effects of weeds on crops in response to the environment. The insights gained can be used to improve crop management. Simple regression models may help predict yield loss caused by weeds shortly after crop emergence, and thus facilitate decisionmaking in weed management.

Many empirical models have been developed to describe the responses of crop yield to one or more parameters that may characterize weed infestation. The most important parameters appear to be weed density and the time of weed emergence during the crop cycle. Precise prediction of yield loss should be based on both factors because they determine the competitive relations between crop and weeds. Most existing models are based only on weed density and therefore do not predict yield losses accurately. Also, weeds often emerge in successive flushes, making it impossible to use a descriptive model that accounts for the effect of the relative time of weed emergence.

A new, simple empirical model for early prediction of crop losses by weed competition was developed in 1991. This model relates yield loss to relative leaf area of weeds (expressed as leaf area of weeds/ leaf area of crop + weeds) shortly after crop emergence using the "relative damage coefficient" q and the maximum yield loss at high weed infestations m as model parameters:

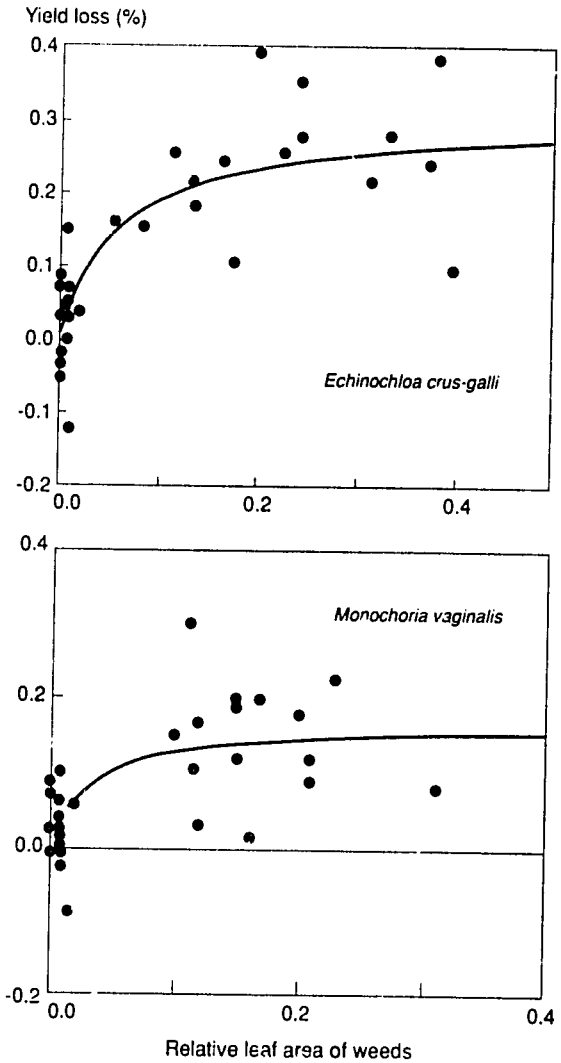
$$YL = \frac{q\,Lw}{1 + \left(\frac{q}{m} - 1\right) Lw}$$

where YL = yield loss, and Lw = relative leaf area of weeds. This relative leaf cover-yield loss model accounts for the effect of weed densities, different flushes of weeds, and the period between crop and weed emergence.

The model was evaluated using data of several weed species in rice, sugarbeets, and tomatoes. In rice, the effect of the weed species *Monochoria vaginalis* and *Echinochloa crus-galli* was studied. The crop was grown with different densities of the weeds (0, 20, 40, 60, or 80 plants per m^2). For all weed densities, preemerged weeds were sown 5 or 22 d after transplanting of rice.

Early emerging weeds reduced crop yield by 21% (*M. vaginalis*) to 26% (*E. crus-galli*) at the highest weed densities. Late emerging weeds did not significantly reduce crop yield, indicating that weed density alone is not an effective measure of weed infestation for prediction purposes. The model for relative leaf area, however, described the data sets for both weed species well, indicating that it accounts for both the effect of weed density and the period between crop and weed emergence (Fig. 32). The relative damage coefficient q was about 5 for both species, but the maximum yield loss was only 17% for *M. vaginalis* and 38% for *E. crus-galli*. This can be explained by the difference in plant height between the species: rice was able to overtop *M. vaginalis* but not *E. crus-galli*.

Conclusions and next steps. The simple model also accurately described data on weed effects on sugarbeets (Netherlands) and tomatoes (transplanted and direct seeded, Canada). Thus, the model may be a useful tool for early decisionmaking in weed management. In 1992, experiments will be conducted in direct seeded rice, where weeds are more harmful than in transplanted rice. Special attention will be paid to practical methods to determine relative leaf cover and to relate it to relative leaf area. In addition, an ecophysiological model for crop weed interactions will be parameterized for rice-weed competition. Specific field experiments will be conducted for this purpose. Such models can help to improve our insight into crop-weed interactions and to identify breeding goals and crop management options that favor the crop in competition with the weeds.



32. The relation between final rice yield loss and relative leaf area of the weeds *E. crus-galli* and *M. vaginalis*, measured 22 d after transplanting.

Leaf blast-leaffolder interaction in lowland rice

This activity investigated the interacting effects of *Pyricularia grisea* and leaffolder (LF) *Cnaphalocrocis medinalis* on the individual and combined development of leaf Bl and LF in the greenhouse. Between August 1990 and March 1991 in the IRRI glasshouse, pregerminated IR72 seeds were directly sown in plastic trays in lowland conditions and 200 kg N/ha was split-applied.

Single and combination treatments of leaf Bl inoculation and LF infestation were applied at 20 to 40 d after sowing (DAS) using a randomized complete block design with three replications. The treatments consisted of an uninoculated check, single leaf Bl inoculation, single LF infestation, LF infestation 7 d after Bl inoculation (Bl-LF), Bl inoculation after LF infestation (LF-Bl), and LF infestation within 24 h after Bl inoculation (Bl-LF [24 h]).

For Bl inoculation, an inoculum suspension of *P. grisea* isolate PO6-6 containing 100,000 spores/ml was sprayed onto the plants through an atomizer attached to a vacuum pump. Inoculation was conducted inside a wooden inoculation chamber lined with wet jute sacks and covered with plastic sheets.

To infest each plant with LF, two second-instar larvae were introduced onto the youngest leaf using a wet fine camel's hair brush. Each seedling was then enclosed in a mylar cage topped with nylon mesh.

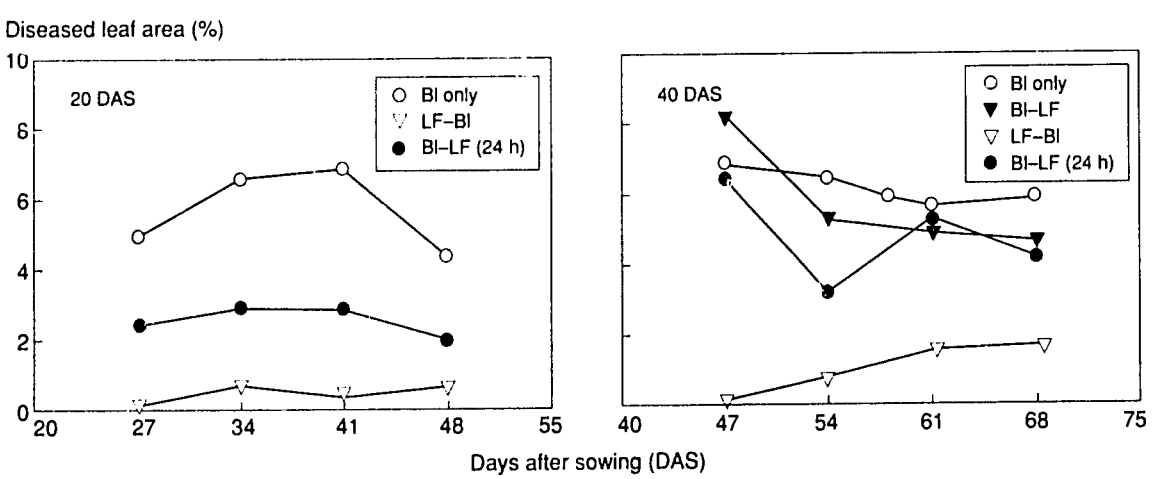
After treatment, four consecutive weekly samplings were conducted for disease and insect feeding assessment. Diseased leaf area and consumed leaf area were traced on clear acetate plastic sheets, which were run through the LI-3000 leaf area meter. The total damaged area was determined as the sum of diseased leaf area and consumed leaf area.

Conclusion. The diseased leaf area indicated an antagonistic effect of LF consumption on Bl development in the 20 and 40 DAS trials. The diseased leaf area in the LF-Bl treatment was significantly lower than in the single Bl treatment in the 20 DAS trial. In the 40 DAS trial, the LF-Bl treatment produced the significantly lowest diseased leaf area among all treatments. When Bl was inoculated 7 d after LF infestation, Bl development was inhibited in both 20 and 40 DAS trials (Fig. 33).

An antagonistic effect between Bl and LF was observed for consumed leaf area in the 20 DAS trial. Treatments LF-Bl and Bl-LF (24 h) showed significantly lower consumed leaf areas than the single LF infestation treatment at 34, 41, and 48 DAS. In the 40 DAS trial, however, treatment Bl-LF produced a significantly higher consumed leaf area than the single LF infestation treatment at 54, 61, and 68 DAS. This implies that when LF infestation occurs 7 d after Bl inoculation, Bl development has a synergistic effect on LF consumption in the 40 DAS treatment (Fig. 34).

The total damaged area in the 20 DAS trial showed a less than additive interaction between Bl and LF. The total damaged areas in the combination treatments were significantly lower than in the sum of all single diseased leaf area in the single Bl inoculation treatment and consumed leaf area in the single LF infestation treatment (Fig. 35).

In the 40 DAS trial, no significant differences were observed for the total damaged areas among the combination treatments of Bl-LF and Bl-LF (24 h),



33. Diseased leaf area in IR72 with treatments at 20 and 40 DAS.

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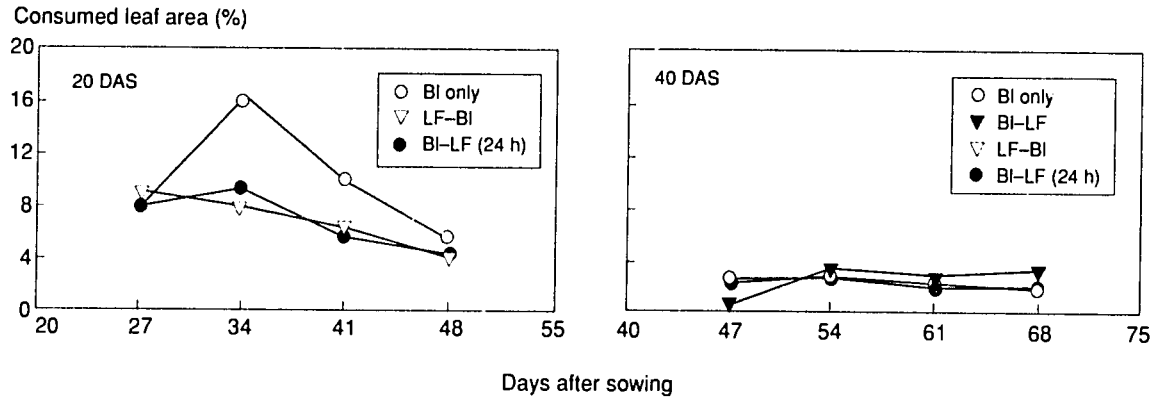
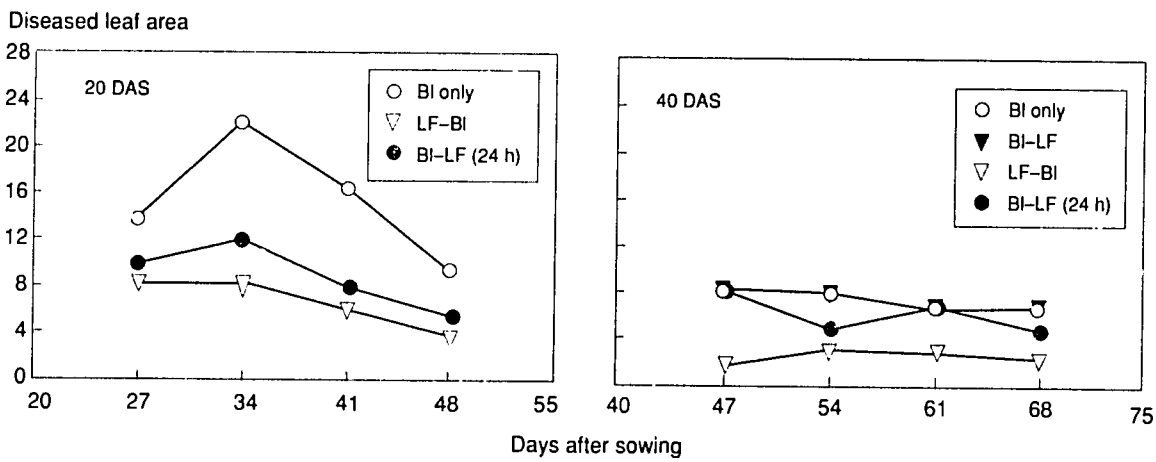


34. Consumed leaf area in IR72 with treatments at 20 and 40 DAS.



35. Total damaged area in IR72 with treatments at 20 and 40 DAS.

and the summed single Bl and LF treatments. In addition, the LF-Bl treatment produced a significantly lower total damaged area than the other combination treatments and added single Bl and LF treatments. This implies an antagonistic interaction of LF and Bl in the treatment with Bl inoculation at 7 d after LF infestation (Fig. 35).

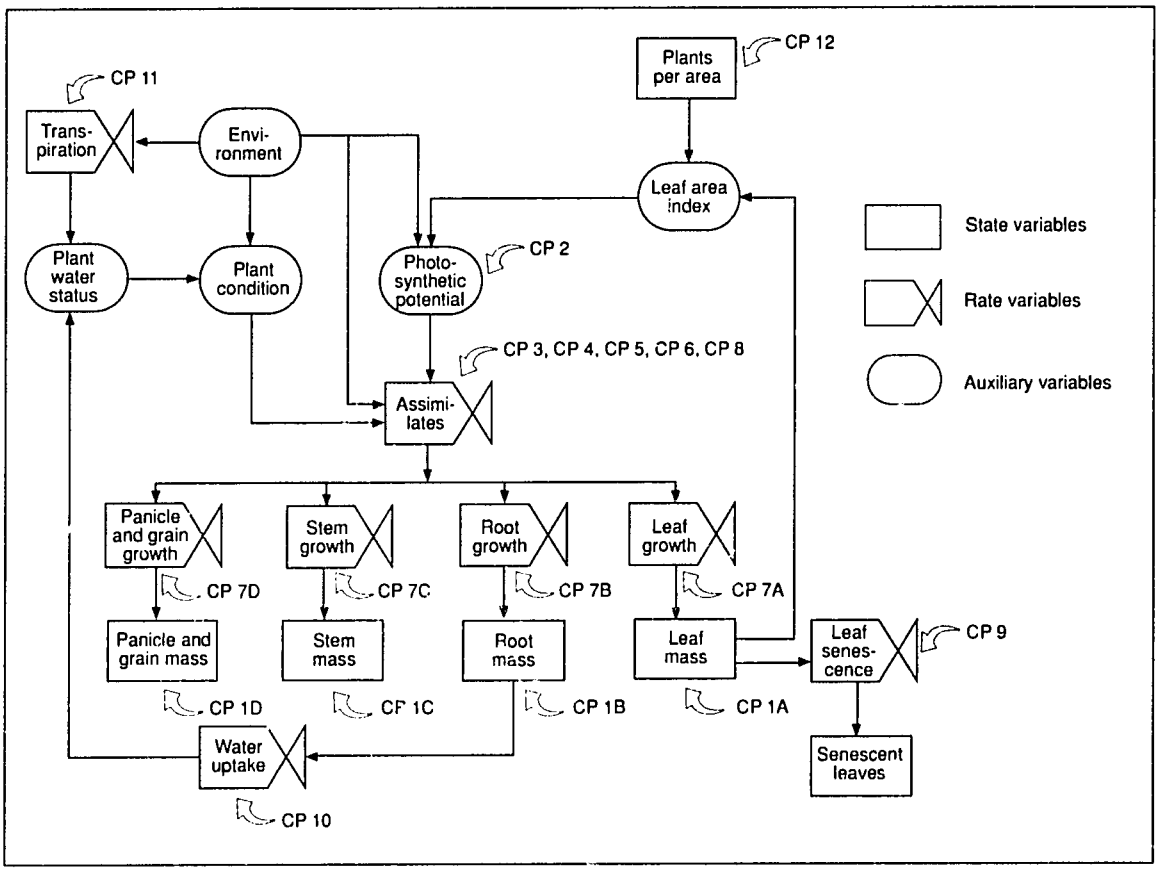
Pest-yield interactions

Coupling pest damage effects to a rice model

A generic pest module was developed for use in coupling pest effects to the crop simulation models of the Decision Support System for Agrotechnology Transfer (DSSAT) developed by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). As part of agricultural decision support systems, the goal of our work was to incorporate relevant pest information into crop models in a way that allows the models to simulate the performance of crops under different regimes of climate, soil type, cultural practices, etc., and under given pest situations.

The pest module was developed and tested, using the CERES-rice model (Fig. 36). It was used for introducing the effects of given infestation levels of different pests into the model via physiological coupling points (CP. Fig. 36) that link pest damage to corresponding rate and state variables of the crop model.

The approach is strictly mechanistic and allows simulations of multiple pest damage effects on a daily basis. The crop physiological processes and variables that can be affected in the coupled model include plant leaf area (CP1A), biomass (CP1A-CP1D), intercepted light (CP2 and CP8), photosynthesis (CP3), amount and translocation of assimi-



36. Relational diagram of CERES-rice with pest coupling points (CP).

lates (CP4 and CP6), respiration (CP5), growth of different plant organs (CP7A-CP7D), water uptake (CP10), transpiration (CP11), and leaf senescence (CP9).

The pest module currently consists of two main components: submodule 1, which creates, edits, and retrieves pest input data; and submodule 2, which handles the computation of pest damage effects.

Sensitivity analysis was performed on the pest-coupled CERES-rice model. To compare the relative importance of different damage mechanisms for crop growth and yield, 50% pest stress was introduced into the crop simulation throughout the growing season via different coupling points. Leaf senescence rate was by far the most influential coupling point, resulting in a complete destruction of the crop. Other coupling points varied in their relative importance for crop development (Fig. 37).

Infestation scenarios were created for leaf Bl, ShB, defoliation, and weed infestation by varying the onset time and the maximum intensity level or progress curve asymptote of the pests. Pest progress was assumed to follow a unimodal curve for leaf Bl and a sigmoid curve for ShB, defoliation, and weed infestation. The coupling points used for simulating the damage effects were CP2 and CP3 for leaf Bl; CP2, CP6, and CP10 for ShB; CP1A for weed infestation; and CP8 for defoliation.

Simulation of single-pest scenarios resulted in response surfaces that indicate nonlinearly increasing yield losses with increasing pest intensities and decreasing onset times (Fig. 38).

Some multiple-pest scenarios were also explored. Simulation results usually showed that the combined effects of multiple pests on yield loss were less than the added effects of each pest alone (Table 57).

Data from three field experiments are currently being analyzed to calibrate and validate our pest-crop coupling approach for multiple pest scenarios involving leaf, collar, and panicle Bl; ShB; BB; and insect pest damage.

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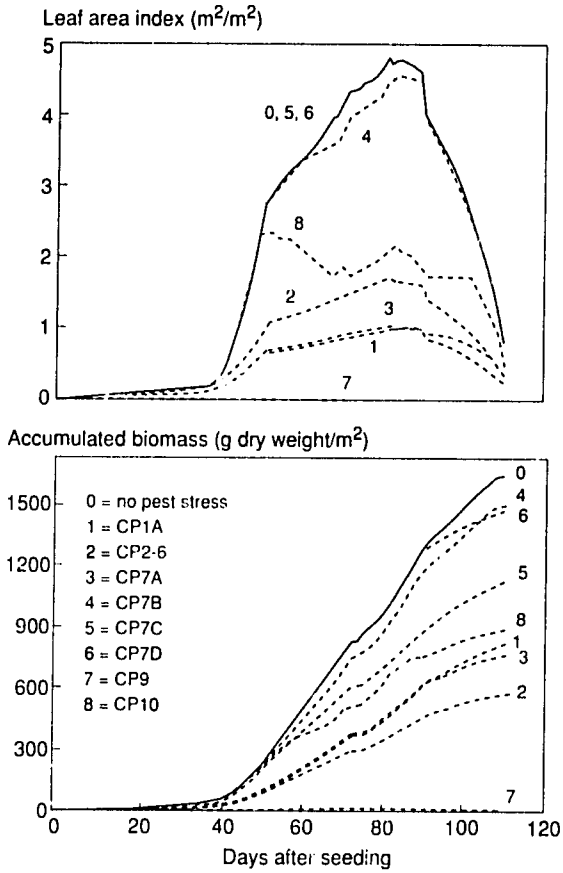


37. Simulated progress of leaf area index and biomass production if 50% pest stress is imposed on different coupling points (CP) during the growing season. For an explanation of the CPs, see Figure 36.

Conclusions and next steps. Sensitivity analysis showed the potential of the approach for investigating crop performance and total yield loss in relation to the population dynamics of various pests. The pest module can also be used to pinpoint the relative importance of damage mechanisms and to identify gaps in the quantitative knowledge of pest effects.

Once calibrated and validated with field data, the pest module can be used to explore multiple pest scenarios with regard to crop performance and to adjust crop simulations for multiple pest effects at the physiological level. Simulation studies might also result in the extraction of simple, yet robust key information on pest-loss relationships that can be applied without using computers. All this in turn will help researchers to develop and improve decision tools for on-farm pest-crop management.

The CERES-rice pest module is generic and mechanistic and can be incorporated into the other CERES models of DSSAT, thus becoming an integrated part of a powerful instrument for agrotechnology transfer.

Table 57. Simulated yield loss due to combined infestations of leaf blast (Bl), sheath blight (ShB), defoliators, and weeds in rice.[a]

		Yield loss (%)			
		X_{max} leaf blast[b] (%)			
X_{max} weeds (m²/m²)	X_{max} defoliation (%)	0		10	
		X_{max} sheath blight (%)			
		0	30	0	30
0	0	0	18.7	30.6	44.1
	40	11.6	27.1	43.3	53.4
2.4	0	41.6	51.2	62.0	69.1
	40	45.8	54.3	65.7	71.7

[a]Additional inputs: leaf Bl onset time = 20 days after seeding (DAS), unimodal progress curve. ShB onset time = 50 DAS, sigmoid progress curve. Defoliation onset time = 40 DAS, sigmoid progress curve. Weed onset time = 10 DAS, sigmoid progress curve. [b]For unimodal pest progress curves, X_{max} refers to the peak of the curve; for sigmoid pest progress curves, X_{max} refers to the asymptote of the curve.

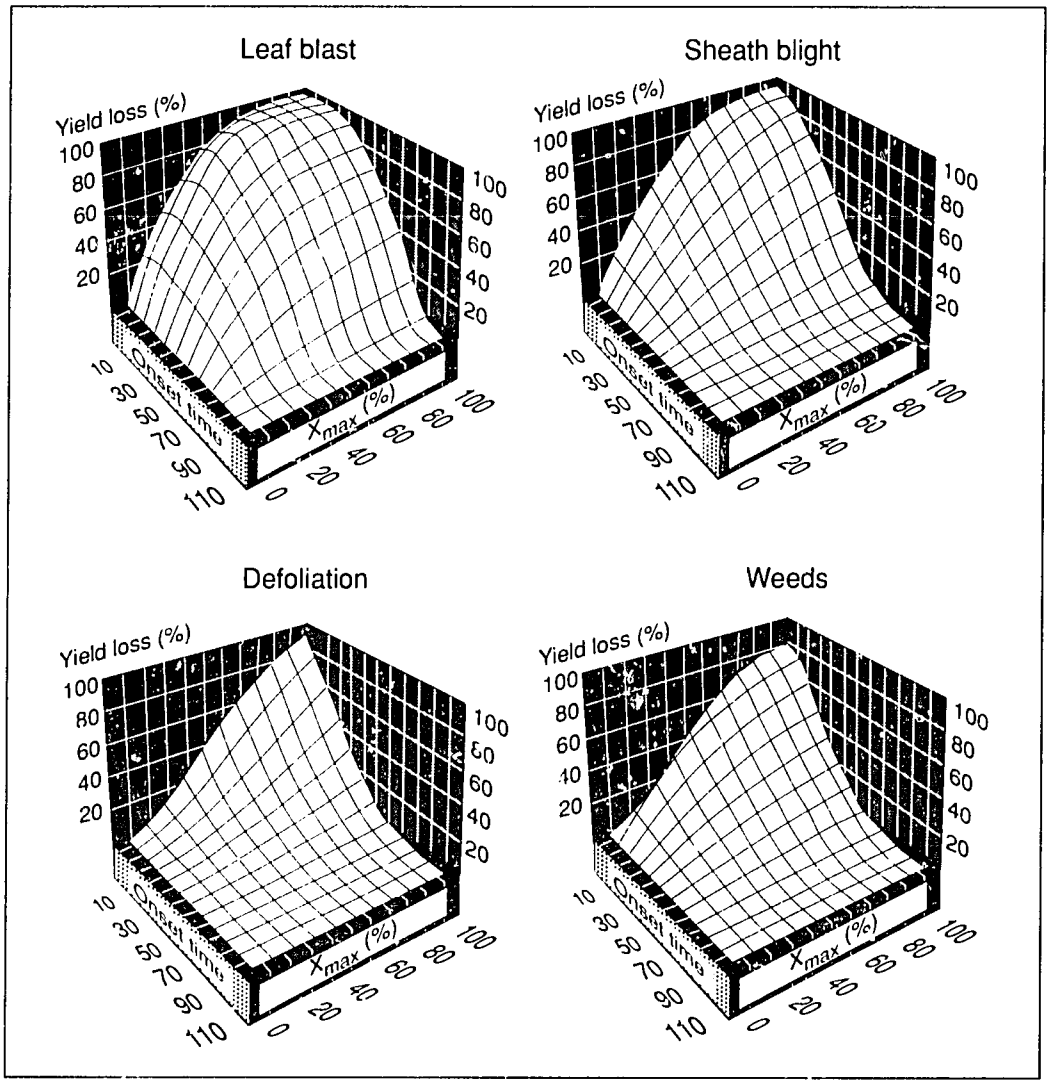
Subprogram V: Plant, soil, water, and nutrient processes

In this project, quantitative theory is applied to obtain an understanding of the fate of materials added to the soil and of how the rice root system obtains nutrients from the soil. This understanding is needed to improve agronomic management practices and develop nutrient-efficient germplasm.

Soil and fertilizer nutrient dynamics

MODEL OF THE FATE OF N FERTILIZER

A reliable, deterministic model of the fate of fertilizer N in ricefields is vital to further advances in N fertilizer efficiency and for understanding yield decline. We have developed a model that can predict the effects of soil, environmental, and agronomic-management variables on N fertilizer movement in flooded soil and its simultaneous reaction with the soil and loss by volatilization and leaching. The model accounts for the following processes:

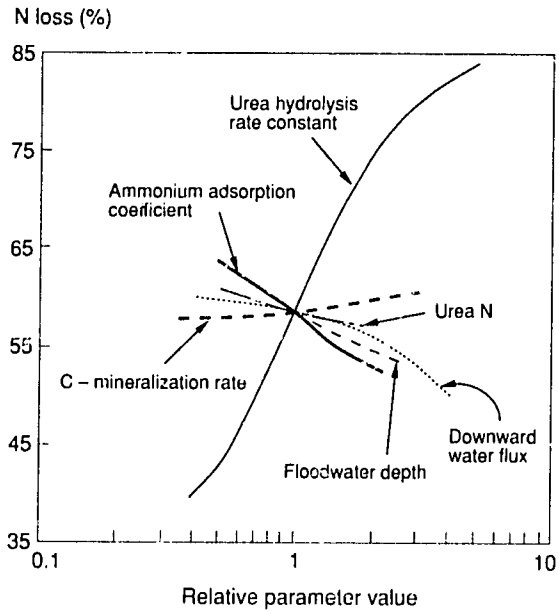


38. Simulated yield loss resulting from pest scenarios for leaf blast, sheath light, defoliation, and weeds.

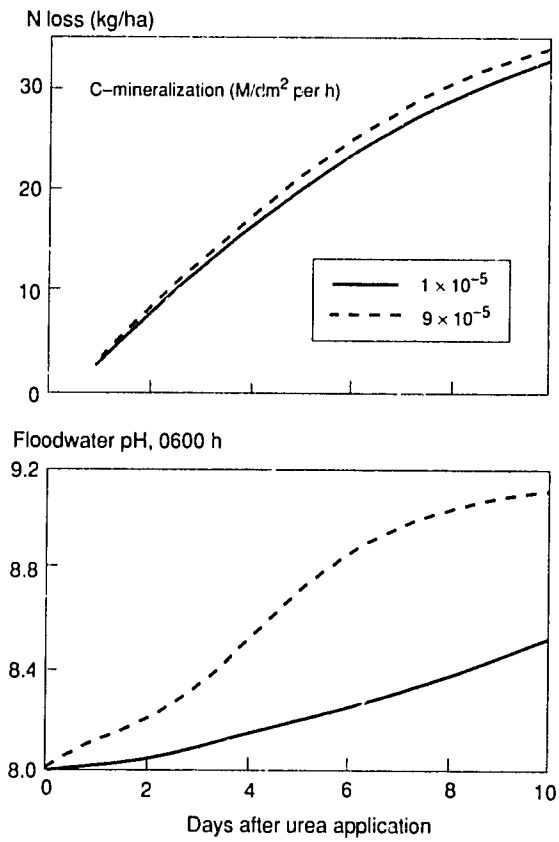
- urea hydrolysis and movement in the soil and floodwater;
- the formation of ammoniacal species in urea hydrolysis and organic-N mineralization, and their movement and volatilization;
- the formation and consumption of carbonate species in urea hydrolysis, organic-C mineralization, and floodwater algal activity, and their movement and volatilization; and
- the formation and consumption of acids and bases in urea hydrolysis, organic-C mineralization, floodwater algal activity, and NH_3 and CO_2 volatilization; and the consequences of the resultant pH changes for other processes.

The simultaneous transfers of NH_3 and CO_2 across the floodwater-atmosphere interface are described using a two-film layer model of the floodwater-air interface (IRRI Program report for 1990).

Figure 39 shows how the predicted NH_3 loss changes as the model parameter values are changed about realistic average values. Variatio in the urea hydrolysis rate constant significantly affects NH_3 loss. Increases in the soil ammonium adsorption capacity and downward water flux moderately decrease NH_3 loss, but variation in other parameters has no dramatic effects. With faster urea hydrolysis, most of the urea is hydrolyzed at the soil-floodwater interface before it can move far into the soil. This



39. Sensitivity of N loss to the model input parameters. The standard parameter values (relative value = 1) are urea N added = 4.0×10^{-3} mol/day², urea hydrolysis rate constant = 2.2×10^{-5}/s, ammonium adsorption coefficient = 0.40 mol/kg, C-mineralization rate = 8.3×10^{-9} mol/dm³ per s, floodwater depth = 0.4 dm, downward water flux = 1.0×10^{-7} dm/s.



40. Effect of CO_2 production through C-mineralization on N loss and floodwater pH. Standard parameter values as in Figure 39.

results in higher floodwater pH and N concentrations, and thus higher NH_3 volatilization. A greater soil ammonium adsorption capacity leads to a lower soil solution concentration of ammoniacal-N and a decreased replenishment of floodwater N from the soil. Similarly, a greater downward water flux results in decreased floodwater N concentrations and hence decreased NH_3 loss because urea and ammoniacal-N are carried deeper into the soil.

Figure 40 shows the effects of the rate of CO_2 production in the soil on NH_3 loss. The higher the rate of CO_2 production in the soil, the higher is the loss of CO_2 from the floodwater, which tends to increase the floodwater pH. The result is higher NH_3 loss. Thus, the proposal that increasing CO_2 production in the soil may be a means of decreasing NH_3 loss is invalid.

Higher floodwater algal activity during the day results in a higher peak pH, but at night it results in more CO_2 being respired, causing a decrease in pH (Fig. 41). Thus, greater midday NH_3 losses with higher algal activity are offset by lower losses at night.

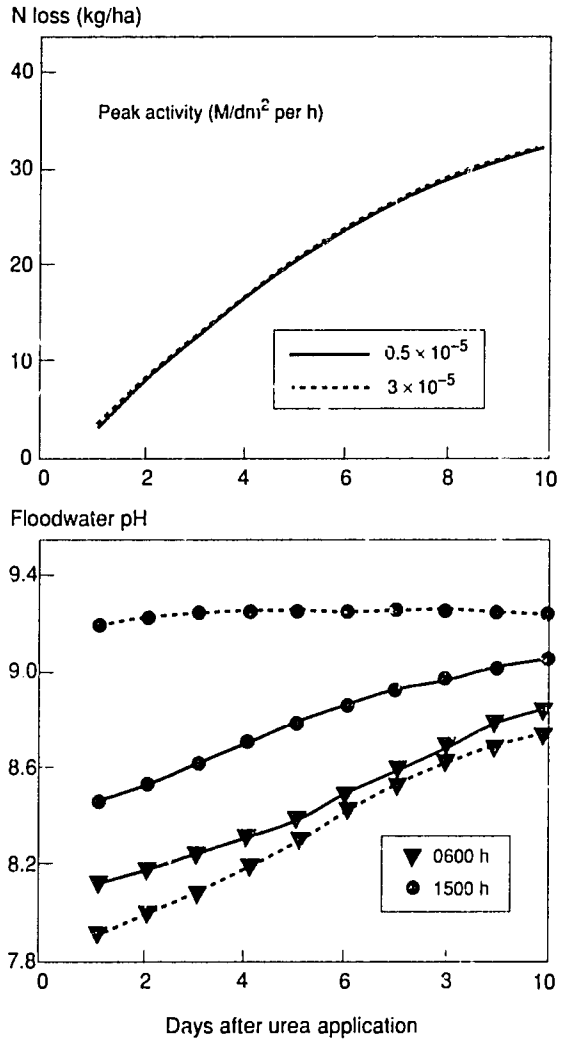
Table 58 shows that when urease activity is high, incorporation of urea in shallow floodwater is advisable, but when urease activity is low, broadcast application with deep floodwater is better.

Further work is being done to incorporate plant uptake of N in the model. This will enable us to study the effects of root growth patterns on N use efficiency of different varieties under transplanted and direct seeded conditions.

Root traits governing rhizosphere conditions

Rice roots growing in flooded soil must supply O_2 to respiring tissues and exhaust respired CO_2. This must be done internally because gas transport through flooded soil is very slow. The root structure required for this ventilation influences the root's ability to absorb nutrient ions from the soil at its surfaces. Gas transfer between the root and soil markedly alters conditions in the narrow zone of soil that is root-influenced, with corresponding changes in nutrient availability.

The root-influenced zone extends just a millimeter or so into the soil, but existing experimental methods cannot analyze the soil with resolutions



41. Effect of floodwater algal activity on N loss and floodwater pH. Standard parameter values as in Figure 39.

Table 58. Predicted amounts of ammonia volatilized in 10 d following urea application at 56 kg N/ha with N mineralization at 1.3 kg N/ha per d.

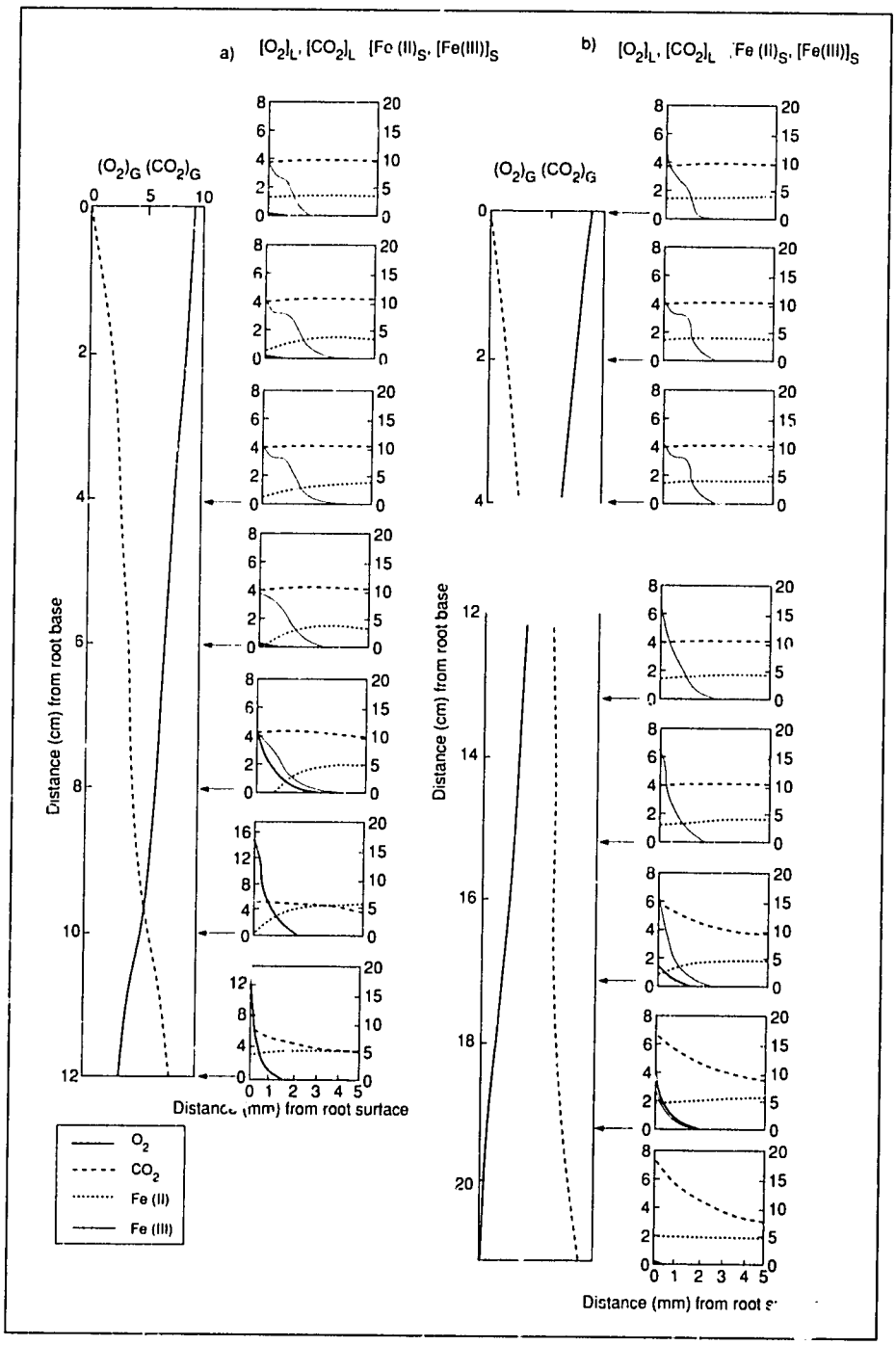
Method of urea application	Floodwater depth (cm)	Ammonia volatilized (kg N/ha) at urea hydrolysis rate constant of		
		.03 h	.08 h	.4 h
Broadcast on floodwater	2	22.2	34.3	46.9
	4	19.7	32.8	48.6
	10	16.9	30.2	51.3
Incorporated in standing floodwater	2	15.9	22.6	28.7
	4	15.9	24.6	34.2
	10	15.8	26.2	42.5
Incorporated without standing floodwater	2	12.7	16.5	18.9
	4	11.9	16.1	19.0
	10	11.8	15.9	19.7

much finer than a millimeter. Because of this experimental difficulty and because the system involves the simultaneous operation of a series of complex, linked processes, simulation models are invaluable in studying the system.

We developed a model to examine how nutrient uptake by rice roots growing in flooded soil is influenced by the ability of the roots to ventilate themselves, the root structure needed for this ventilation, and the associated root-induced changes in the rhizosphere. The model predicts the axial diffusion of O_2 from the atmosphere through the growing root, O_2 consumption in respiration, and radial loss to the soil where it reacts with mobile ferrous iron, and the generation and removal of root and soil CO_2. The model allows for the variations in root parameters with root length and time, and for parameters controlling the transport and reaction of O_2, CO_2, and Fe in the soil. The root parameters are root radius, cortical porosity, tissue respiration rates, and root wall permeability; the soil parameters are the initial Fe^{2+} content, Fe^{2+} sorption coefficients, Fe^{2+} oxidation and reduction rate constants, pH, pH buffer power, CO_2 pressure, and bulk density.

Figure 42 shows predicted profiles of O_2 and CO_2 in the root cortex and the corresponding reactant concentration profiles in the adjacent soil. For the chosen conditions, which represent the upper range of soil O_2 consumption rates, the maximum length of root that can be aerated is 21 cm (Fig. 42b); this is in the range predicted by other models of gas transport through roots. The model shows that substantial amounts of Fe are transferred toward the root surface, resulting in a well-defined zone of ferric hydroxide accumulation; the extent of Fe accumulation changes along the root length and with time. A zone of Fe^{2+} depletion arises where oxidation is intense, but is rapidly filled when the O_2 supply decreases. Re-reduction of Fe(III) is slow compared with oxidation, although the chosen reduction rate is the highest likely. CO_2 is lost from the root to the soil near the root tip, but taken up by the root near the base; the resultant CO_2 concentration profiles in the soil are small.

We also developed a more detailed (but computer-time intensive) model that allows for the pH changes in the rhizosphere resulting from 1) Fe^{2+} oxidation, 2) CO_2 uptake or release, and 3) excess uptake of cations over anions, and the consequences of the pH changes for reactant mobility. Figure 43



42. Predicted concentration profiles in the root cortex and in the adjacent soil after a) 10 and b) 19 d of growth. Cortex concentrations are in mmol/dm^3; soil concentrations are in mol/dm^3 (solution) × 10^4 for O_2, mmol/dm^3 (solution) for CO_2, and mol/dm^3 (soil) × 10^2 for Fe(II) and Fe(III). Root parameter values are as follows: for z (distance from the tip) = 0–2 cm: porosity = 0.075, wall permeability = 10^{-2} dm/s, water influx = 10^{-6} dm/s; for z = 5 cm to root base: porosity = 0.75, wall permeability = 10^{-7} dm/s, water influx = 10^{-9} dm/s; for z = 2-5 cm: porosity and water influx vary linearly, wall permeability varies logarithmically; the respiration rate at z = 0 cm is 10^{-5} mol/dm^3 (root tissue) per s, and it decreases as z^2 to a minimum of 3×10^{-7} mol/dm^3 (root tissue) per s at z = 10 cm; radius of stele = 0.25 mm, inner wall = 0.47 mm, outer wall = 0.5 mm; rooting density = 105 dm^{-2}; initial root length = 2 cm; root longation rate = 1 cm/d. Soil parameter values are a (Fe^{2+} sorption parameter) = 1.5 mol/kg; n_a [parameter for the effect of pH and $Fe(OH)_3$ precipitation on Fe^{2+} sorption] = 30 (dimensionless); P_{CO_2} = 0.5 kPa; initial pH = 6.5; b_{HS} (pH buffer capacity) = 0.033 mol/kg per unit pH; k_s (oxidation rate constant) = 0.3 dm^3/mol per s; $[Fe]_{S\,total}$ = 0.05 mol/kg; bulk density = 1.0 kg/dm^3.

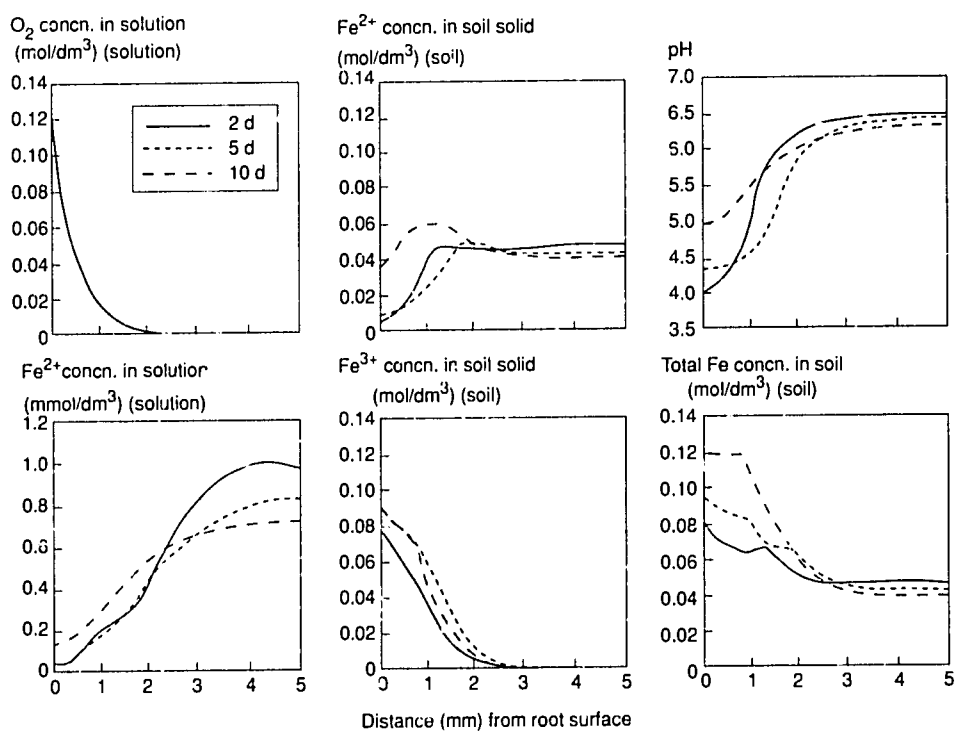
shows the predicted reactant profiles in the rhizosphere for a particular depth in the soil as a root grows through it. The soil is exposed to a declining O_2 concentration. A striking result is the very large drop in pH. Fe^{2+} oxidation can cause a pH drop of this magnitude for a wide range of soil conditions (1989 Program report). The acidification declines as the O_2 concentration declines, but remains substantial. A further striking result is the large total accumulation of Fe near the root. Fe accumulation continues after oxidation declines as Fe^{2+} diffuses into the zone where it has been depleted.

These findings are in agreement with experiments in which profiles of pH and concentrations of reduced and oxidized Fe were measured near a planar layer of rice roots sandwiched between two blocks of reduced soil (Program report for 1990).

Conclusion. The models demonstrate that the soil as "seen" by the rice root is entirely different from the bulk soil, although we normally measure properties of the latter. The models provide a means of assessing quantitatively how root and soil characteristics influence nutrient uptake in this highly complex system. In addition to the changes in soil conditions with distance from the root surface, the models show large differences along the root length. We need to know how the nutrient uptake capacity of the root varies along the root length—averages over the whole root system will not suffice—and how this changes as the root ages. Coupled to this, we need a better description of the root system: the rate at which new roots are formed and grow, their dimensions and geometry.

Effect of rhizosphere conditions on N uptake

The ability of the lowland rice soil-root system to meet the plant's N requirements depends on 1) the ability of the roots to absorb N from the soil solution at their surfaces, and 2) the rate N is delivered to the absorbing root surfaces by diffusion across a zone of depletion in the soil. As depletion proceeds, the



43. Reactant profiles in the rhizosphere. The root parameter values change with time as in Figure 42 for a fixed distance from the root base; $[O_2]$ in cortex is half the atmospheric partial pressure. Soil parameter values are as in Figure 42 with pH buffer power = 0.05 mol/kg per pH unit, and H^+ flux from the root = 3×10^{-9} mol/dm^2 per s, declining 10^3-fold as wall permeability declines.

delivery rate becomes increasingly dominant. N is present in the soil solution chiefly as NH_4^+ ions and their concentration is subject to the same controls as other exchangeable cations: it tends to be high if the concentration of anions in solution is high—in accordance with electroneutrality—but is modified by the concentrations of other exchangeable cations, particularly the divalent ones. Thus as anion concentrations decrease, NH_4^+ diffusion through the soil tends to decrease. In most flooded soils, HCO_3^- is the dominant anion at pHs above about 5.5. However, in a rhizosphere acidified by Fe^{2+} oxidation, HCO_3^- concentrations will be low. Modifying factors are the concentration of Fe^{2+} (if it is high then most of the NH_4^+ will be excluded from the exchange complex and hence maintained in solution) and the effect of acidity on cation sorption.

We developed a model to investigate the effects of Fe^{2+} oxidation in the rhizosphere on the mobility and uptake of NH_4^+. In the model, cation exchange is governed by electroneutrality in the soil solution and solid and by the following relations:

$$\frac{(M1)_L + (NH_4)_L}{[(M2)_L + (Fe)_L]^{1/2}} = K_1 \frac{(M1)_S + (NH_4)_S}{[(M2)_S + (Fe)_S]^{1/2}},$$

$$\frac{(M1)_L}{(NH_4)_L} = K_2 \frac{(M1)_S}{(NH_4)_S}, \text{ and}$$

$$\frac{(M2)_L}{(Fe)_L} = K_3 \frac{(M2)_S}{(Fe)_S}$$

where

M1 represents monovalent cations other than NH_4^+ (e.g., K^+, Na^+);

M2 represents divalent cations other than Fe^{2+} (e.g., Ca^{2+}, Mg^{2+});

subscripts L and S refer to the soil solution and solid, respectively; and

K_1, K_2, and K_3 are coefficients.

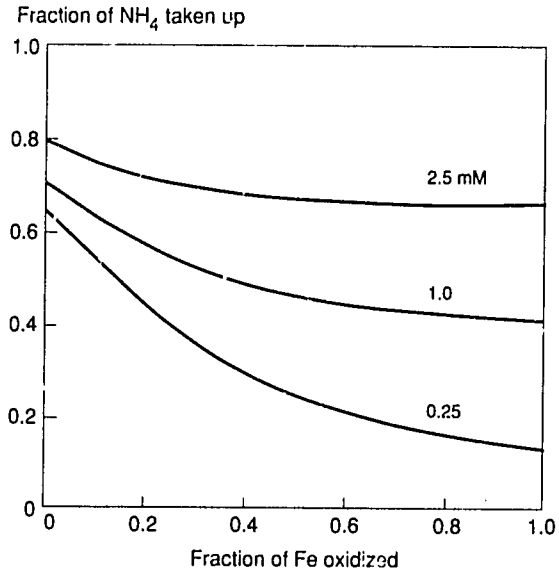
For each mole of Fe^{2+} oxidized, 2 moles of H^+ are produced, and these react with HCO_3^- and the soil solid. The increase in acidity causes 1) a proportionate decrease in pH (proportionality constant = pH buffer power) and 2) an equal decrease in the equivalents of cations on the solid (i.e., acidity is considered nonexchangeable). The rate of NH_4^+ uptake by unit length of root is found by assigning each root a cylindrical zone of exploitation and calculating the rate of NH_4^+ diffusion across the cylinder.

Figure 44 gives an example of the model's predictions for a realistic set of parameter values. It shows that rhizosphere oxidation may greatly reduce N uptake—particularly at low concentrations of anions in the soil—and is thus crucial in the N nutrition of the plant. In addition, acidification due to oxidation may reduce the rates of microbially mediated processes affecting the N supply, such as mineralization of organic N.

Effect of pH and redox conditions on silica sorption by soil

Silica has been reported to benefit rice growth. From the agronomic point of view, it may be considered an essential nutrient. Soils with low clay contents are likely to be deficient in silica. The chemistry of silica in flooded soils is not well understood.

We conducted laboratory experiments to study the effects of pH and redox conditions on silica



44. Effect of Fe^{2+} oxidation in the rhizosphere on the fraction of soil NH_4^+ taken up by unit root length in 10 d. Numbers on curves are concentrations of noncarbonate anions in solution. Other parameter values: rooting density = 500 dm/dm^3, root radius = 0.001 dm, soil bulk density = 1 kg/dm^3, pH = 6.2, CO_2 pressure = 0.1 atm, pH buffer power = 0.05 mol/kg per pH unit, monovalent cations = 0.025 mol/kg, divalent cations = 0.125 mol/kg, NH_4^+ = 0.002 mol/kg, Fe^{2+} = 0.05 mol/kg, and cation exchange coefficients K_1, K_2, and K_3 = 1.0, 0.5, and 1.0, respectively.

sorption by Philippine soils Maahas and Luisiana and Korean soils Yongji and Mangyeong. Their relevant properties are given in Table 59. Upon anaerobic incubation, the soils attained steady-state pHs of 6.5-7 and the following Ehs: 0 mV in Maahas, −100 mV in Luisiana, and −180 mV in Yongji and Mangyeong soils. Anaerobic incubation also increased available SiO_2, exchangeable Fe, and oxalate-extractable Fe in all the soils. Aerobic incubation did not alter the chemical properties of the soils.

All the soils showed predominantly negative surface charge and little positive surface charge under both aerobic and anaerobic conditions, and the increases in negative surface charge with pH were similar under aerobic and anaerobic conditions (Fig. 45). Points of zero charge were slightly higher in the anaerobically incubated soils.

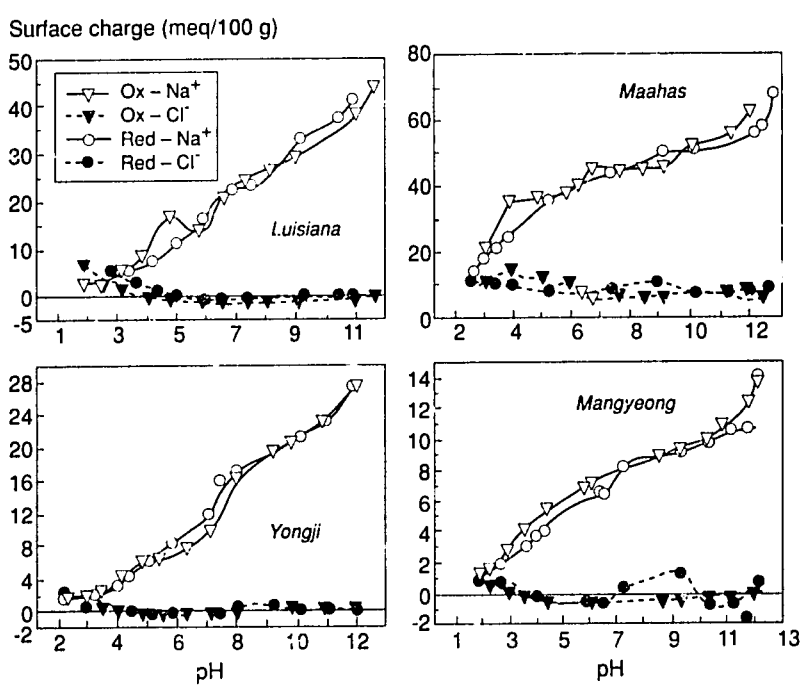
We investigated the effect on silica sorption of four pH levels (5, 6, 7, and 8) under steady-state oxidized and reduced conditions (Fig. 46). Silica sorption was significantly affected by soil type and pH, but not by redox conditions. The increases in sorption with pH paralleled the increases in surface negative charge (Fig. 45). This is because, at pHs below the pK of silicic acid (= 9.6), the form of silica in solution is predominantly the uncharged H_4SiO_4 molecule, and the interaction of H_4SiO_4 molecules with soil surfaces increases as the net surface negative charge increases.

The sorption data for each soil, pH, and redox condition were reasonably well described by linear-linear (C-type isotherm), log-linear (Tempkin isotherm), and log-log (Freundlich isotherm) equations ($r^2 > 0.95$), and, on the grounds of simplicity, we propose the slope of the C-type isotherm as a measure of a soil silica-sorbing power. Fe and Al extracted by various reagents and organic matter were significantly correlated with silica sorption as measured by the C-type isotherm slopes (Table 60). Dithionite-extractable Fe (Fe_d) had the highest correlation with silica sorption.

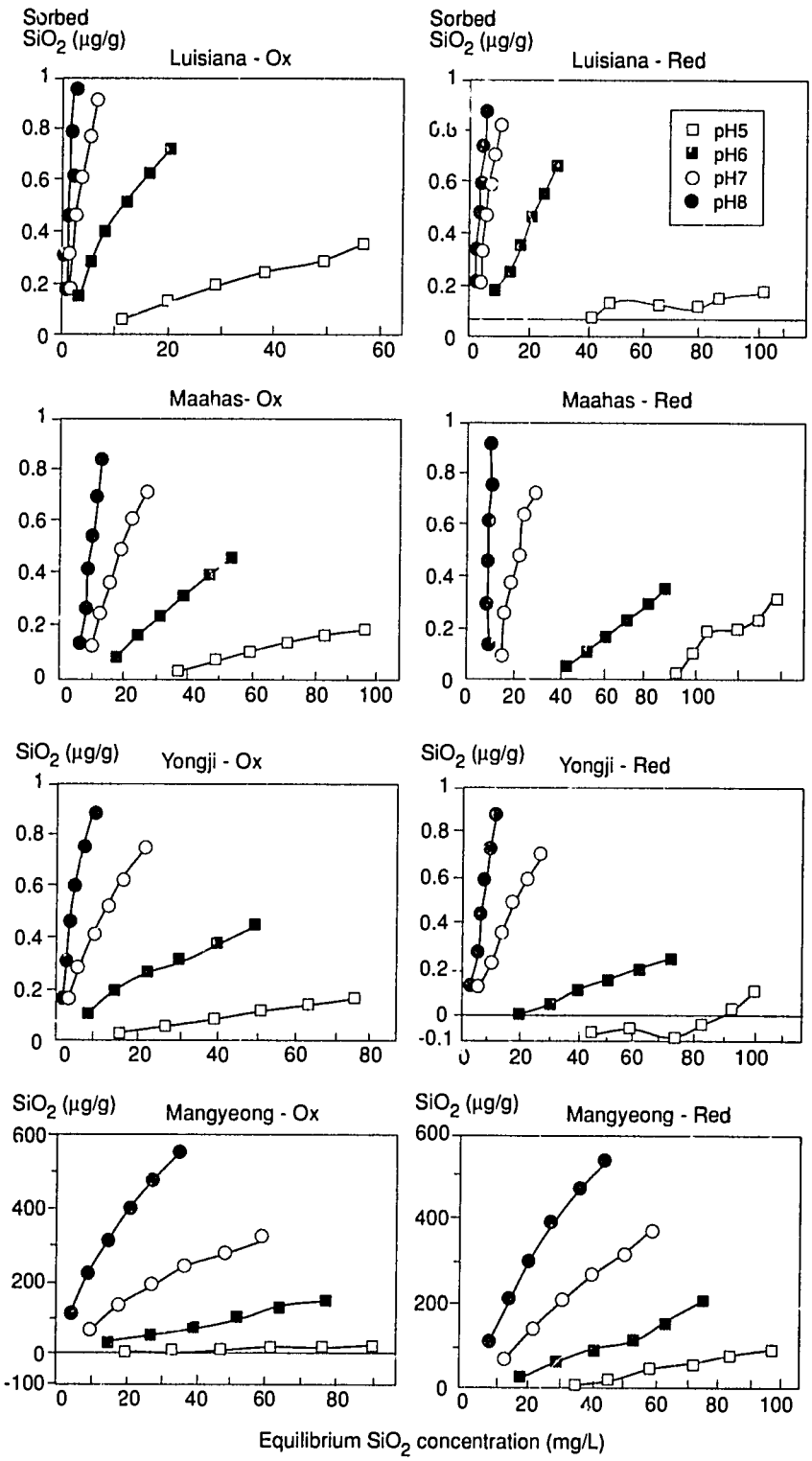
A consequence of the sorption-pH-redox relationship is that acidification of the rhizosphere due to

Table 59. Properties of soils used in experiments on silica sorption.

Property	Luisiana	Maahas	Yongji	Mangyeong
Clay content (%)	73	68	26	10
CEC (meq/100 g)	21.1	44.3	9.78	7.15
pH (1:2)	4.5	6.6	4.9	5.6
Organic C (%)	2.66	1.53	1.43	0.65



45. Surface charge characteristics of soils used in experiments on silica sorption. Na^+ and Cl^- indicate negative and positive charges, respectively.



46. Effect of pH and redox conditions on silica sorption. Ox = oxidized, Red = reduced.

Fe^{2+} oxidation will tend to increase the concentration of silica in solution and hence increase silica availability.

We will continue to study the following:

- mineralization, adsorption-desorption and movement of ammonium in flooded soils, and their modification by rhizosphere conditions;
- P dynamics in flooded soils including the effects of rhizosphere conditions;
- rice root morphology and development, their relation to gas transport and rhizosphere conditions, and differences due to genotype and environment; and
- nutrient uptake characteristics of rice roots including the effect of aerenchyma development and the roles of secondary rootlets and the superficial root mat.

Subprogram VI: Rice grain and seed quality, postharvest and biomass issues

This project has two components—rice grain and seed quality, and postharvest and biomass issues. The grain and seed quality component aims to 1) identify seed vigor factors and crack resistance, and 2) improve methods for determining cooked rice texture, aroma, and nutritional value. The postharvest and biomass issues component aims to design and evaluate 1) engineering developments for harvesting, threshing, cleaning, drying, and milling rice, and 2) biomass utilization technology.

Table 60. Correlation coefficients between C-type slopes at 3 pH levels and soil physicochemical properties in experiments on silica sorption.

Soil property[a]	Correlation coefficients (*r*) at 3 pH levels		
	6	7	8
Fe_p (%)	0.935**	0.900**	0.832*
Fe_o (%)	0.901**	0.802*	0.737*
Fe_d (%)	0.973**	0.948**	0.860**
Al_p (%)	0.917**	0.874**	0.759*
Al_o (%)	0.965**	0.898**	0.795**
Al_d (%)	0.950**	0.921**	0.800*
OM (%)	0.939**	0.875**	0.805*
Clay (%)	0.651^{ns}	0.605^{ns}	0.655^{ns}
CEC (meq/100 g)	0.183^{ns}	0.159^{ns}	0.292^{ns}
Eh (mV)	-0.062^{ns}	0.001^{ns}	0.003^{ns}

[a]Subscripts p, o, and d denote pyrophosphate extractable, acid oxalate extractable, and dithionite-citrate extractable, respectively.

Rice grain and seed quality

Susceptibility to cracking during moisture adsorption

The 12% moisture content of oven-dried grain is below the critical moisture content (CMC) of rough rice (13-16%). Thus, head rice yields obtained from crack resistance screening (3 h in 30 °C water) were lower (1-34%) than those from harvested grains that were shade-dried to 14% moisture (10-62%). Head rice stress was 33-34% for IR60 compared with 1-24% for the other IR cultivars. IRRI elite lines had 1-36% head rice stress, with the stress highest (32-36%) for IR51672-37-3-5-2-2 in the 1990 WS .

Grains of increasing moisture content (13-18%) were obtained by exposing oven-dried rough rice to humid air at 0.5 atm to prevent cracking while adsorbing moisture. They were used to determine CMC during water adsorption. CP-SLO 15 showed CMC at 13% moisture. CMC was 15-17% for seven IR cultivars; differences during adsorption were not significant, but were significant during moisture desorption. Thus, shade-dried (14% moisture) or oven-dried (12% moisture) samples of elite lines can be screened effectively for crack resistance. Head rice yields are lower in the oven-dried samples with moisture content below CMC. Varietal differences were not related simply to endosperm starch properties.

Grain quality of wild rice parents

Fourteen brown rice varieties representing 11 *Oryza* species being used in wide crosses were analyzed for grain quality characteristics. Amylose content (AC) of brown rice ranged from 16 to 20%, while gelatinization temperature (GT) based on alkali spreading value was either intermediate or low. Grain weight ranged from 3 to 18 mg, and length:width ratio from 2 to 6. Brown rice protein was 9-13% and lysine content was 3.4-4.5 g/16.8 g N. Brown rice with no interfering protein bands showed the "absence" of glutelin α_3 band (indicative of higher molecular weight glutelin α_3 band) on SDS-PAGE, suggesting an indica-type reaction. The results indicate that grain quality in wild rice is typical of cultivated rice, *Oryza sativa* L.

Location and water management and quality

In a collaborative study with scientists of Yeongnam Crop Experiment Station (YCES), Milyang, Korea,

selected japonica and indica/japonica Korean varieties were planted at YCES in 1990 and at IRRI in 1991 DS. The IRRI crop had lighter, more translucent and whiter grain, lower AC, harder gel consistency (GC), lower alkali spreading value in 1% KOH (higher GT), higher protein, lower ash, and higher peak pasting viscosity with the rapid VISCO analyzer (RVA) than the YCES crop, particularly the indica/japonica varieties. Water drainage 10, 20, and 30 d after flowering had significant lowering effect on grain weight, AC, and GC of some varieties. Compared with irrigated culture, upland culture at YCES had lower AC and GC values, increased alkali spreading value, and decreased amylograph and RVA peak pasting viscosity, particularly in indica/japonica varieties.

Resistant starch of raw and processed rice

Resistant starch is the fraction of dietary amylose that is not digested in the small intestine, but is fermented by microorganisms in the large intestine, partly or wholly into short chain fatty acids that the body absorbs. In the small intestine, energy absorption of fermented starch is 65% that of glucose. Cooperative studies using growing rats at the National Institute of Animal Science, Foulum, Tjele, Denmark, showed that processing (such as parboiling and noodle extrusion) and, to a lesser extent, cooking, increased resistant starch and reduced digestible energy, particularly in varieties with high and intermediate AC. This suggests that the energy available from cooked parboiled rice in South Asia (where energy intake is already limited) is overestimated by at least 1% compared with cooked nonparboiled rice.

Improved hardness test through amylopectin staling

We investigated the role of amylopectin staling in the reported texture differences of cooked rice varieties with similar AC by measuring Instron hardness of cooked rice stored for >4 h at 2-4 °C followed by 4 h at 42 °C. The method proved useful, particularly for low-GT waxy varieties and for low-AC varieties. Intermediate- to high-GT varieties showed greater increase in hardness when stale than did low-GT varieties, but the intermediate- to high-GT varieties softened again more than did the low-GT varieties when the stale cooked rice was reheated. However, among intermediate- and high-AC varieties, the hardness of stale and reheated rice was usually higher than that of freshly cooked rice, suggesting only partial reversibility. Cooked parboiled IR62 and IR74, which have high AC, also showed increased hardness when stale, but only IR62 (soft GC, intermediate GT), which had been parboiled at 100 °C, resoftened when heated. Thus, varietal differences in amylopectin staling contribute to observed differences in cooked rice texture among varieties with similar AC.

Pasting properties of rice with rapid VISCO analyzer

The manufacturer recently added a cooling program to the RVA. We compared measurement of rice pasting viscosity by RVA and Brabender amylograph.

The RVA unit requires 3 g rice flour/25 ml water and 14.5 min total run: 1.5 min homogenization at 50 °C, 3.75 min heating from 50 to 95 °C at 12 °C/min, 2.5 min at 95 °C, 5.42 min cooling from 95 to 30 °C at 12 °C/min, and 1.3 min at 30 °C. In contrast, the amylograph uses a 10% paste with a 40- to 50-g sample and requires 92 min to run. Shear was higher in the RVA than in the amylograph—even IR8 and Taichung Native 1 showed some breakdown in the RVA. Studies on 27 low-AC (15-20%) Korean varieties, 12 low-GT waxy varieties, 33 nonwaxy elite irrigated lines (20-29% AC), and 10 nonwaxy varieties (15-29% AC, variable GT) demonstrated that the RVA is a good rapid screening technique for pasting properties of rice and requires smaller samples and less time than the amylograph.

Postharvest and biomass issues

Stripper-harvesting systems engineering

A fresh approach to rice harvesting systems is needed to address three areas: 1) reducing losses—traditional, manual methods of rice harvesting result in field grain losses of 1-3%, even under good conditions; 2) reducing harvest costs—the major cost is labor; and 3) improving timeliness of the harvest operation—delays at harvest time are a major problem where harvest labor is scarce, and can cause crop loss, quality degradation, and increased turnaround time.

The stripper system. During the past 2 yr, the Agricultural Engineering Division has been devel-

oping small-scale stripper harvesting systems using a new approach built around the plastic stripper rotor principle for combine harvesters. The principle originated at the Silsoe Research Institute, UK. This simple but efficient rotor can harvest with lower losses than a cutterbar front, even in difficult crop conditions. With the stripper system, only a small proportion of the straw is gathered, e.g., 20% in good crop conditions, compared with 40-60% for hand harvesting. IRRI has pioneered the use of small-scale stripper harvesting systems seeking to meet the objectives above, in a range of geographical and socioeconomic conditions.

Our work advances harvest technology, and has proceeded along three lines:

1. The first system is built around a basic machine, the Stripper Gatherer (SG 600, Fig. 47 and SG 800), which was designed to keep weight and cost to a minimum. The grain and straw harvested by the stripper rotor feed into a removable collection module. The harvested material is rethreshed and cleaned with easily portable equipment set up beside the harvest site.
2. The second system, the Stripper Thresher (ST 600) is based around a machine fitted with a rethresher (Fig. 48). It produces uncleaned grain which is conveyed to sacks that are off-loaded when full.
3. The third system, the Stripper Combine (SC 1000), uses a machine fitted with a rethresher and a "bolt on" cleaner module, which will produce clean grain on board.

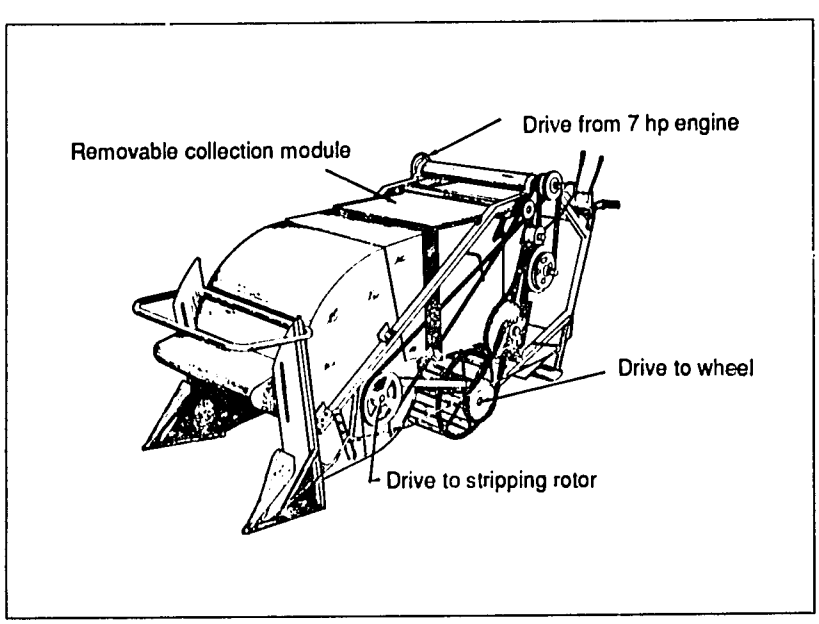
Table 61 describes the systems.

Stripper gatherer. Two models of the stripper gatherer have been field-tested: a 450-mm machine (Program report for 1990) and the 600-mm gathering width version (SG 600). In summary, we found

- The stripper gatherer is highly effective and portable. In good crop conditions, losses were less than 1% in rice. Many rice varieties and other crops have been harvested with the stripper, including the legume crotalaria. Performance at all times has been most promising. The prototypes can be lifted into small ricefields by two men.
- In difficult, lodged crop conditions, losses have been lower than those from small combines of the head feeding type and from cutterbar-equipped

Table 61. Specifications of stripper harvester systems for small area farming.

Item	Stripper gatherer SG 600 (version 2)	Stripper gatherer SG 800 (version 3)	Stripper thresher ST 600
Harvesting width (m)	0.6	0.8	0.6
Field capacity (ha/d)	0.8	1	1
Estimated cost (US$)	1000	1200	2500
Weight (kg)	130	150	250
Estimated labor demand (labor-d/ha)	7	8	6



47. The stripper gatherer (SG 600) version two. Patent coverage has been initiated.

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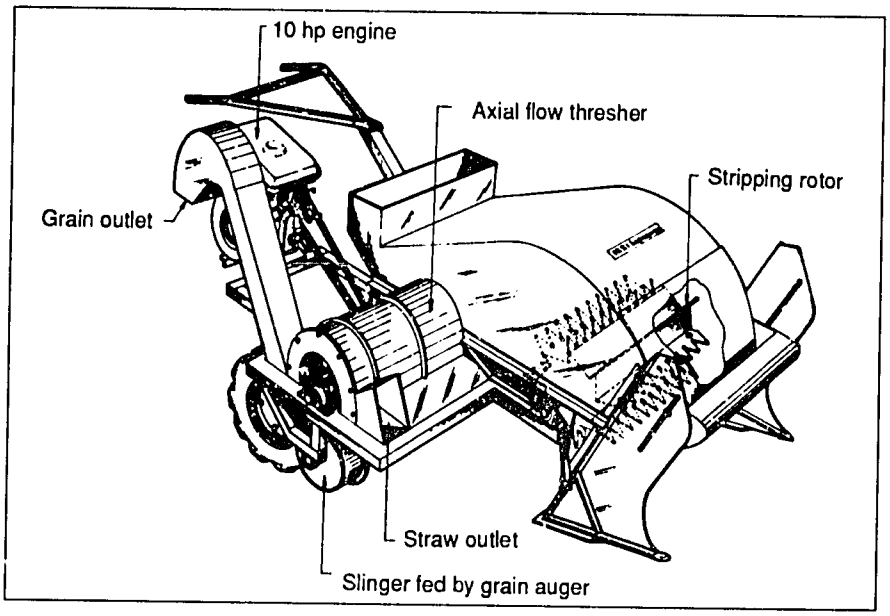


48. The stripper thresher (ST 600) version one. Patent coverage has been initiated.

combines. Usually losses were less than one-half of the losses incurred by manual plus thresher harvesting teams. The stripper gatherer can work faster and with less trafficability problems in wet fields than self-propelled rice combines.

- The walk-behind machine is highly maneuverable and can work in wet fields. The mono-starwheel has proven successful on small strippers, maintaining trafficability where even combines equipped with crawler tracks created deleterious ruts in the field.
- The full-width, mono-starwheel traction system lends itself well to "lock-lodging" the straw left by the stripper head. Thus, a ratooned crop will probably yield more after a stripper than after a combine or traditional hand-harvesting (see straw incorporation after stripper harvesting, p. 206).
- Preliminary cost analysis of the overall stripper-gatherer system indicates that the capital outlay on the SG 800 model would be recouped after 40 ha have been harvested and that the model would be profitable for contract harvesting 14 ha/season.
- The collection module is a satisfactory system for low-cost harvesting. The collected material is hand-carried or skidded in the module to the side of the field where the rethresher or cleaning gang prepares the rice for transport. Effective overall work rate was 8.8 labor-d/ha, compared with approximately 25 labor-d/ha for traditional harvesting in conjunction with a contractor-operated axial-flow thresher.
- The standing straw left by the stripper is greater in volume but not significantly more difficult to incorporate than stubble left by hand-reaping.
- The SG 600 has attracted positive interest from Sri Lanka. A Sri Lankan engineer has spent a month at IRRI learning the technology, so he can reproduce the machine in his country.

The stripper thresher. This self-propelling, walk-behind system produces uncleaned grain, which is bagged on board the machine. Grain losses are very low, as with the stripper gatherer. Field capacity was 6 labor-d/ha.

Need for a stripper combine harvester. Results of the IRRI approach to stripper harvesting have so far generated strong interest from Thailand, Indonesia, Sri Lanka, China as well as the Philippines. The systems are expected to meet needs in labor-scarce areas, such as the central plains of Thailand, where about 500 units of a 3-m-wide combine harvester have been sold since the first cumbersome design was tested in 1987. The first two stripper systems currently under development at IRRI meet a need for labor-saving harvest technology where field size is small and access may be difficult, but these systems are too small for large fields where access is easy.

Combine harvesters currently available in Asia are heavy, complex, and, as a result, expensive to purchase and maintain. Our experience with stripper harvesting shows that significant savings in weight, complexity, and cost are possible with a stripper combine harvester because of the simplicity of the stripper rotor system and the small amount of straw harvested with the grain. When less straw is harvested, rethreshing and cleaning can be carried out by smaller, lighter, and less powerful equipment. The research and development challenge is to take full advantage of the savings possible while ensuring performance in a lodged crop, when more straw is harvested.

A 1-m stripper combine Model SC 1000 has been designed but not yet assembled. Thai and Chinese engineers and other national program staff are hoping IRRI will develop this design to meet their country's needs.

Straw incorporation after stripper harvesting. The rapid progress with the IRRI prototype stripper harvester systems has raised a new question: how does a farmer manage whole, standing straw left after stripping? A pilot experiment was run in May 1991 to compare the time taken and quality of land preparation of two stripper-harvested plots (6 t of whole, attached straw incorporated per ha) with two manually reaped plots (3 t of straw incorporated per ha). A traditional land preparation sequence of moldboard plowing with a PT5 hand tractor, followed by two comb harrowings and final leveling, was chosen as the sequence likely to be most sensitive to levels of straw incorporation.

Results from the pilot experiment are as follows:

- The degree of soil inversion and straw incorporation was less in the stripped straw treatment. Stripped straw lying against the direction of plowing did interfere with the moldboard's usual action of inverting soil and placing it in the furrow left on the previous pass. Stripped straw lying in the direction of plowing, however, did not affect soil flow from the moldboard.
- The time taken, ease, and quality of subsequent harrowing operations did not differ much despite somewhat less soil inversion after plowing the stripped straw areas. The total time taken for land preparation was 8% greater for the stripper-harvested areas.

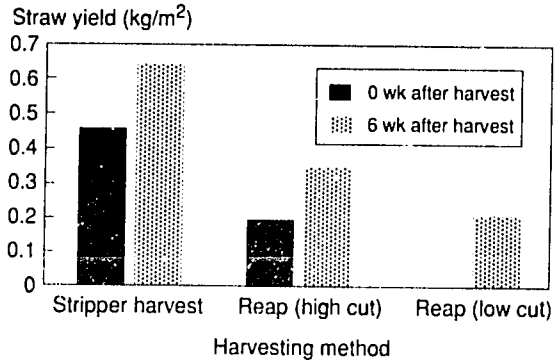
A second experiment checked whether the difference in land preparation time was significant. The experiment used a completely randomized design with four replications. Level of straw incorporation was the single factor at two levels. In the stripped plots, 4.5 t straw/ha was incorporated compared with 1.9 t/ha in the reaped plots. The same sequence of land preparation operations was used in both plots. Land preparation was completed in 2 wk. Grain yield will be measured to establish whether the increased incorporation of organic matter affected yield.

During the second experiment, the stripped straw did not appear to affect ease and quality of moldboard plowing; the same hand tractor, plow, and operator were used. This may have been due to increased decomposition of the stripped straw in floodwater prior to plowing, and because less stripped straw was incorporated.

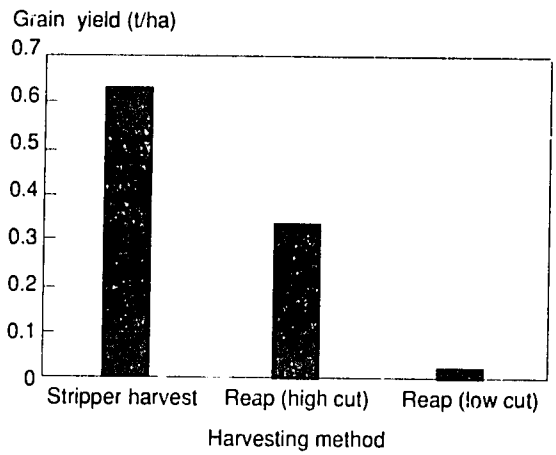
The total time taken for land preparation was 9.5% higher for the stripper-harvested areas, although this was not found to be significant at the 5% confidence level.

Farmers in the Philippines usually incorporate far more organic matter than that contained in the rice stubble at harvest time. Weeds proliferate in fallowed ricefields, and the rice plants continue to grow. An experiment measured the amount of regrowth after harvest. A randomized complete block design was used with three treatments and six replications: stripper harvest; reap (high cut), which simulates high-cut manual reaping; and reap (low cut), which simulates low-cut manual reaping. Figure 49 shows the amount of straw regrowth after 6 wk (the field was dry for 4 wk and flooded for the last 2 wk). The field was harvested on 14 Apr 1991. The increase in straw organic matter was substantial. The amount of straw in the stripper-harvested plots increased an average 1.8 t/ha, from 4.6 to 6.4 t/ha. The weight of straw increased in the two other treatments by almost the same amount—1.5 t/ha in the reap (high cut) and 1.9 t/ha in the reap (low cut) treatments.

We weighed the organic matter (straw and weeds) in two farmers' fields in Bay, Laguna, after the fields had been left fallow for about 2 mo. One field yielded 3 t organic matter/ha and the other yielded 4.3 t/ha. Immature tillers continued to develop during 6 wk regrowth, and yielded some panicles with mature, filled rice. Figure 50 shows that the stripper-harvested treatment yielded the greatest amount of mature grain (0.64 t/ha).



49. Effect of harvest method and turnaround time on weight of straw dry matter for incorporation.



50. Effect of harvest method on grain yield 6 wk after harvest.

Regrowth from manually harvested rice plants is sometimes harvested (usually gleaned by the poorest members of the community). Stripper harvesting would increase this yield potential. More often, however, fallow ricefields are used for animal fodder, and greater regrowth grain yield would increase the nutritive value of the fodder.

Compared with manual reaping, stripper harvesting results in roughly double the length and weight of straw that may be directly incorporated during land preparation. The above experiments indicate that this increase does not significantly raise land preparation time with a moldboard plow and comb harrow. Straw incorporation may be hastened by trampling the harvested straw and allowing it to partially decompose prior to land preparation. Farmers probably will adopt the direct incorporation of stripped straw because, under present conditions, weed and straw regrowth increases the amount of organic material directly incorporated at land preparation to a level approaching the whole straw yield at harvest time.

The greater volume of straw favors rice ratooning after stripping since there will be more metabolizing crop material after harvest. The mono-starwheels (SG 600/800 models) partially lock-lodge the straw for stronger ratoon tillering. Effects of the increased organic matter and lock lodging on ratoon crops will be investigated in more detail.

Socioeconomic analysis of stripper harvesting systems. To assess the likely socioeconomic impact of stripper harvesting systems, this IRRI-Overseas Development Administration collaborative project surveyed 80 farmers and 160 landless rural workers in irrigated areas of Iloilo Province and Bicol region in the Philippines. Iloilo is a relatively labor-deficient area at harvest time); the Bicol region is a labor-surplus area.

Labor in Bicol is scarce during transplanting and, in certain areas, land preparation. The average farm wage is $1.54/d; and the most common farmer-harvester rate of sharing clean rough rice is 10:1 (without meals). The farmer pays for threshing and the harvester for the cleaning cost. Some respondents thresh by foot. Off-farm employment is found in Manila or Laguna Province.

The Bicolano farmers had not seen a mechanical harvester. In Iloilo, farmers' perceptions of harvesters have been influenced by past experience with demonstrations of reapers or through hearsay. Most farmers expressed a desire to use an economical and technically sound machine. They raised concerns about the stripper's ability to harvest lodged crop, harvest in wet and muddy soils, and harvest direct seeded rice, which is replacing transplanted rice in many Iloilo areas.

Farm laborers in both Iloilo and Bicol, especially the women harvesters, perceived that the stripper harvesters could threaten their main source of income. Gender and equity issues are being carefully considered.

Preliminary results indicate that, provided farmers are convinced of the technical and economic merits of the stripper harvester, Iloilo farmers will be attracted to the system because of the potential for more intensified rice farming, less losses, and reduced input costs. The introduction of the stripper, however, must be accompanied by acceptable changes in labor arrangements. A stripper harvesting system can be set up to provide almost no labor

displacement but to reduce loss and drudgery, and improve timeliness.

Thresher developments

Crop flow in the IRRI axial-flow threshers. An "inductive crop-flow measuring system" designed at Hohenheim University was used to optimize the performance of the IRRI modular thresher (TH11). (This joint project with Hohenheim University, Germany, is funded by the German Agency for Technical Cooperation.)

The system uses magnets enclosed in heat-shrinkable plastic tubes as signal transmitters. The tubes are added to the crop where the magnets induce signals while passing coils inserted in the concave inside the thresher. Using a data acquisition system and computer, the signals are amplified in a display unit, which records coil location and travel time. The computer program package calculates the signal transmitter tracks and projects the tracks into the developed views of the concave circumference. The power requirement of the threshing drum is determined using a torque meter. The concave is divided into three sections to determine grain separation over concave width. The effects of feed rate, threshing drum speed, and different louver adjustments on crop flow and threshing performance were determined in several test runs. Crop flow was found to be strongly influenced by louver angle, which determines the number of crop revolutions around the threshing drum (we found a maximum of 11).

The measuring system showed that the original louver angle ought to be modified to improve flow in the feed section and reduce backfeeding at the feed opening. Effects of design modifications on the performance of the axial-flow thresher are being tested. A thresher test stand with grain conveyor and multicrop thresher is being constructed for further research and development work.

IRRI treadle thresher. A new prototype lightweight treadle thresher with friction drive, sheet-metal chassis, and involute, interchangeable threshing bars was fabricated. The treadle thresher operates in three modes: 1) thresher mode, 2) winnower/blower mode, and 3) transport mode (accessories allow the unit to operate as a wheelbarrow). The prototype weighs 30 kg and is estimated to cost approximately US$75.

Initial test results showed that the treadle thresher threshes more than twice the amount of grain daily as does trampling or hand beating. Further tests are being conducted to optimize the design.

Drying

The technical feasibility of low-temperature, in-storage drying under humid tropical weather conditions was assessed in a joint project with Hohenheim University.

The system tested consists of a rectangular bin, an air sweep floor for air distribution and unloading, an electric heater, and a centrifugal fan. Two WS tests showed that a maximum 2-m depth of rice can be dried from 27.5% moisture levels to safe storage levels in one pass. Under humid tropical conditions, the ambient air is slightly preheated (6-9 K) at night to prevent crop spoilage. Because of the low-airflow and high-efficiency fan that forces air through the rice, extremely low power is used (40 W/m^3 of grain). Under the Philippine Trade Standards for grading rice, rice dried using this system was found to be of premium quality.

Present efforts are geared toward constructing the same unit using locally available materials. The system will be modularized to accommodate the required capacity, material, and preheating system.

Milling

Ultralite centrifugal huller. Hulling continues to be a major source of income for rural women. To reduce drudgery of this task, we designed an ultralite centrifugal huller. The huller weighs 15 kg with engine and is compact (overall dimensions are 400 × 400 × 600 mm). The unit was field-tested in Carusocan, Santa Barbara, Pangasinan (site of the Women in Rice Farming Project). Initial test results showed that the huller performs best with parboiled rice. Interviews with women users indicated high acceptance of the machine's performance. Further test and development work will be conducted in consultation with prospective users.

Small-scale rice mill. Optimum operating conditions of the MR150 micromill were identified using the response surface methodology. With rib depth of 7 mm, screen clearance of 6 mm, and peripheral speed of 5 m/s, the micromill achieved a milling recovery of up to 70%, head rice recovery of up to 80%, whiteness number of up to 37, and negligible amounts of unhulled grains.

Acceptability of the machine was field-tested in several localities in collaboration with the Philippine

Rice Research Institute. Initial results indicate that access to commercial mills is the most significant factor affecting acceptance of the machine. End-user interview responses also indicated areas for possible improvement of the design.

Ongoing modifications will improve the livestock feed recycling unit and increase the capacity to 200 kg/h. We will evaluate the feasibility of milling with high moisture content grains (16-18%) to lower breakage and reduce energy required for drying. Product storability will also be studied. The performance of the micromill for different varieties will be examined.

Continuous rice husk gasifier-combustor for drying rice

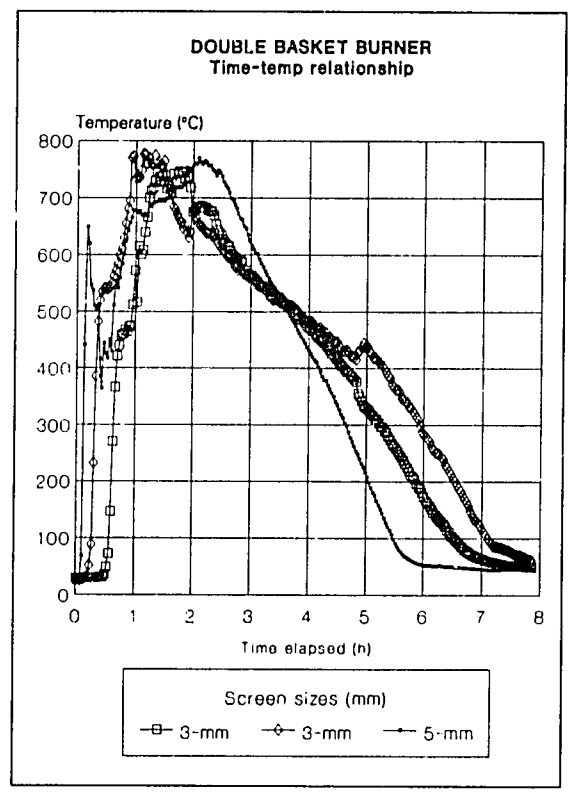
Rice husk is a much cheaper fuel than kerosene. Conventional direct combustion rice husk furnaces with flat or inclined grates cause incomplete combustion and generate ash, dust, and sparks. Batch-type gasifier combustors are bulky, as they contain rice husk or inactive ash. A continuous-flow model with compact, lightweight, and simple construction; easy control of heat rate; clean burning flame; and provision for continuous rice husk feeding is currently being tested.

Preliminary tests on the inclined reactor (the first in a series of furnace configurations) to synchronize the feeding rate with the combustion and ash-removal rates are under way. The gasifier-combustor was designed to be operable continuously for at least 8 h. It is compact and lightweight to allow for mounting as a component of a mobile dryer.

Double-basket rice hull burner

Amorphous rice hull ash is potentially valuable as a cement extender, for brick making, or even for silicone, silica gel, and electronics-grade silicon. The double-basket burner is a simple, low-cost, annular device made of wire mesh and intended to produce amorphous rice hull ash. To produce the chemically active amorphous silica in a burning bed of rice hulls, sufficient air is required for complete combustion but without permitting conditions (time-temperature-pressure-air) that favor crystalline silica formation (slagging).

Two prototypes of a modified double-basket burner were tested and their thermal properties evaluated using a data logger recording from strategically placed bimetallic temperature probes. Test results showed that peak temperatures did not exceed 800 °C, thus minimizing the possibility of slagging, which can occur if conditions are favorable at temperatures above 750 °C. The best performance was obtained with 5-mm wire mesh (Fig. 51). Further tests will be conducted with hulls of different rice varieties.



51. Data from temperature probes inserted in rice hulls burned to produce amorphous silica. This is a potential use for a rice by-product that is otherwise a nuisance in some areas.

International Programs

International programs

Germplasm conservation and dissemination

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Germplasm conservation and dissemination

Subprogram I: Germplasm conservation and dissemination

Germplasm collection, acquisition, and research

FIELD COLLECTION

In 1991, three important regions of rice genetic diversity were visited in collaborative germplasm collecting missions. In a multiteam effort with the National Bureau of Plant Genetic Resources, the state of Madhya Pradesh in India was explored for wild rices. In Papua New Guinea (PNG), with staff of the Department of Primary Industry, remote parts of the southern coast were visited and three species collected: *Oryza longiglumis*, *O. officinalis*, and *O. rufipogon*. On the banks of the Fly River PNG, the unexpected find of *O. minuta*, previously reported only from the Philippines, was of particular interest. Staff of the Agricultural Research Institute in Myanmar were joined by IRRI staff in collaborative collecting efforts in that country. Wild rices were collected in the lowland valleys; on the Shan Plateau, local traditional cultivars as well as the wild rice *O. granulata* were collected.

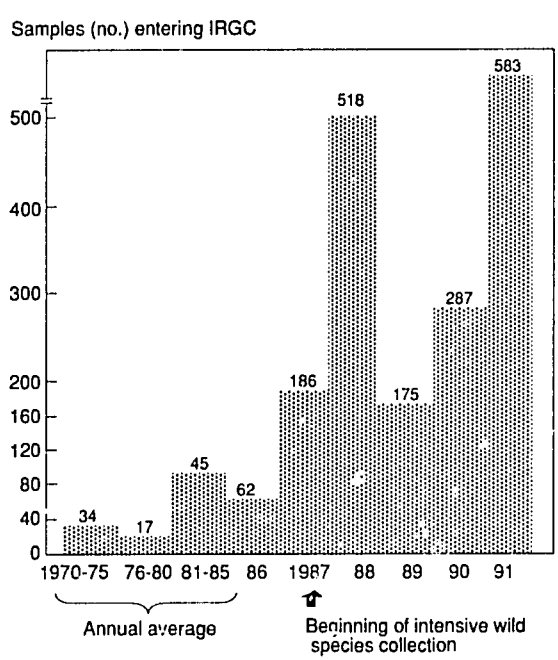
ACQUISITION

A total of 2,905 seed samples was received during the year: 2,322 samples of *O. sativa* and 583 of the wild relatives of rice. Donations of germplasm were received from Cambodia (1,250 samples), Brunei (305), Laos (256), Malaysia (106), and the Philippines (104). Major donations resulting from collaborative collecting included seed samples from India (343) and Myanmar (91). Among special types received were some samples reported to have durable blast resistance and some cytoplasmic male sterile lines.

Progress in collection and acquisition of wild germplasm in recent years has been dramatic, with a total of 1,749 incoming samples in the last 5 yr compared with only 794 in the previous 16 yr (Fig. 1). It will be easier to handle this important germplasm when the nursery area has been expanded as part of the genebank renovation.

MONITORING OF VIABILITY OF STORED SEED STOCKS

In addition to regular viability monitoring of stored seeds, we are testing the initial viability of all accessions entering the Active and Base Collections and have followed a sequential viability monitoring system that is more cost- and time-efficient. Of the



1. Collection/acquisition of wild species germplasm, 1970-91.

4,596 accessions tested for initial viability, only 46 had a viability of less than 85%, the lowest acceptable for an accession of the japonica race to enter the Base Collection. Most of the 46 were japonica varieties.

Fungal flora on stored rice germplasm

We are undertaking a long-term study to monitor the fungal flora on germplasm stored in the medium-term storage room of IRGC (about 2 °C, 40% relative humidity) to determine whether this might have an effect on germination and vigor of stored seeds. After 3 yr of monitoring, we find no significant change in germination or differences in vigor (as measured by seedling root length) among stored seeds, treated or untreated with fungicides.

The fungus *Aspergillus* sp. shows an increase over time in stored seeds untreated with fungicide, but the fungus *Penicillium* sp. declines. Neither fungus is present in treated seed lots. Fungal genera from untreated seed lots number 19 compared with 9 from treated seed lots. Of the fungal genera that can infect seed, *Curvularia* and *Fusarium* produce significantly lower infection in seeds treated with fungicide.

At this stage of the study, there is no indication that seed fungi have an adverse effect on the germination or vigor of stored germplasm. It is likely that as seeds get older and physiclogically weaker, measures to protect germinating seed stocks from pathogen infection may be warranted.

Cytological characterization of wild species germplasm

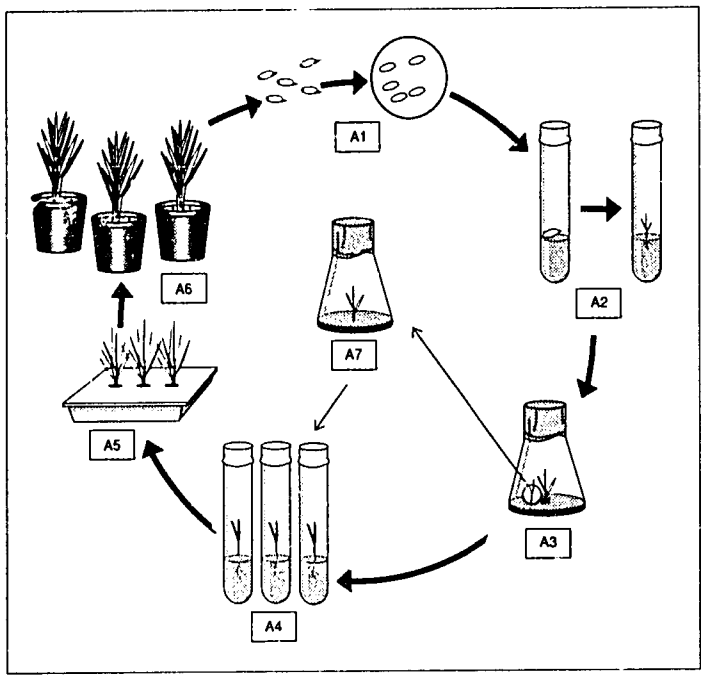
Oryza schlechteri recently collected in Papua New Guinea is a tetraploid with 48 chromosomes (Fig. 2). Two species of *Leersia* from Africa—*L. perrieri* and *L. tisseranti* in the IRGC—are confirmed diploids with 24 chromosomes. Most of the other species in the genus *Leersia* are reported to have 48 or more chromosomes.

We have also checked the chromosome numbers of all the IRGC accessions of *O. punctata*, which can be either diploid or tetraploid. Both chromosome races are found in West and East Africa. In addition, we have confirmed that the Sri Lankan populations of *O. eichingeri* are diploid.

Improved conservation by in vitro culture

Protocols have been developed using single seeds and callus to multiply the cultivated rices indica, japonica, and *O. glaberrima*. Slightly modified procedures from those reported earlier have been developed to multiply plantlets of *Oryza* species

2. The 48 chromosomes of *O. schlechteri* during root tip mitosis.



3. Protocol for proliferation of plantlets from seeds. A1 and A2: mature seeds are placed on germination media. A3: young seedling is transferred to the proliferation medium. A4: older tillers are separated from the tiller cluster and placed in rooting media. A5: after 2 wk, seedlings are transferred to culture solution. A6: seedlings are transplanted into pots. A3 and A7: emerging shoots from dissected tiller cluster can be subcultured into fresh proliferation medium for further proliferation.

having the CC, BB, and BBCC genomes. The germination media had reduced agar (0.4%) and sucrose (3%) compared with the germination media for cultivated rices. After germination, developing embryos were transferred to a modified second medium having a lower sucrose concentration, casein hydrolysate, and a different combination of plant hormones. Plantlets of these wild species were successfully grown to maturity.

Protocols developed for species with AA, BB, CC, and BBCC genomes allow multiple plant development from a single seed and/or callus and can be used to safeguard accessions that produce few seeds or for which there are low viability seed stocks (Fig. 3). However, attempts to use the present procedures with *O. longistaminata* have not been successful and methods of inducing callus and plantlets from this species are being investigated.

Seed germination protocols

We have established the protocol for breaking dormancy and germinating seeds of species maintained in IRGC from genera closely related to *Oryza*: *Chikusichloa aquatica*, *Leersia perrieri*, and *Rhynchoryza subulata*. Dormancy can be broken by applying a temperature of 50 °C for 7 d and removing the palea and lemma before germination. To germinate, seeds are placed on filter paper in a germinator at 30 °C with a 12-h day (Table 1).

Seeds of *Porteresia coarctata* exhibited recalcitrance. Germination was 67 to 83% using embryos excised from nondried seeds harvested 22 to 29 d after flowering (Fig. 4). Embryos collected 22 d before or 32 d after flowering commenced did not germinate.

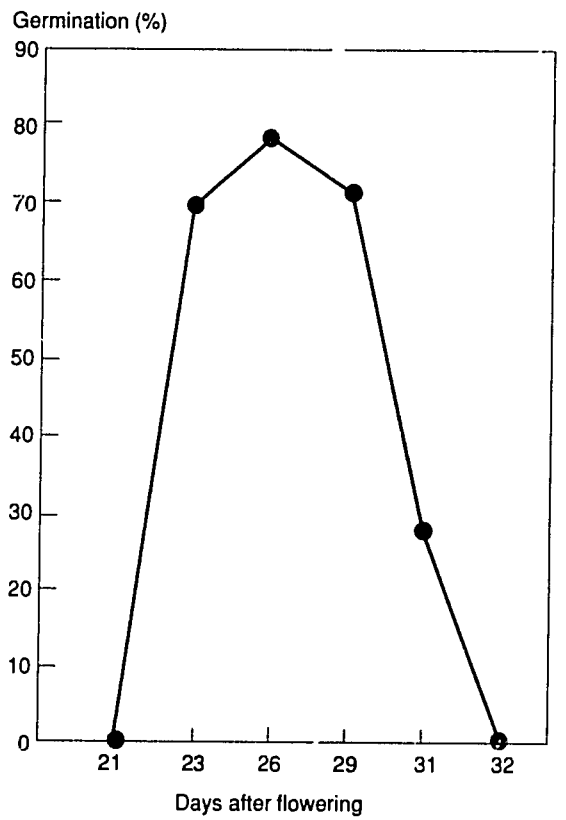
Embryos excised from seeds of *Hygroryza aristata*, and air-dried at room temperature (25-27 °C) for 7 to 14 d, showed 85% germination. Seeds exposed to temperatures higher than 30 °C failed to germinate.

Rice genetic resources working group meeting

The first meeting of the Rice Genetic Resources Working Group was held at IRRI in August. The close interaction among scientists conserving rice

Table 1. Germination of seeds of species in genera related to rice.

Species	Germination (%)	Days to maximum germination
Chikusichloa aquatica	88	15
Leersia perrieri	86	34
Rhynchoryza subulata	79	8



4. Germination of *P. coarctata* embryos collected at different days from initiation of flowering.

genetic resources is meant to further harmonize international efforts to conserve rice germplasm. Discussion focused on these areas:

1. Solutions to common problems that all rice genebank curators face, such as reliable equipment to help reach the best standards for seed preservation;

2. Extending and improving the internationally agreed upon set of descriptors for rice to encompass passport data and germplasm management descriptors;

3. Interaction between IRRI and national genebanks on the cross-matching of germplasm so that the same accession at IRRI and in national programs can be correctly identified by the accession numbers of both programs.

Germplasm conservation, dissemination, and assistance to national agricultural research systems

Seed production and characterization

In 1991, 9,459 accessions were planted on 22 ha: 10 ha off-farm and 12 ha on-farm in the two seasons.

During the wet season (June to November), 2,343 accessions were completely characterized in the field. We compared 90 probable duplicates in the field, and found 38 to be phenotypically different from varieties in the existing collection. We regenerated on culture media 129 accessions that had few and/or weak seeds; 54 reached maturity.

Three hundred and eighty-eight wild rice accessions were grown in the screened nursery area; 85% were new incoming samples and 15% rejuvenation of old seed stocks. In the nursery area where special protection is available, 1,781 accessions of *O. sativa* with few seeds or special types were grown.

O. glaberrima accessions totaling 195 were completely characterized in 1991, and 324 wild rice accessions were characterized up to the reproductive stage.

Inventory of seed stocks

A thorough inventory of the holdings of wild rice in 1991 showed that we have 1,887 accessions of wild rice and 879 incoming samples. All species in the genus *Oryza* are now represented in the IRGC collection. The breakdown by species of conserved wild species is shown in Table 2. Progress in updating the inventory of the cultigens *O. glaberrima* and *O. sativa* was started during 1991 and is expected to be completed in 1992.

Data base management and development

International cross-matching of rice accessions. Efforts were intensified to cross-match rice germplasm accessions held in IRGC with the accession number of the same germplasm in other genebanks. The identification number of the germplasm donors was stored in the computer with the IRGC accession number. This information was completed

Table 2. *Oryza* species and the number of distinct accessions conserved in the International Rice Germplasm Center, IRRI, December 1991.

Species	Accessions (no.)	Incoming samples (no.)
O. alta	10	
O. australiensis	25	
O. barthii	146	13
O. brachyantha	11	
O. eichingeri	18	
O. glumaepatula	32	
O. grandiglumis	8	
O. granulata	7	14
O. indandamanica	1	
O. latifolia	33	
O. longiglumis	5	1
O. longistaminata	109	64
O. malampuzhaensis	5	
O. meridionalis	39	
O. meyeriana	7	4
O. minuta	47	18
O. nivara	318	168
O. officinalis	155	83
O. punctata	41	6
O. rhizomatis	18	
O. ridleyi	11	7
O. rufipogon	494	267
O. schlechteri		1
O. spontanea and hybrid populations	309	233
Oryza species	38	
Total	1887	879

for India, China, Japan, and Laos and given to representatives of those countries for further verification and additions.

Revised version of IRRIGEN released. A revised version of the microcomputer-based rice genetic resources software IRRIGEN and printed operational manuals were released free of charge to 16 national program collaborators in Asia and Africa.

Data base management assistance to Cambodia. The Cambodia-IRRI project was assisted in the development of a Cambodian germplasm data base. Passport and characterization data on 1,275 newly collected germplasm samples from Cambodia were entered into the data base.

IRGC data base on-line. Improved international communication systems now make it possible for the information on IRGC accessions to be directly accessed from many other countries. Revision of the data base files has been initiated to ensure compatibility among them.

BASE COLLECTION AND DUPLICATE STORAGE

A total of 4,328 accessions have been processed for the Base Collection (long-term storage) and Active Collection (medium-term storage) during the year. Of these accessions, 4,184 were *O. sativa*, 78 *O. glaberrima*, and 66 wild species.

IRRI sent 5,008 accessions for duplicate "black box" storage at the National Seed Storage Laboratory (NSSL), Fort Collins, Colorado. Currently, about 62% of IRGC accessions are in the Base Collection; of these, 44,965 have been sent for duplicate storage at NSSL. Most of the accessions in IRGC are also stored in the national centers where they originated.

SEED DISTRIBUTION AND INFORMATION DISSEMINATION

A sharp drop in the number of requests for germplasm and in the number of samples distributed during the year to scientists within IRRI would seem to indicate the change of personnel within the institute, change in evaluation methods, which are more detailed and can only involve a limited number of accessions, as well as more judicious selection of germplasm for evaluation. Within IRRI, 24,310 seed samples were distributed (Fig. 5).

With 8,949 samples of cultivated and wild rice being distributed in response to 188 requests, the distribution of seed samples to the national programs remains unchanged over recent years.

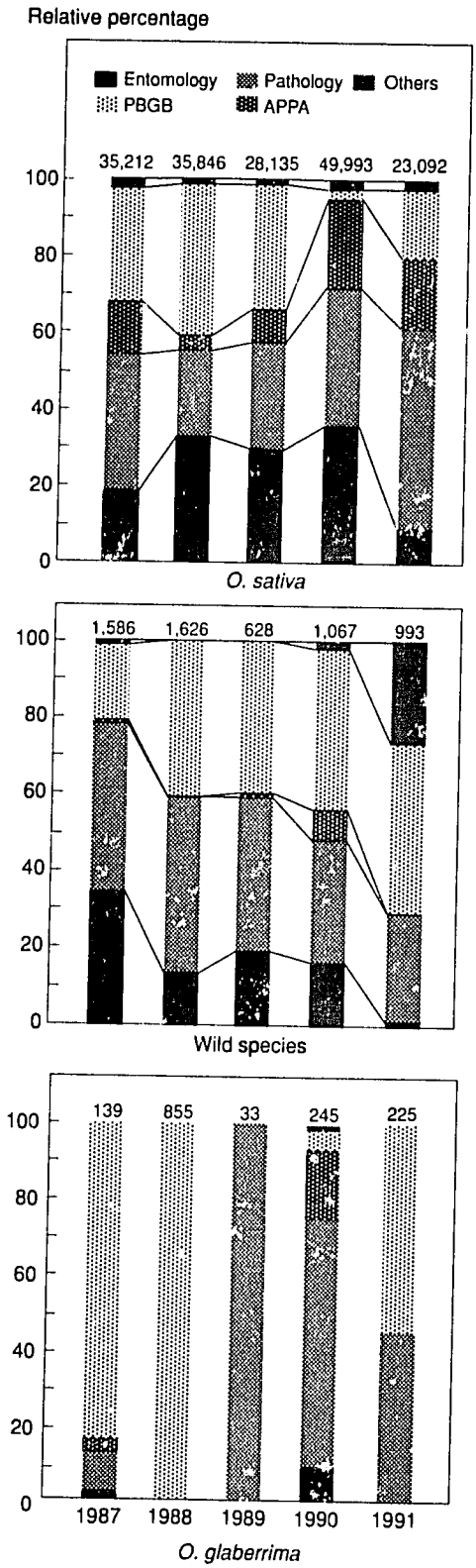
Changes in operational procedures in IRGC related to packaging, cleaning, and time of distribution were introduced during the year. The principal changes involved computerized labeling of seed packets and prepacking of 10-seed lots for distribution.

TECHNICAL ASSISTANCE TO GENEBANKS OF NATIONAL AGRICULTURAL RESEARCH SYSTEMS

IRGC staff visited the newly constructed genebank at PhilRice (Philippine Rice Research Institute) and discussed operational procedures and ways of efficiently developing operations. In addition, IRGC donated containers to store accessions in the PhilRice genebank.

The Center's associate geneticist discussed genebank operations with staff of the newly opened Myanmar Seed Bank and was invited to lecture to the staff on rice genetic resources.

IRGC staff held a training session for IRRI staff working on wild *Oryza* to explain methods of grow-



5. Distribution of seed samples from IRGC to different divisions of IRRI since 1987. Numbers on top of bars indicate number of accessions.

Table 3. Phytosanitary certified seed lots sent by IRRI to different regions, January-December 1991.

Region[a]	Shipments (no.)	Seed lots (no.)	Total weight (kg)
East Asia (4)	101	22,259	2,908.88
Southeast Asia (9)	105	35,272	912.74
South Asia (6)	106	33,605	1,063.86
West Asia and North Africa (6)	19	7,843	133.03
Europe (14)	61	1,858	135.93
Sub-Sahara Africa (18)	36	8,684	272.07
Latin America (12)	32	8,037	190.83
North America (2)[b]	32	7,274	203.19
Oceania (3)	13	1,061	44.74
Total	505	125,893	5,865.26

[a]Numbers enclosed in parentheses refer to the number of countries included per region. [b]Includes duplicate samples sent to NSSL, Fort Collins, Colorado, USA.

ing and caring for these delicate materials. A Cambodian and an Indian trainee undertook their special projects in IRGC and were also given hands-on training in data management operations. Two staff from PhilRice underwent a 2-wk on-the-job training on genebank operations.

Subprogram II: Seed health

The Seed Health Unit (SHU) and the Philippine Plant Quarantine Service processed and certified 125,893 seed packets (seed lots) from IRRI and sent them to collaborators in 74 countries in 9 regions (Table 3). Major IRRI sources of seeds were INGER with 89,020 seed lots; Plant Breeding, Genetics, and Biochemistry (PBGB) Division with 20,079, and IRGC with 14,955 (Table 4). Other sources were Plant Pathology; Soil Microbiology; Agronomy, Plant Physiology, and Agroecology (APPA); and Training Center. During the year, 6,715 rice seed lots were received from 27 countries and 2,821 plantlets and rice cuttings from the USA and Papua New Guinea (Table 5). The major consignees of incoming rice seeds were PBGB and IRGC followed by INGER, Plant Pathology, and APPA divisions. Rice cuttings and plantlets were imported by PBGB and IRGC (Table 6).

In the postentry certification of incoming germplasm, the following plant quarantine objects were identified: a) weed from 50 seed lots (1.9% of total seed lots) with 11 weeds species belonging mostly to *Echinochloa* spp., *Fimbristylis* sp., *Pas-*

Table 4. Sources of seed in lots sent by IRRI to different countries through the Seed Health Unit, January-December 1991.

Source of seeds	Shipments (no.)	Seed lots (no.)	Total weight (kg)
Plant Breeding, Genetics, and Biochemistry	185	20,079	3,244.04
INGER	134	89,020	2,293.04
IRGC	137	14,955	265.75
Training Center	1	1	0.14
Plant Pathology	41	1,324	29.07
Agronomy, Plant Physiology, and Agroecology	4	22	3.49
Soil Microbiology	3	492	29.73
Total	505	125,893	5,865.26

Table 5. Origin of imported germplasm received by IRRI from January to December 1991.

Origin[a]	Shipments (no.)	Seed lots (no.)	Total weight (kg)
Rice seeds			
East Asia (4)	15	2084	29.78
Southeast Asia (8)	17	2427	37.20
South Asia (4)	23	829	68.53
West Asia and North Africa (1)	3	1027	11.88
Europe (3)	4	29	0.43
Sub-Sahara Africa (1)	1	49	4.91
Latin America (4)	6	67	0.70
North America (1)	1	184	1.30
Oceania (1)	1	19	0.07
Total	71	6715	160.86
Rice cuttings or plantlets			
North America (1)	3	2784	-
Oceania (1)	1	37	-
Total	4	2821	-

[a]Number of countries in parentheses.

palum sp., and *Scirpus juncoides*; b) insect and insect damage in 568 seed lots (21.9% of seed lots) from the major species *Sitotroga cerealella*, *Sitophilus* sp., *Rhizopertha dominica*, and *Tribolium confusum*; and c) soil or seeds with soil found in 312 seed lots or 12% of seed lots. Smutted (*Ustilaginoidea virens*) seeds were found in only 0.15% of seed lots (Table 7). All incoming rice seeds were fumigated before phytosanitary tests. Quarantine objects were separated from seed lots and autoclaved before disposal.

Routine seed health tests (RSHT) of incoming

Table 6. Consignees of imported germplasm received by IRRI from January to December 1991.

Origin	Shipments (no.)	Seed lots (no.)	Total weight (kg)
Rice seeds			
Agronomy, Plant Physiology, and Agroecology	3	186	3.82
INGER	19	363	74.79
IRGC	24	2774	17.72
Plant Breeding, Genetics, and Biochemistry	21	3082	60.08
Plant Pathology	4	310	4.45
Total	71	6715	160.86
Rice cuttings or plantlets			
IRGC	1	37	-
Plant Breeding, Genetics, and Biochemistry	3	2784	-
Total	4	2821	-

seeds revealed 11 rice pathogens affecting seed lots; infection ranged from 4% by *Pyricularia oryzae* to 93% by *Trichoconis padwickii* at varying detection levels. RSHT of pretreated seeds received showed that treatments effectively controlled *Fusarium moniliforme* and *Pyricularia oryzae*, but only partially controlled the other seedborne pathogens (Table 8). Materials and seeds used in RSHT were autoclaved before disposal. Incoming seeds were released to consignees only after the prescribed seed treatments—hot water 52-57 °C for 15 min and fungicidal slurry of benomyl and mancozeb both at 0.3% by seed weight—were administered.

RSHT of seeds for export also showed the 11 seedborne pathogens, with *P. oryzae* affecting 0.1% seed lots and *T. padwickii* affecting 99.9% seed lots. RSHT of treated seeds with hot water and fungicide completely controlled *Sarocladium oryzae*, *P. oryzae*, and *Aphelenchoides besseyi*, and drastically reduced infection of the other pathogens in terms of infected seed lots and detection levels (Table 9). All outgoing seeds were given the recommended seed treatments except those sent to countries that specify no pre-export seed treatments.

Crop health was inspected on seed multiplication plots of IRGC, INGER, and PBGB. Incoming seeds totaled 4,167 planted in designated postentry areas. In the dry season (2,885 entries), 79% showed no disease and 13% had only bacterial leaf streak. In the

Table 7. Quarantine objects identified from 2,589 incoming seed lots received by IRRI from January to December 1991.

Quarantine objects	Infested seed lots (no.)	Percent
Weed-contaminated		
Weeds	50	1.93
Echinochloa sp.	50	1.93
Fimbristylis sp.	15	0.58
Paspalum sp.	8	0.31
Scirpus juncoides	7	0.27
Aeschynomene sp.	3	0.12
Ischaemum rugosum	3	0.12
Paspalum distichum	2	0.08
Fimbristylis miliacea	2	0.08
Scirpus supinus	1	0.04
Digitaria sp.	1	0.04
Aeschynomene indica	1	0.04
Unidentified	1	0.04
Insect-damaged	568	21.94
Insects		
Sitotroga cerealella	185	7.15
Sitophilus sp.	151	5.83
Rhizopertha dominica	134	5.18
Tribolium confusum	48	1.85
Liposcelis entomophilus	3	0.12
Cryptolestes ferrugineus	2	0.08
Soil or seed with soil	312	12.05
Smut or smutted seeds	4	0.15

wet season (1,282 entries), 61% were disease-free. The major diseases observed were leaf scald (affecting 11% of entries) and rice blast (16%) (Table 10). Diseases observed on plants originating from incoming seeds were not of the introduced type. Outgoing seed multiplication plots numbered 8,577 entries in the dry season, 86% of which were disease-free. Sheath rot affected 7% of entries while both narrow brown leaf spot and leaf scald affected 2% of the entries. Wet season planting totaled 8,567 entries, 16% of which were disease-free. Bacterial leaf streak affected 65% of the entries; leaf scald, 49%; rice tungro, 20%; and bacterial blight, 11%. Incidence of other diseases was low.

The phytosanitary certification activities of SHU are under the supervision of the Philippine Plant Quarantine Service. Monthly reports of these activities and payments of phytosanitary certificates and import permits were made to the Plant Quarantine Service.

The third 1991 Rice Seed Health Training Course was held from October 5 to October 31 with participants from Bangladesh, Cambodia, China, Korea, the Philippines, and Sri Lanka. The participants were exposed to hands-on evaluation of infested and infected rice seed lots, using available seed testing methods for detection and identification of quarantine objects like insects, weed seeds, soil, smutted seeds, and pathogens found on discolored and non-

Table 8. Rice pathogens detected in routine seed health test (RSHT) of 1991 incoming seeds received without[a] and with[b] treatment.

Pathogen	Without treatment			With treatment[c]		
	Affected seed lots (%)	Detection level (%)	Mean value (%)	Affected seed lots (%)	Detection level (%)	Mean value (%)
Trichoconis padwickii	92.6	1 - 77	26.2	37.0	1 - 56	24.0
Curvularia spp.	90.5	1 - 50	7.0	37.0	1 - 17	6.7
Sarocladium oryzae	21.1	1 - 11	2.0	18.5	1 - 2	1.2
Gerlachia oryzae	29.5	1 - 9	2.7	3.7	1	1.0
Fusarium moniliforme	40.5	1 - 6	1.3	0.0	0	-
Drechslera oryzae	79.5	1 - 59	6.6	40.7	1 - 4	1.5
Pyricularia oryzae	4.2	1 - 10	2.8	0.0	0	-
Phoma spp.	73.2	1 - 27	2.5	29.6	1 - 12	3.8
Nigrospora spp.	41.6	1 - 26	3.7	33.3	1 - 5	2.6
Tilletia barclayana[d]	15.8	1 - 89	45.6	14.8	1 - 13	7.5
Aphelenchoides besseyi[e]	13.7	1 - 30	6.5	40.7	1 - 59	24.0

[a]Based on 200 seeds/seed lot of a total of 190 seed lots. [b]Based on 200 seeds/seed lot of a total of 27 seed lots. [c]Declared treatments were mancozeb, benlate, and pyrimiphos methyl 25%. [d]Contaminated seeds were rejected for certification. [e]Actual nematode count.

Table 9. Rice pathogens detected in RSHT of 1991 INGER nurseries without[a] and with[b] treatment.

Pathogen	Without treatment			With treatment		
	Affected seed lots (%)	Detection level (%)	Mean value (%)	Affected seed lots (%)	Detection level (%)	Mean value (%)
Trichoconis padwickii	99.9	1 - 97	33.1	8.9	1 - 6	1.2
Curvularia spp.	87.7	1 - 46	4.7	5.7	1 - 3	1.1
Sarocladium oryzae	31.0	1 - 46	2.0	0.0	0	-
Gerlachia oryzae	23.1	1 - 20	1.9	0.1	1	1.0
Fusarium moniliforme	13.4	1 - 5	1.2	0.4	1	1.0
Drechslera oryzae	12.8	1 - 6	1.3	4.4	1 - 3	1.1
Pyricularia oryzae	0.1	1	1.0	0.0	0	-
Phoma spp.	59.3	1 - 37	2.2	0.6	1 - 2	1.1
Nigrospora spp.	32.2	1 - 30	2.3	0.2	1	1.0
Tilletia barclayana[c]	2.3	1 - 10	1.7	0.5	1 - 2	1.3
Aphelenchoides besseyi[d]	0.2	1 - 42	12.0	0.0	0	-

[a]Based on 200 seeds/seed lot of a total of 1,988 seed lots. [b]Based on 200 seeds/seed lot of a total of 1,988 seed lots. [c]Contaminated seeds were rejected for certification. [d]Actual nematode count.

Table 10. Entries in multiplication plots of IRGC, INGER, and Plant Breeding, Genetics and Biochemistry Division inspected for crop health and found infected with rice diseases of incoming[a] and outgoing seeds in 1991 dry and wet seasons.

Disease	Incoming[b]		Outgoing[c]	
	Dry season (%)	Wet season (%)	Dry season (%)	Wet season (%)
No disease	79.24	61.39	86.14	16.47
Rice tungro	1.87	1.79	0.90	20.21
Grassy stunt	-	-	-	0.01
Ragged stunt	-	-	-	-
Sheath rot	1.25	4.60	6.55	7.79
Sheath blight	1.73	9.67	0.85	0.23
Stem rot	-	0.47	-	5.08
Narrow brown leaf spot	0.24	-	1.94	0.27
Leaf scald	0.52	11.08	2.05	48.99
White leaf streak	-	-	-	-
Blast	0.69	16.15	0.06	0.27
Brown spot	-	-	-	-
Bakanae	-	-	0.20	-
Bacterial leaf streak	13.14	8.27	0.08	65.82
Bacterial blight	1.59	0.55	0.65	11.16
Leaf smut	-	-	-	-
False smut	0.45	-	0.68	0.01
Bacterial stripe[d]	-	0.31	-	-
Sclerotium seedling blight[d]	-	0.08	-	-

[a]Diseases observed on plants originating from incoming seeds were not of an introduced nature. [b]Based on 2,885 entries in dry season (DS) and 1,282 entries in wet season (WS). [c]Based on 8,577 entries in DS and 8,567 entries in WS. [d]Observed at seedbed stage.

discolored rice seeds. One participant gave a successful lecture demonstration on seed transmission method of *Xanthomonas oryzae* pv. *oryzicola*. Seed treatments were also demonstrated to assess their effectiveness. Crop health inspection and field sampling were done to ascertain disease incidence on mother plants before harvest; they provided disease information before seed health testing.

International programs

Information and knowledge exchange

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Information and knowledge exchange

IRRI's important role as a facilitator of the worldwide flow of rice information is carried out through the Information and Knowledge Exchange Program. Five subprograms are involved: library services, scientific publication, rice data bases and data base information services, conferences and workshops, and public awareness.

Activities carried out by the Information Center are planned to meet the following objectives:

- collecting, documenting, and providing free access to the world's literature on rice;
- publishing scientific information and promoting the flow of current rice research findings to scientists everywhere;
- compiling, updating, evaluating, interpreting, and disseminating primary and secondary data on rice and rice ecosystems;
- facilitating the participation of collaborating scientists in planning rice research, setting priorities, sharing results, and promoting dialogue on institutional and policy issues; and
- creating an accurate understanding of rice, rice research, and IRRI's objectives and work plan among donors, policymakers, and the general public worldwide.

The importance of information and knowledge exchange in the international rice research community is steadily increasing.

Subprogram I: Library

Library services

Completion of a systems analysis of library operations is a first step toward computerization of IRRI Library procedures. Biological Abstracts on CD-ROM improved the library's capacity to respond to information requests received from all over the world. The computerized azolla data base is being used for fast retrieval of literature.

The collection of original English translations of rice literature published in other languages is stored on magnetic tape (in duplicate storage) and may eventually be disseminated on CD-ROM.

By the end of 1991, the Rice Literature Search System (LSS) included approximately 180,000 entries; all of the original documents are represented in the library's book and periodical collections. The library's monograph collection (books, pamphlets, reprints, and translations) now numbers 96,678 documents; the serials collection, 4,184 titles.

Six issues of Rice Literature Update were published; each averaged 1,500 citations of the library's latest acquisitions. Reprint requests totaled 612 from 60 countries. That required the retrieval and copying of 23,715 pages of rice documents.

Subprogram II: Scientific communication

Publication of research results

An ad hoc Publications Advisory Committee submitted a thorough analytical report and recommendations in April. Committee members also screened

current book proposals and helped set priorities for publication. That committee was reconstituted as a standing Publications and Communication Committee (PACC) to develop procedures for the publication of scientific documents.

A Peer Review of the Publications and Communication activities was conducted 20-25 November by a team of six members, five external and one internal. They made 26 recommendations. Several have already been put into practice; two were modified to better fit current circumstances.

Seventeen books were published in English in 1991. The first electronic book published is a computer edition of *Publications of the International Agricultural Research and Development Centers: 1990*. At least 149 editions of 34 IRRI books have been copublished in 45 languages in 29 countries.

Subprogram III: Rice data bases

Rice data bases and data base information services

Establishing corporate data bases was a major activity for which a representative task force developed the work plan. Computer Services is helping the Plant Pathology Division design a system for an RFLP fingerprint data base for rice pathogens.

IRRI researchers are now connected with the global INTERnet network, enabling them to communicate with colleagues in advanced institutions and with an increasing number of other organizations and companies around the world. This is part of CGNET II, a network that will link NARS and CGIAR institutions with each other and with the global scientific community.

The Local Area Network (LAN) is expanding. Fiber optic cables were installed to connect users in the NC Brady Laboratory and the new biofertilizer building to the system. A single cabling system in the biofertilizer building will integrate telephone and LAN connections.

Subprogram IV: Conferences and workshops

Information exchange through conferences

IRRI was host to or the cosponsor of 24 conferences, workshops and meetings in 1991. The complete list is given in Table 1.

Subprogram V: Public awareness

Public awareness

The new *IRRI Hotline* provides decisionmakers in the donor community with information about the targets and achievements of IRRI. *IRRI 1990/1991: A continuing adventure in rice research* highlights the Institute's annual accomplishments in a corporate report format.

IRRI activities were featured in "The World's Food Supply at Risk" in the April 1991 issue of National Geographic magazine. Other major features in important media resulted from visits of 140 journalists to IRRI, including 18 representing international media.

An all-new "Rices of IRRI" multiprojector slide program was prepared and is now shown to all visitors to the Institute. A basic set of slides describing IRRI activities is available to new media contacts; a set also is maintained at the CGIAR secretariat in Washington, D.C., USA.

IRRI hosted a Senators' Day in August, to acquaint Philippine legislators with the Institute's goals and activities. The Philippine Department of Agriculture has adopted as its official song "Farmers and Fishermen, You Are Our Heroes," composed by a liaison communicator.

A video consultant arrived in September to produce programs for public awareness and training activities and to train several nationally recruited staff in video production techniques.

Table 1. Conferences, workshops, and meetings.

Date	Title	Venue	Participants (no.)	Countries (no.)
14-25 Jan	SARP Workshop on Systems Analysis and Simulation for Rice Production	IRRI	40	9
7-8 Feb	World Bank-IRRI Workshop on Issues in Rice Research and Production	IRRI	50	3
18-22 Feb	IPM Network Workshop on the White Stem Borer in West Java	Sukamandi, Indonesia	35	5
26 Feb-10 Mar	INSURF Site Visit and Planning Meeting	Indonesia	34	11
20-22 Mar	Rice Research Consortia Planning Meeting	IRRI	118	9
15-20 Apr	SARP Workshop on Simulation of Impact of Diseases on Rice	CRRI, Cuttack, India	40	9
6-11 May	SARP Workshop on Simulation of Processes Regarding Water, Nutrients, and Roots	UPM, Serdang, Malaysia	25	9
15-17 May	Upland Rice Consortium Planning Meeting	IRRI	25	4
31 May-4 Jul	Workshop on Strengthening Research, Extension, and Training Capabilities in Mechanization Engineering for Rice Agriculture	IRRI	75	20
24-28 Jun	IPM Network Workshop on Pest Problems in Hybrid Rice in Hunan, China	Hunan, China	29	4
10-13 Jul	Meeting on Deployment of *Bacillus thuringiensis* Endotoxin in Engineering Rice Plants	IRRI	40	13
28-31 Jul	Mid-term Planning Meeting for IRRI-ADB Project on Botanical Pest Control	Dhaka, Bangladesh	17	6
13-15 Aug	Rice Research Prioritization Workshop	IRRI	53	13
22-24 Aug	First Rice Genetic Resources Working Group Meeting	IRRI	18	9
30 Sep-2 Oct	Asian Regional Workshop on Sustainable Agricultural Research	Bangkok, Thailand	60	21
30 Sep-3 Oct	INGER-Africa and Rice Research Conference	Bouaké, Ivory Coast	32	15
30 Sep-4 Oct	22d ARFSN Working Group Meeting	Beijing, China	32	15
14-16 Oct	IRRI-NARS Collaborative Training Workshop	IRRI	17	5
10-16 Nov	INGER-Latin America and Rice Research Conference	Mexico	150	24
24 Nov-6 Dec	Deepwater Rice Monitoring Tour	India and Bangladesh	14	4
2-4 Dec	INGER Global Advisory Committee Meeting	Dhaka, Bangladesh	18	13
2-6 Dec	International Symposium on Systems Approaches for Agricultural Development	Bangkok, Thailand	150	22
9-13 Dec	Workshop on Impact of Farming Systems Research	Kandy, Sri Lanka	32	8
16-20 Dec	Training cum Planning Workshop on Biological Control of Rice Diseases	IRRI	11	47

Program summary

Activities of the Information and Knowledge Exchange Program are expanding. The three units of the Information Center—Library Services, Communication and Publications Services, and Computer Services—are working with other IRRI scientists to enhance the accessibility of improved data and information exchange through new telecommunication linkages with several countries.

Those linkages will gradually expand and speed interactions with national agricultural research systems.

International programs
Networks

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Networks

Subprogram I: International Network for Genetic Evaluation of Rice

The International Network for Genetic Evaluation of Rice (INGER) is a global rice improvement network funded by the United Nations Development Programme. Active collaboration among the national rice research systems and the international agricultural research systems is the key feature of this network. Its objectives are to facilitate genetic improvement of rice and to promote genetic diversity for different ecosystems through global exchange, evaluation, and utilization of improved breeding materials originating from sources worldwide.

1990 NURSERY RESULTS

INGER composed 921 sets of 23 types of nurseries (13 for ecosystem and 10 for stress tolerance) and distributed them to 35 countries. With the occurrence of new biotypes of gall midge, the International Rice Gall Midge Nursery (IRGMN), which was discontinued in 1983, was revived to evaluate and identify varieties and breeding lines with broad-spectrum resistance to gall midge populations. The presence and distribution of gall midge biotypes were also monitored.

Ecosystem-oriented nurseries. Top entries for the three maturity groups of irrigated rice—the International Irrigated Rice Yield Nursery—Very Early (IIRYN-VE), -Early (IIRYN-E), and -Medium (IIRYN-M)—are listed in Table 1. Table 2 presents details of the best performing entries in the two rainfed lowland yield nurseries of early (IRLYN-E) and medium (IRLYN-M) maturity. The highest yielding entries in the nurseries for the two maturity groups of upland rice—early (IURYN-E) and medium (IURYN-M)—are given in Table 3; those for deepwater rice are in Table 4. The best performing entries in the different observational nurseries are presented in Table 5.

Nurseries for resistance or tolerance screening. Tables 6 and 7 list the best performing entries in nurseries established for specific biotic and abiotic stresses.

Detailed results and analysis of the various yield and stress-oriented nurseries are given in INGER annual nursery reports, published separately.

Table 1. Best performing entries in the 11th International Irrigated Rice Yield Nursery-Very Early, 18th IIRYN-E, and IIRYN-M, 1990.

Designation	Origin	Days to flowering	Yield (t/ha)
11th IIRYN-Very Early[a]			
IR50404-57-2-2-3[b]	IRRI	84	5.2
IR53970-100-3-3-2	IRRI	86	4.9
AT77-1[b]	Sri Lanka	90	4.8
IR50[b]	IRRI	85	4.8
IR39357-45-3-2-3	IRRI	84	4.7
RP1442-2-2-3-5-1[b]	India	87	4.7
18th IIRYN-Early[c]			
S818b-10-2[b]	Indonesia	92	5.2
IR13429-150-3-2-1-2	IRRI	91	5.0
OR79-21	India	89	5.0
C702015	Taiwan (China)	89	4.9
IR49457-33-1-2-2-2	IRRI	92	4.9
IR52280-117-1-1-3	IRRI	90	4.9
18th IIRYN-Medium[d]			
B3894-22C-78-5[b]	Indonesia	97	5.0
BR736-20-3-1	Bangladesh	102	4.9
IR49461-181-2-3-2	IRRI	105	4.9
IR49500-54-1-2-3[b]	IRRI	98	4.9
RP1551-13-22-1	India	103	4.9

[a]Based on overall mean yield in 26 trials. [b]Also highlighted in previous years' tests. [c]Based on overall mean yield in 21 trials. [d]Based on overall mean yield in 10 trials.

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Table 2. Best performing entries in the 10th International Rainfed Lowland Rice Yield Nursery, 1990.

Designation	Origin	Days to flowering	Yield (t/ha)
	IRLYN-Early[a]		
IR46[b]	IRRI	101	4.0
BR51-315-4[b]	Bangladesh	103	3.8
IR29341-41-1	IRRI	102	3.8
RD21[b]	Thailand	100	3.8
BR51-120-2[b]	Bangladesh	104	3.6
	IRLYN-Medium[c]		
IR31662-34-1-2[b]	IRRI	110	3.4
BRC16-127-4-1	Bangladesh	105	3.3
RP1641-123-16-3-1	India	112	3.3
RP1491-24[b]	India	111	3.2

[a]Based on overall mean yield in 10 trials. [b]Also highlighted in previous years' tests. [c]Based on overall mean yield in 11 trials.

Table 3. Best performing entries in the 16th International Upland Rice Yield Nursery, 1990.

Designation	Origin	Days to flowering	Yield (t/ha)
	IURYN-Early[a]		
IET1444[b]	India	79	2.3
BR21 (BR1656-22-1)[b]	Bangladesh	78	2.2
B3619C-TB-8-1-4	Indonesia	80	2.2
Tella Hamsa	India	78	2.2
IR25890-82-5-3	IRRI	78	2.1
	IURYN-Medium[c]		
IR29429-B-3-B-1-4[b]	IRRI	98	2.3
Makiling[b]	IRRI	99	2.2
IR27078-3-6[b]	IRRI	106	2.2
KU82	Thailand	97	2.2
B3622e-TB-5-4-4	Indonesia	90	2.1

[a]Based on overall mean yield in 12 trials. [b]Also highlighted in previous years' tests. [c]Based on overall mean yield in 7 trials.

Table 4. Best performing entries in the 3d International Deepwater Rice Yield Nursery (IDRYN) at 2 test sites in 2 countries, 1990.

Designation	Origin	Days to flowering	Yield (t/ha)
CR149-4156-226	India	132	4.1
BKNFR78023-38-1K-1-1	Thailand	123	3.9
RP2078-51-61	India	117	3.7
IR11141-6-1-4	IRRI	130	3.4
IR21074-53-P1-B-1-108	IRRI	127	3.0

Table 5. Best performing entries in the observational nurseries based on across-locations phenotypic acceptability ratings, 1990.

Designation	Origin	Days to flowering
18th International Irrigated Rice Observational Nursery[a]		
IR52350-3-3-2-1	IRRI	92
IR48613-148-1-1-2	IRRI	95
IR49517-57-2-3-6-2	IRRI	96
IR48525-100-1-2	IRRI	103
IR49500-54-1-2-3	IRRI	103
IR51673-50-2-1	IRRI	104
IR39323-182-2-3-3-2	IRRI	110
IR49461-144-2-1-2	IRRI	110
13th International Rainfed Lowland Rice Observational Nursery[b]		
IR43022-6-3-1-3	IRRI	106
IR28941-1-3-5-1-2	IRRI	107
IR29341-15-2-1-1	IRRI	108
IR43012-38-3-3-2	IRRI	109
IR42241-76-2-2-2	IRRI	109
B5332-13d-Mr-1-1	Indonesia	110
IR31238-474-3-P1	IRRI	113
CN836-3-10	India	115
16th International Upland Rice Observational Nursery[c]		
B5592F-5-ST-32-12	Indonesia	88
BR1888-29-2-3-4	Bangladesh	88
BR1890-10-2-1-1	Bangladesh	87
IR26958-34-2	IRRI	95
Cartuna (Acc. 10595)	Indonesia	81
YN91-42	Myanmar	98
15th International Deepwater Rice Observational Nursery[d]		
Baish Bish (Acc. 45023)	Bangladesh	110
BKNFR81023-9-2-2-3	Thailand	125
B5332-13d-Mr-5-1	Indonesia	126
RP2078-81-53	India	131
RP2078-21-103	India	114
9th International Tidal Wetland Rice Observational Nursery[e]		
IR26702-25-1	IRRI	113
IR31406-333-1	IRRI	110
IR42207-65-2-3	IRRI	109
FRG7-BR1	Bangladesh	110

[a]Based on 59 trials. [b]21 trials. [c]29 trials. [d]13 trials. [e]Based on phenotypic acceptability ratings at Myaung Mya and Muang, coupled with tolerance for submergence at Los Baños.

Utilization of 1990 nursery entries

National rice improvement programs are actively utilizing INGER entries. In 23 countries, 857 entries were further evaluated in follow-up yield tests at state, national, or local levels, whereas 521 were used as parents in the breeding programs of 18 countries (Table 8). The most frequently utilized entries are listed in Table 9.

Because of their outstanding performance, INGER entries ITA150 and ITA257 from IITA were

Table 6. Best performing entries in the 1990 INGER biotic stress nurseries.

Nursery[a]	Trials (no.)	Entries[b]
IRBPHN	21	**PTB33, BG367-2,** IR32876-54-2-2-2, **RP1579-1863-73-32-53,** RP1579-1864-70-33-54, RP1785-75-3-2-2, RP2068-18-4-7, RP2068-18-2-11
IRWBPHN	13	**BG379-2, IR2035-117-3,** RP2068-18-2-11, RP2068-18-4-7, **WC1240 (Acc. 13742)**
IRSBN		
• Vegetative stage	7	**IR39357-133-3-2-2-2, IR39385-124-3-3-2-3, W1263 (Acc. 11057)**
• Maturity stage	5	BR319-1, BR51-74-6/J1, IR35361-59-3-3-2
IRBN		
• Leaf blast	47	**IR32429-47-3-2-2, IR59311-113-1,** CT6516-23-1-2, CT6516-23-2-7, **C711327,** IRAT258, IRAT264, IRAT267, Iri 386, IR47686-9-1-B-1, IR47686-9-2-B, P3299F4-7, P5166F2-25-2, P5589-1-1-3P-3-6P, TKY1024, **Tetep**
• Panicle blast	9	Chokoto, IR21820-154-3-2-2-3, IR22082-41-2, **IR31892-46-3-2,** Makiling, DPI 1091-5, **Tetep,** IR12665-7-1-3-6, IR14497-15-2, P3299F4-7, P4728F2-25-3, RAU4072-46, RP2243-19-2, TKY1024, TM4865
IRBBN		
• Field	27	Cisadane, **IR22082-41-2,** IR4442-46-3-3-3, **RP2151-32-2-11-3, RP2151-192-1, RP2151-21-22,** IRAT291
• Greenhouse	5	BJ1, **IR54,** Nigeria 5, IRAT291, IR29658-43-3-2-1, **RP2151-192-1, RP2151-21-22, RP2151-32-2-11-3,** RP2151-64-3-1-1
IRTN		
• Field	5	**ARC10342, ARC11554, Habiganj DW8,** IR24632-145-2-2-2-3, **Pankhari 203, Utri Merah (Acc. 16682)**
• Greenhouse	3	**ARC10342, ARC11554, Habiganj DW8, Pankhari 203, Utri Merah (Acc. 16682), DWA8, Ketaribhog, Utri Rajapan (Acc. 16684)**

[a]IRBPHN = International Rice Brown Planthopper Nursery, IRWBPHN = International Rice Whitebacked Planthopper Nursery, IRSBN = International Rice Stem Borer Nursery, IRBN = International Rice Blast Nursery, IRBBN = International Rice Bacterial Blight Nursery, IRTN = International Rice Tungro Nursery.
[b]Entries in boldface were also highlighted in previous years' tests.

released as varieties in Cambodia in 1991. The former was named Sita and the latter Rimke.

1991 NURSERY DISTRIBUTION

A total of 856 sets of 25 types of INGER nurseries (13 for ecosystem types and 12 for stress tolerance) were composed and distributed to 49 countries: 665 nursery sets were sent to 18 countries in Asia, 29 to 3 countries in West Asia and North Africa, 83 to 14 countries in Sub-Saharan Africa, 62 to 9 countries in Latin America, 6 to 3 countries in Europe, and 11 to 2 countries in Oceania. A total of 1,927 nursery entries were distributed around the world (Table 10).

MONITORING VISITS AND PLANNING MEETINGS

The 1991 monitoring tour to eastern India and Bangladesh with a focus on boro rice, and the deepwater rice traveling workshop to Bangladesh, India, and Thailand organized by INGER further strengthened linkages among rice scientists. The boro rice visiting team recommended the initiation of a regional INGER boro nursery in view of the potential and opportunities for raising yields in that season. The INGER advisory committee, composed of rice scientists from 15 countries, met in Dhaka, Bangladesh, 2-4 Dec 1991 to review the results of the 1990-91 trials and formulate the network plans for 1992.

The observations and recommendations relative to the monitoring tour and meeting are published separately.

Table 7. Best performing entries in the 1990 INGER abiotic stress nurseries.

Nursery[a]	Trials (no.)	Entries[b]
Soils		
IRSTON		
• Salinity	5	IR28909-2-0-1, IR51491-AC-4-6, IR51491-AC-4-7, IR51500-AC-11-1, **Nona Bokra, Pokkali,** WAR72-M6-3-1
• Alkalinity	1	CAC703, CSR9, IR51491-AC-4-6, IR68, ITA230, KKN7205-35-1-SKN-1-1
• Saline-sodic	2	CSR10, CSR12, CSR13, CSR9, IR51500-AC-11-3
IRALON	4	FY309-4, BW85, **B3240-Eng 4,** IR29137-16-1-6, **ITA245,** Tetep
Temperature		
IRCTN	33	**IR15569-22-2-3-2-2-3-1-1-3,** IR18482-Plp3-1-2-1-1-1, PD450, Yun Geng 9 (Acc. 61860), HP5247-Plp-1-1-2, **IR18482-Plp3-2-3-4-1-1,** IR25425-Plp9-1, Hai 8 (Acc. 47561)
Moisture		
IRDTN	8	IR47686-6-1-2, IR47686-6-2-2-1, **Kinandang Patong,** TOX906-67-1-1, Carijo, IR47686-4-4-B-1, **IR47686-6-2-1-1,** IR47686-31-1-1, IR47686-6-1-1, IR47686-8-4-3

[a]IRSTON = International Rice Salinity Tolerance Observational Nursery, IRALON = International Rice Acid Lowland Observational Nursery, IRCTN = International Rice Cold Tolerance Screening Nursery, IRDTN = International Rice Drought Tolerance Screening Nursery. [b]Entries in boldface were also highlighted in previous years' tests.

INGER in Latin America

The INGER-Latin America network continues to strengthen the exchange of information on germplasm development and performance. Activities during the period were planned along the general guidelines established by the second meeting of the Steering Committee of INGER-Latin America held in Concepcion del Uruguay in March 1990.

A total of 102 nursery sets were distributed in 1990. Ten lines from the observational nursery performed well throughout the region and were selected in at least 50% of the locations (Table 11). Materials nominated by national programs have been increasing, representing one-fourth of the total entries during 1989-91. Of the 36 cultivars released in Latin America during 1989-90, 21 were obtained from introduced populations. That indicates the importance of germplasm exchange.

The following were organized by INGER-Latin America in 1991:

- Fourth Germplasm Evaluation and Selection Workshop for Central America and Mexico, in Culiacan and H. Cardenas, Mexico, 4-9 Nov 1991.
- Eighth International Rice Conference for Latin America and the Caribbean, in Villahermosa, Tabasco, Mexico, 10-16 Nov 1991.

INGER in Africa

INGER-Africa is in the process of reformulating its future activities as well as its target rice areas in Africa in consultation with concerned institutes, including West Africa Rice Development Association.

Results of 1990 INGER-Africa nurseries were received and analyzed in 1991. Promising entries for different environments and stresses are listed in Table 12. Detailed analysis of the results is presented in the annual nursery report for INGER-Africa. INGER-Africa facilitated the release of 34 varieties originating from 6 African countries and 49 from outside Africa in 22 African countries. Several ITA lines were released in Nigeria in 1991 (ITA117, ITA150, ITA230, ITA257, ITA301, and ITA315). A total of 361 sets of 10 INGER-Africa nurseries were composed and distributed to 32 countries in Africa.

Analysis of results of multilocation irrigated rice yield trials at 20 test sites revealed a highly significant interaction between genotype and environment. The study confirmed that selected genotypes from Asia will be extremely useful in the irrigated ecosystem in Africa. The appropriateness of the three-tier testing approach in composing the entries for advanced trials was also confirmed.

A total of 1,253 entries were evaluated for blast reaction under upland conditions at the International

Table 8. Utilization of 1990 INGER nursery entries.

Region, country	For hybridization	For yield testing		
		Local	State	National
East Asia				
China	122	62	33	11
Japan	1	-	-	-
Korea	21	1	-	9
Taiwan	39	-	-	-
Southeast Asia				
Cambodia	9	95	-	88
Malaysia	4	11	-	-
Myanmar	47	207	15	-
Philippines	58	130	-	-
Thailand	345	138	-	-
Vietnam	73	54	33	2
South Asia				
Bangladesh	69	368	-	8
India	155	300	81	-
Nepal	55	30	20	19
Pakistan	25	116	-	-
Sri Lanka	39	21	-	-
West Asia and North Africa				
Egypt	123	-	-	39
Iran	29	48	-	-
Sub-Saharan Africa				
Nigeria	-	6	-	-
Rwanda	-	19	-	-
South Africa	-	-	7	7
Tanzania	-	21	-	-
Latin America				
Colombia	-	-	-	21
Dominican Republic	-	-	-	116
Mexico	8	11	25	-
Europe				
Spain	-	13	-	-
Total	1222	1651	214	320

Institute of Tropical Agriculture. Many genotypes adapted to African and Latin American environments, mainly for upland culture, were resistant and would serve as good sources of durable blast resistance.

The following workshops and monitoring visits were organized in Africa in 1991:

- Monitoring visit to Burundi, 24 May-2 June.
- Rice in Africa workshop, WARDA, Bouake, 30 September-3 October.

Subprogram II: Crop and resource management networks

International Network on Soil Fertility and Sustainable Rice Farming (INSURF)

The International Network on Soil Fertility and Sustainable Rice Farming (INSURF) focuses on sustainable rice-based farming systems and development of an integrated and holistic approach to soil nutrient management. INSURF puts emphasis on integrated nutrient management and long-term fertility studies that aim to increase productivity and maintain soil health at a minimum cost without adverse effects on the environment. Research work

Table 9. 1990 INGER nursery entries most frequently included in national follow-up trials.

Entry	Origin	Nursery[a]
AT77-1	Sri Lanka	IIRYN-VE
BG989	Sri Lanka	IIRON
BR1890-10-2-1-1	Bangladesh	IURON
BR802-104-1-2-1	Bangladesh	IIRON
B3894-22C-78-5	Indonesia	IIRYN-M
C702015	Taiwan (China)	IIRYN-E
DR34-PD6-PD4-PD2	Pakistan	IIRYN-M, IIRON
Duansan	China	IIRON
Hua Lien Yu 124	Taiwan (China)	IIRON
IRAT 118	Madagascar	IRCTN
IR25425-PLP9-1	IRRI/India	IRCTN
IR25898-69-2-2	IRRI	IIRYN-E
IR31785-58-1-2-3-3	IRRI	IIRYN-VE, IRBN
IR35366-28-3-1-2-2	IRRI	IIRYN-M, IIRON
IR35366-62-1-2-2-3	IRRI	IIRYN-E
IR36	IRRI	IIRYN-E
IR39323-182-2-3-3-2	IRRI	IIRYN-M, IIRON
IR39357-45-3-2-3	IRRI	IIRYN-VE, IRBN, IRBBN, IRWBPHN
IR39357-71-1-1-2-2	IRRI	IIRON
IR41054-81-2-3-2	IRRI	IRLON
IR42000-211-1-2-2-3	IRRI	IIRYN-VE
IR43012-38-3-3-2	IRRI	IRLON
IR47761-27-1-3-6	IRRI	IIRON
IR49457-33-1-2-2-2	IRRI	IIRYN-E
IR49461-144-2-1-2	IRRI	IIRON
IR49500-54-1-2-3	IRRI	IIRON
IR50363-8-1-1-3	IRRI	IIRYN-VE
IR50404-57-2-2-3	IRRI	IIRYN-VE
IR51673-172-1-3	IRRI	IIRON
IR52280-117-1-1-3	IRRI	IIRYN-E
IR52297-64-3-2-2	IRRI	IIRON
IR52350-3-3-2-1	IRRI	IIRON
IR53301-133-1-1-2	IRRI	IIRON
IR53910-147-3-2-1	IRRI	IIRON
IR53970-100-3-3-2	IRRI	IIRYN-VE
IR54742-13-29-12-9-2	IRRI	IIRON
IR68	IRRI	IRLON, IRSTON
Luke 3	China	IIRYN-E
OR79-21	India	IIRYN-E, IIRON
RP1442-2-2-3-5-1	India	IIRYN-VE, IRCTN
RP1699-26-1-1	India	IIRYN-E
RP1832-23-3-4	India	IIRYN-E, IIRON
RP2086-74-6-1	India	IIRYN-VE, IIRON
S818B-10-2	Indonesia	IIRYN-E
Tainung Sen Glutinous 2	Taiwan (China)	IIRYN-E, IRBBN

[a]IIRYN-VE = International Irrigated Rice Yield Nursery-Very Early, IIRYN-E = early, IIRYN-M = medium, IIRON = International Irrigated Rice Observational Nursery, IURON = International Upland Rice Observational Nursery, IRCTN = International Rice Cold Tolerance Nursery, IRBN = International Rice Blast Nursery, IRBBN = International Rice Bacterial Blight Nursery, IRWBPHN = International Rice Whitebacked Planthopper Nursery, IRLON = International Rainfed Lowland Rice Observational Nursery, IRSTON = International Rice Salinity Tolerance Observational Nursery.

Table 10. Origin and types of entries in the 1991 INGER nurseries dispatched from IRRI.

Nursery[a]	Sets dispatched (no.)	Entries (no.)	Entries (no.) sent to					
			National program	International centers and organizations				
				IRRI	CIAT	IITA	IRAT	IRGC
IIRYN-VE	58	18	10	8	-	-	-	-
IIRYN-E	42	25	17	3	-	-	-	-
IIRYN-M	28	17	11	4	2	-	-	-
IIRON	101	166	106	44	13	-	-	3
IRLYN-E	17	21	19	2	-	-	-	-
IRLYN-M	13	21	18	3	-	-	-	-
IRLON	48	170	93	65	-	-	1	11
IURYN-E	19	15	15	-	-	-	-	-
IURYN-M	20	19	8	9	1	1	-	-
IURON	56	173	100	37	6	3	11	16
IDRYN	16	19	17	2	-	-	-	-
IDRON	28	106	58	47	-	-	-	1
ITRON	8	20	-	18	-	-	-	2
IRCTN	63	106	89	7	-	-	-	10
IRSTON	63	43	27	14	-	-	-	2
IRALON	18	16	5	9	-	-	-	2
IRDTN	34	80	28	46	2	-	1	3
IRBN	79	364	225	76	21	1	6	35
IRBBN	40	138	65	56	-	-	7	10
IRTN	22	110	54	39	-	-	4	13
IRBPHN	37	105	66	20	-	-	8	11
IRWBPHN	23	66	24	30	-	-	-	12
IRSBN	26	51	19	30	-	-	-	2
IRGMN	9	20	9	9	-	-	-	2
IRUN	9	38	34	4	-	-	-	-
Total	867	1927	1117	587	45	5	38	135

[a]IIRYN-VE = International Irrigated Rice Yield Nursery-Very Early, IIRYN-E = -Early, IIRYN-M = -Medium, IIRON = International Irrigated Rice Observational Nursery, IRLYN-E = International Rainfed Lowland Rice Yield Nursery-Early, IRLYN-M = -Mediun, IRLON = International Rainfed Lowland Rice Observational Nursery, IURYN-E = International Upland Rice Yield Nursery-Early, IURYN-M = -Medium, IURON = International Upland Rice Observational Nursery, IDRYN = International Deepwater Rice Yield Nursery, IDRON = International Deepwater Rice Observational Nursery, ITRON = International Tidal Wetland Rice Observational Nursery, IRCTN = International Rice Cold Tolerance Nursery, IRSTON = International Rice Salinity Tolerance Observational Nursery, IRALON = International Rice Acid Lowland Soils Observational Nursery, IRDTN = International Rice Drought Tolerance Screening Nursery, IRBN = International Rice Blast Nursery, IRBBN = International Rice Bacterial Blight Nursery, IRTN = International Rice Tungro Nursery, IRBPHN = International Rice Brown Planthopper Nursery, IRWBPHN = International Rice Whitebacked Planthopper Nursery, IRSBN = International Rice Stem Borer Nursery, IRGMN = International Rice Gall Midge Nrusery, IRUN = International Rice Ufra Nursery.

on less favorable ecosystems such as strongly acid uplands is also given emphasis.

Collaborative research trials

During the 1990-91 cropping seasons, about 30 collaborating scientists from 10 countries participated in the following network collaborative research trials: a) integrated use of inorganic and organic N fertilizers in different rice ecosystems, b) long-term fertility trial in different rice ecosystems, and c) soil fertility management of strongly acid upland soils (pH <5) for rice.

Integrated use of inorganic and organic nitrogen

The integrated nutrient management trials in different rice ecosystems focus on generating appropriate and economically feasible technologies that involve

Table 11. Entries most commonly selected from the 1990 Latin American observational nursery for advanced trials.

Designation	Days to flowering	Yield (t/ha)	Reaction to Blast	Narrow brown leaf spot	Leaf scald	Brown spot	Grain discoloration
IR54751-1-19-13-17-3	99	4.1	3	3	1	0	5
IR54751-4-22-10-17-3	87	4.6	3	3	2	1	6
CT8008-3-12-3P-M-1P	85	6.6	1	3	2	9	3
CT8008-16-29-3P-M-2P	93	5.8	3	1	5	5	5
CT8455-1-13-1-M-2P	79	3.9	1	1	2	3	7
CT8470-22-13-1-M-4P	77	5.6	1	1	1	7	7
IR39485-151-2-1-3	84	4.2	3	3	1	5	5
IR54742-18-17-20-15-2	97	4.7	3	1	1	5	3
CT8249-2-7-2-M-1P	86	4.8	3	1	2	9	5
CT8470-26-11-4P-M-4P	90	5.2	3	5	1	0	7
International checks							
Cica 8	96	5.2	5	3	4	5	3
Oryzica 1	89	5.6	7	7	7	9	8

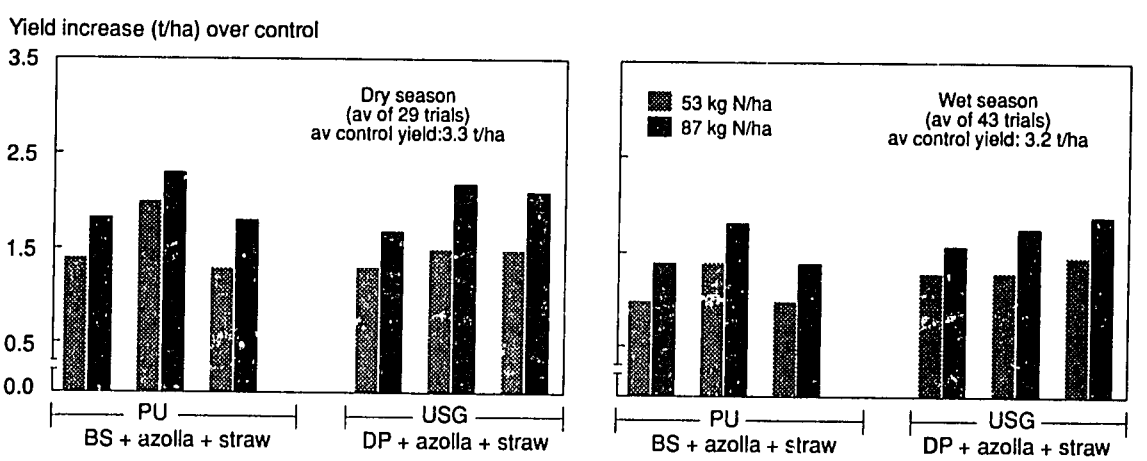
inorganic N combinations with azolla, rice straw, green manure (GM), and other biofertilizers. Yield stability and their long-term effects on soil properties are primary considerations in evaluating the technologies.

Irrigated lowland rice. *First in series.* As of 1991, 77 trials at 16 sites in 8 countries had evaluated the effectiveness of organic N sources such as azolla and rice straw in combination with inorganic N fertilizers.

The average yield response of irrigated rice shows that prilled urea and urea supergranules combined with either azolla or rice straw were equally or slightly more effective than were pure inorganic fertilizers at two N rates (Fig. 1). In general, yield increases over the control for the fertilizer treatments were comparable. Azolla proved to be a better source of N than rice straw. Materials with wide C:N ratio like rice straw may depress yield because of partial immobilization of N.

Second in series. Fifteen trials were conducted at 18 sites in 5 countries in 1991, bringing the total number of trials in the second integrated nutrient management in irrigated rice from 29 in 1990 to 44.

Results suggest that the organic N sources are as effective as the equivalent amount of inorganic N



1. Average yield responses of irrigated rice to 2 rates of N applied as inorganic fertilizer alone or combined with organic sources. First international trial on integrated use of inorganic and organic N fertilizers in irrigated rice, 1984-91. PU BS = best split urea, USG DP = deep placed urea supergranules.

Table 12. Promising entries in Africa based on 1990 INGER-Africa nurseries.

Nursery[a]	Entries[b]
AIRAT	IR28128-45-3-3-2, **ITA302, ITA304,** S499B-28, TOX960-42-1
AIRON	FARO 31, IR24632-145-2-2-2-3, IR24632-206-3-2-2, IR35546-17-3-1-3, **DR33-PD5-PD2-PD4-PD1,** ECIA36-2-2-1-4, TOX3093-10-2-3-2-3, TOX3098-12-1-1-1, TOX3133-59-1-2-4-1, TOX981-11-2-3
AIRPSS	BR716-7-2-1-1, BR827-35-2-1, DAK83-99-27-3, FAROX315-2-2, RP1125-3-2-1, TOX3098-3-1-1-5, KKN7205-45-2-SKN-1-1, MK14-87, TOX3069-66-2-1
AURAT	**IDSA10** (IRAT262), **IDSA16** (IRAT 268), IRAT112, ITA130, ITA301, M55
AURON	**IR14632-2-3,** TGR68, TGR78, TOX1010-6-9-3-201, **TOX1768-3-1-1-101-1, TOX1889-4-101-1-1-2**
AURPSS	IDSA10 (IRAT262), **IRAT239** (IREM 779), IRAT240 (IREM 950), IRAT269, CNA6246, CNA6647, CNA6680, CNA6698, IDSA3 (IRAT213)
ARLRESS	B4354G-PN-75, BR51-282-8-HR83, CR213-1002, IET6279, IR33461-39-3, IR41111-13-1-1-2, IR45411-40-2-1, IR46375-CPA-19-3-1, OR143-7, RP1057-391-1
ARBN	ITA120, IRAT124, IRAT147, ITA117, IR1552, ITA311, ITA323, Mallika (Sel), ROK16, TOX1010-6-9-3-201, TOX1011-4-A2, TOX1854-101-1, TOX1855-102-10-1, TOX955-208-2-102

[a]AIRAT = African Irrigated Rice Advanced Trial, AIRON = African Irrigated Rice Observational Nursery, AIRPSS = African Irrigated Rice Preliminary Screening Set, AURAT = African Upland Rice Advanced Trial, AURON = African Upland Rice Observational Nursery, AURPSS = African Upland Rice Preliminary Screening Set, ARLRESS = African Rainfed Lowland Rice Evaluation and Screening Set, ARBN = African Rice Blast Nursery.
[b]Entries in boldface were also highlighted in 1989.

source. Organic N sources contribute to the efficiency of the inorganic N fertilizer as shown by higher yields when they were applied in combination. The reason might be the slow but prolonged supply of N from the organic source which supplies the needs of the rice plant during the period when inorganic N is not available. Results also show that a variety of alternative N sources can be tapped to supplement the expensive chemical fertilizer used in rice production.

Table 13. Grain yield of rainfed upland rice from treatments with integrated inorganic and organic N fertilizer.

Treatment[a]	Grain yield			
	1988	1989	1990	1991
Control	1.8 cd	2.7 bc	0.7 a	1.0 a
PU	2.5 b	3.2 ab	0.3 a	1.2 a
AS	2.9 a	3.0 ab	0.5 a	1.3 a
PU + GM1	2.2 bc	2.8 bc	0.6 a	1.1 a
PU + GM2	2.4 b	3.4 a	0.7 a	1.3 a
PU + BM	2.4 b	2.9 bc	0.7 a	1.4 a
PU + GM3	2.6 ab	3.2 ab	0.4 a	1.2 a

[a]N rate = 60 kg/ha. PU = prilled urea, AS = ammonium sulfate, GM1 = cassia, GM2 = gliricidia, GM3 = sunflower leaves, BM = barnyard manure (poultry). All organic fertilizers were incorporated before planting, inorganic fertilizers were applied in splits.

Rainfed lowland trial. *Gliricidia sepium*, *Sesbania rostrata*, and poultry manure were evaluated as potential source of supplementary N in rainfed lowland rice in five trials (1987-91 wet season [WS]) in Bacnotan, La Union, Philippines. The organic sources contributed as much as 48 kg N/ha, which comprised two-thirds of the total N applied. Organic N sources were applied basal while inorganic N were topdressed.

Results showed that inorganic and organic N source combinations were as effective as the inorganic fertilizers applied alone. All the organic N sources tested were found to be comparable N alternatives that could supplement N required under rainfed lowland condition.

Rainfed upland trial. The rainfed upland trial consists of seven treatments involving the use of inorganic N fertilizer, alone or in combination with organic sources as GM or barnyard manure (BM) (Table 13). For combinations, one-half of the applied N came from organic sources and the rest, from prilled urea. Results from 1988 and 1989 show that the organic N sources can partially substitute for the total N requirement of the crop. Grain yields obtained from plots fertilized with inorganic N fertilizers were significantly higher than that of the control and similar to those with inorganic-organic fertilizer N combinations. No N response was observed in 1990 and 1991 because drought and blast disease occurred during the reproductive stages of the crops.

LONG-TERM FERTILITY TRIALS IN IRRIGATED RICE

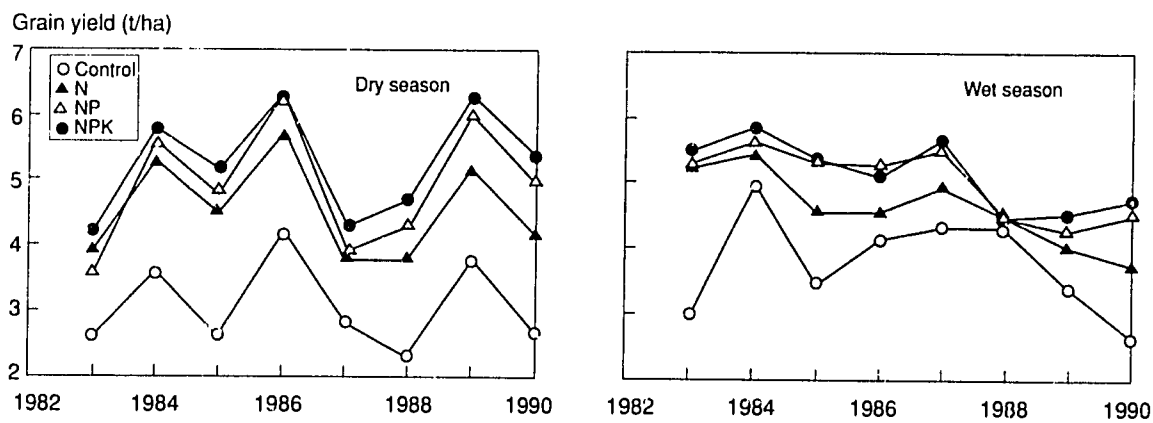
The long-term fertility trials seek to generate information on the long-term consequences of continu-

ous chemical fertilizer and combined organic and inorganic fertilizer application under intensive cropping on soil health and productivity.

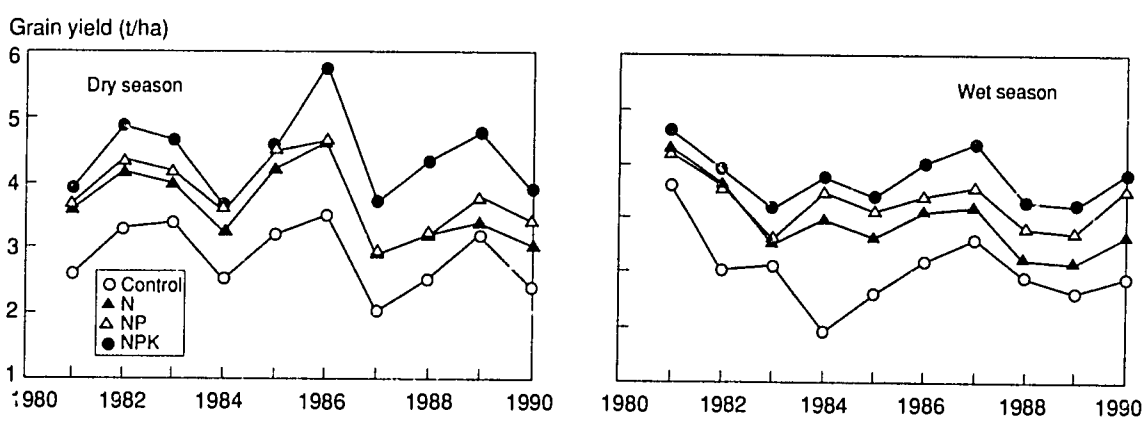
First in series. This trial, begun in 1976, monitors fertility changes in soil under intensive rice cropping and continuous application of N, P, K fertilizers and other limiting nutrients such as S and Zn. By 1991, a total of 263 trials had been conducted at 24 sites in 13 countries. However, only nine sites—four in China, two each in Indonesia and the Philippines, and one in India—are ongoing.

China. Results over 8 yr of long-term fertility trials in Guanshanping and Shipai and 10 yr in Jinxian show that yields in different treatments varied greatly with climate changes within and over the years. Yield in control plots decreased considerably with time. Treatments with N had similar yields, which were higher than those of the control and the rest of the treatments without N. N is still the most limiting nutrient element in all the sites in China. Rice grain yield did not decline significantly with the application of N fertilizer alone in 8-10 yr of intensive cropping and continuous chemical fertilizer application (Fig. 2,3). No cumulative effectiveness was obtained from chemical fertilizers applied either alone or in combinations. Fertilizer efficiency has not been observed to decrease with the continuous use of chemical fertilizers.

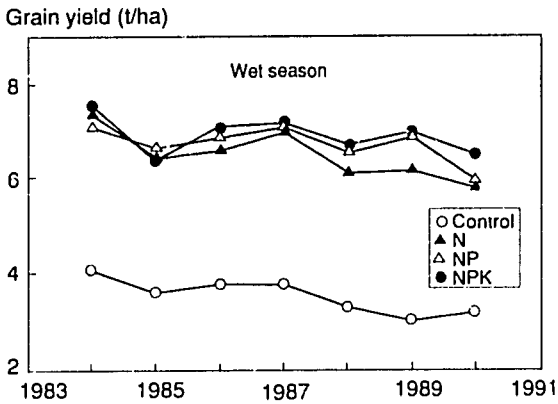
India. Intensive cropping with application of only N or NK fertilizers resulted in conspicuous yield decline over the years in Pantnagar (Fig. 4). This was apparently due to the depletion of soil nutrients. Soil analysis showed that available P, which was 9 ppm initially in 1984, had dropped to 7 ppm in 1988. The yields with NPK and NPK + Zn, on the contrary, were maintained at high levels



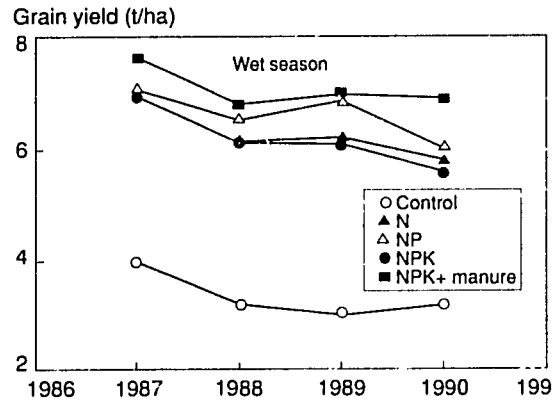
2. Long-term grain yield trends for nonfertilized and fertilized plots in Shipai, Guangdong, China. First long-term fertility trial in irrigated lowland rice, 1983-90.



3. Long-term grain yield trends for nonfertilized and fertilized plots in Jinxian, Jiansxi , China. First long-term fertility trial in irrigated lowland rice, 1981-90.



4. Long-term grain yield trends for nonfertilized and fertilized plots in Pantnagar, Uttar Pradesh, India. First international long-term fertility trial in irrigated lowland rice, 1984-90.



5. Long-term grain yield trends for nonfertilized and fertilized plots in Pantnagar, Uttar Pradesh, India. Second international long-term fertility trial in irrigated lowland rice, 1987-90.

Table 14. Changes in some chemical properties of soil[a] in Maros, South Sulawesi, Indonesia, after 10 yr of continuous chemical fertilizer application and rice croppings. Long-term fertility trial in irrigated lowland rice, 1977-87.

Treatment	pH (1:1)	Organic matter (%)	Total N (%)	Available P (ppm)
		1977		
	6.4	11.5	0.24	10.8
		1987		
Check	5.3	5.5	0.18	2.1
N	5.1	6.4	0.23	3.0
P	5.3	6.0	0.21	4.0
K	5.2	6.0	0.21	3.6
NP	5.3	6.3	0.21	3.3
PK	5.3	6.2	0.21	2.7
NK	5.2	6.2	0.21	3.6
NPK	5.1	6.2	0.21	3.9
NPK + Zn	5.3	6.1	0.21	3.6

[a]Texture: silty clay with 44% clay, 11% sand, and 44% silt.

(above 7 t/ha). Continuous application of P together with N, K, and Zn was found to maintain high crop productivity over the years in Pantnagar.

Indonesia. Yield response to fertilizer N was significantly higher than that to P and K applied either singly or in combination at the sites in Lanrang and Maros. Results show that N played the most important role in increasing rice grain yield. It is foreseen, however, that yield will decrease in the long run in plots given N fertilizer alone because of the depletion of P, K, and other micronutrients.

Some changes in the properties of an Inceptisol soil in Maros were observed after 10 yr of continuous rice cropping and chemical fertilizer application (Table 14). Soil pH, organic matter content, and available P substantially dropped in all treatments.

Second in series. The second long-term fertility trial for irrigated rice ecosystem was initiated in 1987. This trial includes treatments on inorganic and organic fertilizer combinations and site-specific problems. As of 1991, 30 trials had been conducted at 11 sites: 3 in India; 2 each in Indonesia, Myanmar, and Pakistan; and 1 each in Malaysia and Nigeria.

Four WS trials conducted in Pantnagar, India, showed that farmyard manure (FYM) in combination with NPK enhanced grain yield (Fig. 5). Yields from treatments with N were maintained at a high level.

In Indonesia, average grain yield from four trials conducted at the Lanrang and Maros sites showed that N was the key nutrient element in increasing yield. At both sites, NPK + FYM showed promise for increasing yields. The grain yield trend of nonfertilized plots in Lanrang showed declining yields with time. However, this observation was not evident in Maros.

In Myanmar, results of four WS trials in Kyaukse showed gradually decreasing grain yield trends for both fertilized and nonfertilized plots. Average grain yield of treatments involving N from the four trials did not differ significantly. FYM and nutrient elements other than N play important roles in increasing rice grain yield with time. N alone is not enough to maximize yield increase at this site.

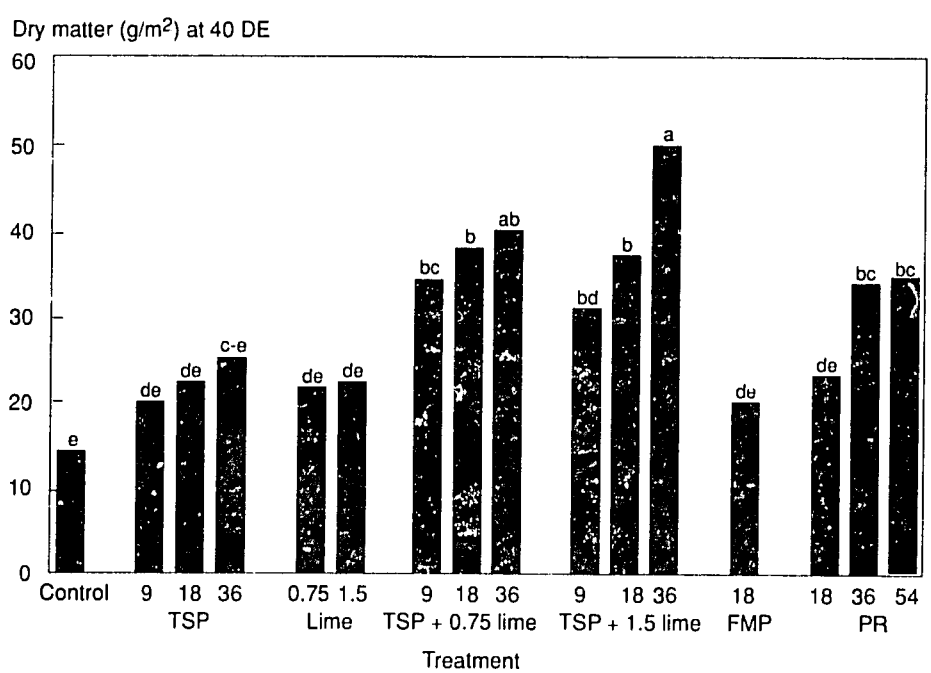
Soil fertility management for strongly acid upland soils (pH <5)

Trials on soil fertility management for strongly acid upland soils have been ongoing at different sites since 1984. These trials with common treatments aim to determine the proper management techniques with regard to lime and P fertilizer source for increased upland rice yield. Another objective is to determine if lime and P fertilizers applied to rice would have any residual effect on the second crop.

Results from initial trials show that upland rice had no response to lime application and little to P fertilizers. The same was true for cowpea, which was planted as a second crop. Apparently, there was a cumulative treatment effect because yields of both rice and cowpea improved with time in all fertilized plots except during drought. The combination of lime and P fertilizer consistently showed the highest yields for both crops, especially at the Cavinti site.

In 1991, sites in the Philippines were reduced to two—Cavinti in Laguna, and Minsacuba, a barrio in Claveria, Misamis Oriental—for better management of the trials. For the Cavinti trial, yield potential for each plot was not realized because of disease pressure (rice blast) and drought during the reproductive stage. Therefore, accumulated dry matter (DM) at 40 d after emergence (DE), rather than grain yield, is presented in Figure 6. In terms of DM, the best treatment was a combination of 36 kg P/ha as triple superphosphate (TSP) and 1.5 t lime/ha. In general, plots treated with TSP in combination with lime and those treated with higher rates of phosphate rock (PR) gave DM yields that were significantly higher than that of the control. The rest of the treatments—TSP and lime applied singly and at different rates, fused magnesium phosphate (FMP), and PR at 18 kg P/ha—were not different from the control. Grain yield responses to the different treatments during seasons with sufficient rainfall were similar to these results. Dry matter yield of cowpea at 40 DE followed the same pattern as that of rice for all the treatments. Compared with rice, however, cowpea responded more to the residual TSP and lime combined as observed from their DM at 40 DE.

In the case of the Minsacuba, Claveria site, drought was also experienced during the reproductive stage for the 1991 rice crop. For this reason, grain yields were low and the treatments did not significantly differ. However, the preceding cowpea crop had sufficient rain during the season and treatment ef-



6. Rice dry matter at 40 DE in Cavinti, Laguna, Philippines, 1991. TSP = triple superphosphate, FMP = fused magnesium phosphate, PR = phosphate rock. Lime rate is in t/ha; P rate in kg/ha. Bars with common letters are not significantly different at the 5% level by DMRT.

fects were observed. Cowpea grain yield harvested in January 1991 is presented in Figure 7. The residual effect of the treatments is shown by the higher yields from plots treated with lime either singly or in combination with TSP. As at the Cavinti site, PR at higher rates gave yields comparable with those from TSP and lime combinations.

These results strongly suggest that for both sites, lime must be applied to the rice crop to get a good head start. Higher rates of PR showed improvement with time and are now comparable with the P and lime combination. For Cavinti, TSP must be added to lime to get good yields while for Minsacuba, lime alone may be a sufficient soil additive to increase yield. Barring the effects of adverse weather conditions and pest and disease pressure, it may be expected that fertilizers and lime applied to rice will have a carry-over effect on the following crop.

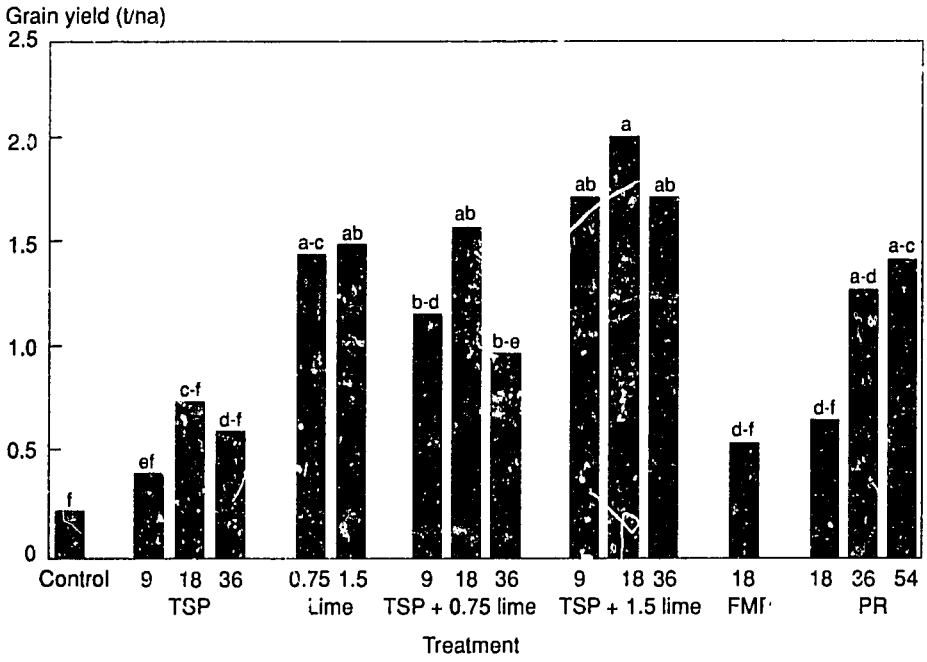
MANAGEMENT OF OTHER NUTRIENTS

Long-term sulfur fertility trial. The effect of continuous application of high analysis fertilizers—urea, TSP, and potassium chloride with and without S or Zn—on rice grown in a clay soil on the IRRI farm was evaluated in a long-term fertility trial. In the 19th (1991 dry season [DS]) cropping season, yield responses to NPK alone were comparable with those to NPK + Zn, NPK + S, NPK + S + Zn combinations, and were significantly higher than those from Zn alone and the control (Fig. 8). Despite application of high-analysis fertilizers containing almost no S, S deficiency was not apparent. It is believed that S content (2.3 ppm) of irrigation water on the IRRI farm is enough to sustain rice crop needs.

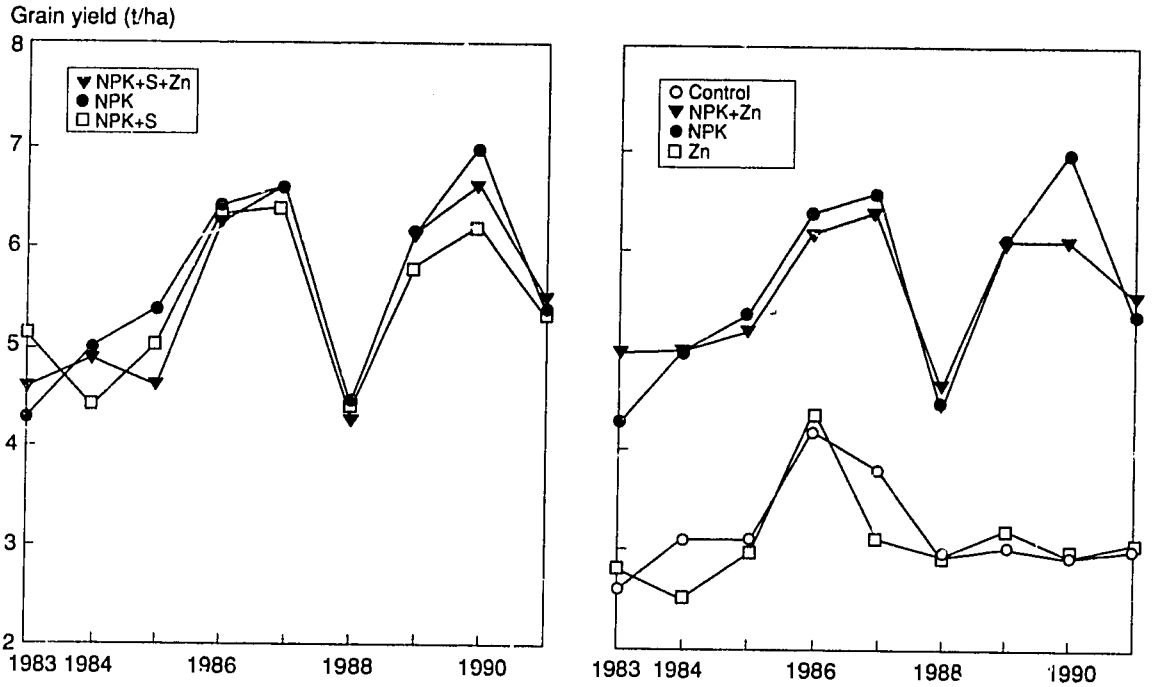
N continued to be the major limiting nutrient at this site. Addition of Zn alone or other nutrient elements without N was not beneficial. The observed yearly fluctuations in yield were partly due to changes in rice varieties planted and adverse weather conditions.

INSURF subnetworks

In 1991, the subnetworks became ecosystem- or subecosystem-based. Lead centers that are not ecosystem-based are now considered resource centers. The following are INSURF resource centers and subnetworks: 1) Azolla Resource Center, NARC, China; 2) Green Manure Resource Center; TNAU, India; 3) Sulfur and other Micronutrients Resource Center, PhilRice/UPLB, Philippines; 4) Resource Center on Direct-Seeding, MARDI, Malaysia; 5) Acid Upland Subnetworks, SARIF, Indonesia; 6) Infertile Rainfed Lowland Subnetwork, LDD, Thai-



7. Cowpea grain yield at Minsacuba, Claveria, Misamis Oriental, Philippines, 1991. Bars with common letters are not significantly different at the 5% level by DMRT.



8. Grain yield trends over 9 yr of 7 treatments during dry seasons in Block 421-A, IRRI farm. Long-term sulfur fertility trial in irrigated rice, 1983–91.

land; and 7) Favorable Rainfed Lowland Subnetwork, SURIF, Indonesia.

SITE VISIT AND PLANNING MEETING

The INSURF site visit and planning meeting, a biennial activity of the network, was held in Indonesia 26 Feb-10 Mar 1991. Thirty-four scientists representing 12 countries and 23 research organizations participated in the 7-d site visit and 4-d planning meeting. During the meeting, the following decisions were made:

- Subnetworks will be ecosystem and subecosystem-based. Lead centers that are not ecosystem-based will be considered resource centers.
- Roles of subnetwork and resource center coordinators were identified and discussed.
- Subnetworks will focus more on long-term experiments to address sustainability problems.
- Standard and optional treatments to be implemented by the subnetwork lead centers and satellite sites were formulated and agreed upon.
- Methodologies in data gathering, processing, and report preparation were standardized.
- Minimum data sets useful in simulation modeling were identified and will be collected in all INSURF trials.
- The INSURF newsletter will be initiated and released biannually at IRRI headquarters.

INSURF NEWSLETTER

The INSURF newsletter *Netwatch* facilitates efficient information flow within the network. The first issue was released in August 1991. Succeeding issues will be released biannually at IRRI headquarters. Materials for publication are solicited from network collaborators.

Asian Rice Farming Systems Network (ARFSN)

The main objective of the network is to identify more productive rice-based farming systems in different rice ecologies acceptable to smallholder farmers. Activities focus on on-farm research using the farming systems approach. Seventeen countries (Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Laos, Malaysia, Madagascar, Myanmar, Nepal, Pakistan, Philippines, South Korea, Sri Lanka, Thailand, Vietnam) are involved in identifying improved technologies, sharing research information and methodologies, and methodology improvement.

Several ongoing research activities at selected farming systems key sites represent different rice ecologies—cropping patterns testing, women in rice farming, crop-animal farming systems, rice-fish farming systems, impact of farming systems, rice-wheat cropping systems, data management of on-farm trials, engineered equipment for timeliness of intensified cropping, and varietal testing of upland crops after rice. A new area of research collaboration in 1991 is the extrapolation of agricultural technologies using the Geographic Information Systems (GIS).

At a farming system key site, studies are conducted on cropping patterns, animal systems, crop-animal systems, and component technology research such as variety trials, fertilizer rate, pest control, and others. The trials vary from site to site, depending on major research issues identified at each. The output of the collaborative research activities is shared within and across countries through meetings/workshops, field visits, and exchange of publications.

Cropping patterns testing

Cropping systems testing was conducted in farmers' fields and at experiment stations at key farming systems sites in countries involved in the network. Cropping patterns were evaluated in different rice ecologies: rainfed lowland, irrigated, deepwater, and upland. At some sites, component technology evaluation in varietal and fertilizer trials was also conducted. In cropping pattern trials, two or more experimental cropping patterns were evaluated and compared with the farmers' existing cropping pattern. The major objective was to increase production, farmers' income, and cropping intensity, taking into consideration resources available to the farmer. Most sites identified promising cropping patterns that are economically and biologically better than the farmers' pattern.

India. Six rice-based cropping patterns were evaluated in farmers' fields in Kumarganj, Faisabad, India, under upland conditions. The rice - mustard system proved the most profitable, followed by rice - linseed and rice - lentil. Recognizing the higher profitability with mustard, a cropping pattern with mustard was evaluated in mixed cropping with barley in farmers' field: barley was broadcast and row seeded. The barley equivalent yields of mustard and barley were significantly higher in the pure crop than in the mixed crops. Similarly, the pure crop barley yields were lower than for pure mustard or mixed with barley, suggesting that for increased income, farmers have two options: a pure crop of higher value mustard or a mustard + barley mixed crop with row seeding. A pure crop of a lower value crop such as barley is not profitable.

At the upland rice site (Hazaribhag, India), crop intensification was attempted by utilizing available residual soil moisture through intercropping of upland rice with upland crops such as pigeonpea and by relay or sequential cropping of short-duration pulses or oilseeds after rice harvest. Maximum yields in terms of land equivalent ratio and economic benefits were obtained with rice variety Kalinga III intercropped with pigeonpea, grown in 4:1 row ratio. Seeds were sown behind the plow with four rows of rice followed by one row of pigeonpea.

In the rainfed lowland areas in Chinsurah and Kendrapara, India, a three-crop system involving jute - rice - wheat and jute - rice - lentil gave net returns of 26 and 38%, respectively, and is better than rice - mustard, the common farmers' cropping pattern.

In the deepwater ecosystem in Ghaghraghat, India, on-station trials of maize, jute, mungbean, and early rice with floating rice mixed or intercropped were conducted. Maize was found to be the best, followed by jute. In farmers' fields, broadcast and row seeded (2:1) maize was also compared with no maize mixed or intercropped with rice. Row seeding gave the highest yield (2.2 t rice/ha + 0.82 t maize/ha) and highest net return of $120/ha. Similarly, linseed, lentil, and mustard were evaluated after deepwater rice at the research station. Linseed gave the highest yield, followed by lentil. These two crops were further evaluated in a farmer's field with no fertilizer, 20 kg N/ha, normal seed rate, and 50% extra seed rate. The highest net income was from linseed and lentil and was obtained with 20 kg N/ha and 50% extra seed.

Myanmar. In Myanmar, rice-based cropping pattern trials were conducted at four sites in collaboration with ARFSN: Yezin, partially irrigated; Patheingyi, fully irrigated; Kyaikmaraw, rainfed lowland; and Pyay, rainfed lowland. In on-farm trials, peanut - transplanted rice (TPR) gave a net return of 72 and 96% over the existing farmer's cropping pattern of sesame - TPR in Yezin and Patheingyi, respectively. TPR - chickpea and TPR - mungbean were the most promising in Kyaikmaraw, and TPR - chickpea, in Pyay. On-station trials were conducted

in Yezin, Kyaukpadaung, and Pyay. Direct seeded rice - TPR - cowpea, TPR - wheat, and direct seeded rice - TPR gave the highest net returns in Yezin; mungbean - TPR and sesame - mungbean - TPR in Kyaukpadaung; and direct seeded rice - chickpea in Pyay. Sesame - mungbean - TPR and direct seeded rice - chickpea were the outstanding cropping patterns giving 445 and 121% returns above variable costs (RAVC), respectively, over the dominant farmers' cropping pattern.

Malaysia. Studies on the rice - upland crop pattern in Malaysia showed the possibility of rice - watermelon in single crop areas with 3-4 mo DS during the early part of the year. Studies conducted in Kedah Province showed that farmers could have a gross income of $1257-$2844/ha from rice (September-January planting) and $2587-$4957/ha from watermelon (February-April planting). Research efforts also concentrated on cultivating upland crops after rice. Upland crops that can be processed by factories such as tomato (for tomato sauce), peanut (for peanut butter), and sweet corn (for canned food) were considered.

Bangladesh. Cropping pattern testing in Bangladesh was carried out in different land and soil types at different agroecological areas. Transplanted aman - potato - boro rice gave the highest net return ($1735/ha), 45% better than that from the farmers' cropping pattern at Bogra. In high Barind tract of Rajshahi, t. aman - mustard - boro rice was 36% better than the farmers' pattern. In the floodplain at Rangpur, broadcast aman - T. aman/grass pea and jute - mungbean - tobacco gave high net returns ($1020 and $1516/ha, respectively)—54 and 41%, respectively, better than farmers' cropping patterns. B. aman - black gram - lentil also gave a 68% better net return than B. aman - fallow - lentil, the farmers' pattern in the highland rainfed areas of Faridpur. In the chala land of Shreepur, the recommended BR20 - radish cropping pattern generated tenfold better net return than the farmers' pattern (local rice - black gram or peanut). In Mirzapur, the higher net return of deepwater rice was due to introduction of the new variety BR3, which yielded 6.37-7.25 t/ha, whereas the predominant rice variety gave only 1.3-2.3 t/ha.

Korea. Six cropping patterns were tested under irrigated conditions in collaboration with Kyeongbuk Provincial Rural Development Administration in Korea. The most promising cropping patterns were cucumber - Chinese cabbage - pea - rice and sesame - garlic - rice, which gave 77 and 52%, respectively, better net returns than rice - barley, a farmers' cropping pattern.

Vietnam. In the deepwater area of Thotnot, Haugiang, Vietnam, three cropping systems were tested: rice (MV) - rice (MV), peanut - kenaf or maize - deepwater rice, and kenaf - kenaf - deepwater rice (transplanted). Most promising was the second pattern, which gave a total yield of 18 t rough rice equivalent/ha. In another village in Thotnot, seven cropping patterns were evaluated. Rice - rice was compared with deepwater rice in rotation with peanut, kenaf, peanut - maize, maize, tobacco, and mungbean. The deepwater rice - peanut and deepwater rice - peanut - maize gave higher net returns than the rice - rice system.

China. The cropping system testing in China was conducted under irrigated conditions. In Guangdong, China, the cropping pattern of vegetable - rice - rice increased farmers' income and improved soil fertility. An annual net return of 137-171, higher than for rice - rice, was obtained. Among vegetables, lettuce - rice - rice gave the highest net return. Nutrients in the soil also improved because of large amounts of vegetable residue. At the cropping systems testing site in Shaoxing, Zheijiang, the farmers' cropping pattern of barley - rice - rice gave higher yields than did the introduced cropping patterns of barley - rice - maize and broad bean - maize - rice. Barley (wheat)/maize silage - rice in Shanghai and triticale silage - rice in Beijing gave good profits and were readily accepted by farmers. The acreage of triticale silage in Beijing increased to more than 700 ha, whereas the area of maize for silage in Shanghai increased to more than 3,000 ha to meet the demands of the dairy enterprise.

In Taiwan, several new cropping patterns were found more profitable than the existing patterns. The most productive and profitable were watermelon - rice, which gave 90% higher net return than monocrop rice in the northern district; rice - cucumber - maize and rice - watermelon - peanut in the central district; rice - soybean - maize in the districts of Chainan and Taitung; and soybean - rice - green manure and peanut - rice - green manure in Hualien district. Most of these promising patterns are demonstrated in different areas with total acreage of 640 ha.

Philippines. Several Philippine key sites representing the rainfed lowland (Carmen in Bohol and Tumauini in Isabela), irrigated (Compostela, Davao

del Norte), and upland (Janiuay in Iloilo and Magallanes in Cavite) ecosystems are involved in the network. In Bohol, the TPR - TPR - mungbean pattern was readily accepted by farmers in Carmen and nearby municipalities and gave an average net return of $960-$1350. In Compostela, research studies on rice - mungbean - rice pattern consistently gave higher net returns than did the farmers' rice - rice.

In Janiuay, upland rice - maize + cowpea/gliricidia cropping system was compared with farmers' existing cropping pattern of upland rice - maize. Gliricidia planted in hedgerows produced a herbage yield of 0.20 t/ha. Net returns from the improved cropping pattern was 33% better than from the farmers' cropping pattern. In Cavite, on-farm trials of upland rice + cowpea - maize + siratro and fancy rice - cowpea or sweet potato cropping patterns were conducted in barangays Cabulusan and Pacheco. In the first cropping pattern, UPLRi-7 yielded an average of 1.72 t/ha, whereas UPLRi-5 yielded 2.01 t/ha. No yield data were obtained for cowpea (var. IT 82D-889) because of continuous rain during the flowering to maturity stages. In the second cropping pattern, Sigadis Milagrosa (local fancy rice variety) was used at both sites. Average grain yield was 1.80 t/ha in Pacheco and 2.31 t/ha in Cabulusan.

Nepal. In Nepal, the improved rice - wheat cropping pattern using high-yielding varieties and improved management practices gave higher net returns than did the farmers' rice - wheat cropping pattern using local practices at irrigated lowland sites in Naldung, Mainaphobhar, and Patan. In Khandbhari, rice/lentil/maize was more economical than the farmers' cropping pattern under rainfed lowland condition. In Patan, rice + maize - wheat + mustard proved the most promising.

Madagascar. In Kianjasoa, Madagascar, rice - rice and rice - ratoon rice using different varieties were evaluated under irrigated condition. Tainan 1 (2067) yielded 7.2 t/ha in the first rice crop and 2798 Tache Koual in the second rice season (7.4 t/ha), followed by IR36 (5.3 t/ha). Tainan 1 (2067) also showed good ratooning ability, with the crop yielding 2.2 t/ha. In Sambaina, three cropping patterns in the well-drained soil were evaluated. Rice yield of rice - wheat, rice - potato, and rice - bean was higher (2.8-3.7 t/ha) than the farmers' monocrop rice (1.7 t/ha). In addition to rice, wheat yielded 4.4 t/ha; potato, 13.1 t/ha; and bean, 3.1 t/ha.

Women in rice-based farming systems

Several gender-related studies are being conducted at key farming systems sites in the Philippines, Indonesia, Nepal, Thailand, and India in collaboration with national institutions.

Philippines. In Matalom, Leyte, concerns specific to women were integrated into upland rice farming systems research by the Farm and Resource Management Institute, Visayas State College of Agriculture. After a benchmark survey, several on-farm experiments and special studies were conducted. They include evaluation of the cooking and eating qualities of IRRI upland rice varieties or lines, evaluation of local and introduced sweet potato cultivars for high yield and less weevil infestation, on-farm experiments on peanut production and processing, evaluation and adaptation of the IRRI micro rice mill, and experiments on the native chicken. The cooking and eating qualities of four best upland rice lines from the Acid Upland Yield Trial (AUYT) and Lubang (local upland rice variety) were evaluated by local women in three villages. Lubang was preferred, followed by IR55419-04 (VRi-15), IR55411-54 (VRi-14), IR55411-50 (VRi-13), and B2997C-7B-4-2-1 (VRi-2). Results of the study have significant implications for the upland rice breeding program. Current breeding objectives include high yield, short duration, drought tolerance, pest resistance, and adaptability to adverse soil condition. The characteristics preferred by farmers, women in particular—color, aroma, size of grain, and stickiness—are not considered by breeders.

One technology with potential for adoption is the micro rice mill developed at IRRI. The mill was rated positively by women in terms of quality of milled rice, rice bran product, length of milling time, size of rice mill, and energy requirement. In three upland rice areas in Matalom, an electric-driven micro rice mill comes every week to the three villages and is operated by women's groups. The associations operating the rice mill charge a milling fee. From the income generated, small loans at a low interest rate become available to women who want to invest in small enterprises. As of December 1991, the associations earned a net income of $48 in San Salvador, $78 in Elevado, and $59 in Esperanza.

Women cited these advantages in using the micro rice mill: it is portable, easy to operate, reduces time in transporting palay to the village, reduces time in queuing at the town mill, reduces drudgery in hand

pounding rough rice, and generates income for the association, which, in turn, allows the women to obtain loans at a low interest rate.

The mill was also highly acceptable in the northern part of the Philippines where women form the bulk of the labor force in rice production and processing.

Another technology that showed potential for adoption in rice-growing areas, which experience labor shortage, is the Ultralite transplanter developed by the IRRI Engineering Division. In collaboration with PhilRice, the Ultralite transplanter was demonstrated on a 40-m^2 farm in a village in Mountain Province where women do most of the rice cultivation. On-farm testing showed that transplanting on a 40-m^2 farm is normally finished in 4 h. With the Ultralite transplanter, it takes only 1 h. The Ultralite has potential for adoption, but women farmers should first be trained to operate the transplanter and to prepare the seedlings.

Indonesia. Under rainfed conditions, rice is followed by soybean or mungbean. In Sitiung, West Sumatra, application of animal manure is a common practice; hence, raising cattle is an important component of the system. Time allocation surveys indicated that crop production and cattle raising are activities that require the use of family labor. Women spend about 4 h a day collecting fodder for the animals, which provide manure for the crops. This activity takes the time they could devote to farming and other remunerative employment opportunities. Animal fodder production is expected to reduce time spent by women in collecting animal fodder, improve the quality of animal fodder, encourage farmers to raise cattle, sustain the application of animal manure on rice and nonrice crops, and thus raise production levels. Planting forage crops on the rice bunds increases the fodder supply for cattle.

Nepal. Most farming systems in Nepal integrate crop, animal, and tree, with rice as the major crop. A study in Mohana and Baghmara villages in Ratnanagar, Chitwan district, shows that women and children play a significant role both in contributing labor and by making decisions for crop and animal production. Women are more involved in fuelwood collection from the forests, as they are responsible for cooking and feeding the family. On the average, women spent 3-[illegible] h carrying fuel wood from the forest during winter and 4-5 h during summer. Fodder is also not available in abundance because forest pastures are overgrazed. Because collecting fodder, fuelwood, and timber is the prime responsibility of women, the research team has given attention to multipurpose tree species within the rice-based systems. At the same time, interventions to improve rice production are being introduced.

Thailand. Gender-related studies in the rainfed environments in Khon Kaen and Chiang Mai in Thailand showed the increasing tendency of male labor to migrate in search of nonfarm employment. Because rice is grown mainly for home consumption, other sources of income were deemed important. Through farming systems research, several technologies for female-dominated tasks were tested and evaluated. Results from the on-farm experiments on improved poultry production in Amphoe Phrao, Chiang Mai, showed that the technology resulted in better income distribution throughout the year, improved the nutrition of the family, and improved the working relations between male and female family members. Although poultry management was traditionally dominated by women, men participated in the activity when this showed potential for generating income for the family. In Phattalung village, one of the objectives was the improvement of native poultry husbandry through the introduction of native chickens called "Colon". This exotic breed is one of the best for meat and is easier to raise than the improved breeds. Village women were trained to vaccinate this breed. Initial results showed that improved native poultry production can provide additional income of $40-$80 from 40 birds in 2 mo. At both sites, other experiments to increase cropping intensity are being conducted.

India. The IRRI-ICAR Collaborative Rainfed Project in eastern India under the Narendra Deva University of Agriculture and Technology conducts gender-related studies. One study showed that women's participation in the labor force is determined by social status (caste) and availability of male labor. There seems to be a shortage of male labor in both villages with male heads of households and other male members engaged in either seasonal or permanent nonfarm employment. Of the total sample households interviewed, only 50-64% have heads who are fully engaged in farming.

This has implications for the residual labor force like widows and farmers' wives who are de facto household heads when their husbands leave the villages to seek employment elsewhere.

The social status of upper caste women does not permit them to work in the fields regardless of the size of their holdings. However, they are knowledgeable about farming and are involved within the homesteads in such activities as seed management, seed storage, and preparation of cowdung cakes for fuel.

In rice and wheat production, the contribution of female labor from the lower caste ranged from 35 to 44% of total labor input. In both villages, the majority of the women have problems with storage pests. About 30-50% of the seeds in stock are lost to pests, thus affecting the purity and availability of seeds for the next season.

Crop-animal farming systems

Philippines. Research activities are conducted in Santa Barbara, Pangasinan, representing rainfed lowland rice ecology, and at Trece Martires, Cavite, representing upland rice ecosystem. In Pangasinan, a follow-up cattle fattening experiment was conducted from October 1990 to April 1991 to further test the appropriateness of the scheme based on strategic supplementation with urea, legumes, and rice straw concentrate. Eleven 2-1/2-yr-old Brahman grade bulls were randomly allotted as control and treatment groups to farmers. Cattle fed 2 kg of legumes (dry basis), rice bran (0.5% of body weight), and urea-treated rice straw and given free access to salt and dicalcium phosphate attained relatively higher growth rates than the animals fed a combination of weeds and rice straw plus tethering. In the draft animal power experiment, the use of the sledge and dead load eliminated problems related to the use of the plow. Draft exerted by the animal is directly related to the increase in power generated. Both cattle and carabao could pull draft equivalent to 10-15% of their body weight at sustained speed and ease.

In the food and forage legume intercropping, mungbean and cowpea were intercropped with siratro *Macroptilium atropurpureum* and sunnhemp *Crotalaria juncea* in Santa Barbara. The grain and fodder yields of mungbean (1.09 and 1.06 t/ha, respectively) and cowpea (0.90 and 0.47 t/ha, respectively) intercropped with siratro were higher than those of their monocrops (mungbean 1.03 t grain/ha and 1.04 t fodder/ha, and cowpea with 0.70 t grain/ha and 0.45 t fodder/ha). Crotalaria significantly decreased mungbean and cowpea yields by 31 and 36%, respectively. Forage yields of siratro and crotalaria were 6.70 and 11.32 t dry matter/ha, respectively, for a 6-mo period. Rice (IR74) cultivated after the intercropping experiment and with the last forage legume regrowth applied as green manure had higher yields in plots previously planted to food legume crops and intercrops over the fallow/control treatment. This indicates that the rice - food grain + forage pattern can produce both food grain (rice and legumes), animal feed (forage crops and crop residues), and organic fertilizer for the following rice crop.

In Cavite, the use of cowpea/cassava-based diet was compared with the usual farmers' practice of feeding fattening pigs with mixtures of concentrate, kitchen refuse, and crop by-products. Treatment and control animals showed similar growth rate (0.5 kg/d). However, feed conversion efficiency was better in pigs fed the experimental diet (4.2 kg) than in the control animals (5.4 kg). Likewise, the lean meat yield of the experimental animals was better than that of the control group. This is significant as the market price of pigs is influenced by carcass quality. Cooperators in the pig fattening project also received five hens and one rooster each to study the viability of the native chickens for supplementing farm income. Increased inventory of chicken and number of eggs produced by hens were noted in the treatment groups, indicating the beneficial effect of energy and protein supplement on the productivity of the chickens.

China. Crop-animal systems research implemented in Beijing and Zhenjiang in China focused on rice-dairy and rice-pig. In Beijing, triticale was introduced in the cropping system as a source of fodder for making silage fed to dairy cattle. Triticale has high fodder production (54.8 t/ha), double that of maize (33.8 t/ha), and barley (22.8 t/ha), the traditional sources of silage in the area. The total nutrient output is almost double that of barley or maize. The quantity of milk produced by triticale-fed dairy cattle was similar to that from animals fed with maize silage (19.7 kg/head per d); however, the quality of the former was better.

In Zhenjiang, introducing maize in the system practically improved the existing cropping pattern in the locality. In higher areas where rice suffers from drought, maize was planted. The area of maize increased from zero to 1,200 ha in 1991. Furthermore, the inclusion of maize as a component in the diet of pigs improved the performance of the animal

in terms of feed efficiency and shorter feeding duration to reach marketable weight. In a demonstration involving 24 weanlings of different grades of swine divided into three groups, the adoption of an improved breed of swine with corresponding improved feeding management gave high net return compared with the local breed fed the usual diet.

Nepal. Activities in the crop-animal systems research sites in Naldung focused on different forage production strategies to increase feed supply in rice-based cropping systems. It included the evaluation and screening of forages and fodder trees along contour hedgerows and the adoption of forage legumes planted after rice. Dudhilo *Ficus neriifolia*, khanyu *F. semicordata*, gogan *Saurauia nepalensis*, badhar *Artocarpus lakoocha*, and syal fusro *Grewia tiliaefolia* are fodder trees with potential for success along terraces and hedgerows. Since the potential for lopping (herbage production) and effects on food crops planted along alleys have to be assessed, the experiment will be continued. In the food-forage production strategy involving oat intercropped with locally grown winter legumes, the Swan and Amuri cultivars produced significantly high green forage. Amlisho *Thysanolaena maxima*, a multipurpose shrub planted widely in Naldung, was studied for its production potential. The leaves are utilized as feed to animals and flowers are made into brooms. Fodder production of a clump of Amlisho (18.75 m^2) was 64 kg/ha per yr.

Rice-fish farming systems

Rice-fish farming systems is a collaborative research of national agricultural research systems and the International Center for Living Aquatic Resources Management (ICLARM). The network collaborates with the Philippines, Indonesia, India, Thailand, Korea, and Vietnam. The objective of the collaboration is to identify more productive rice-fish farming in irrigated and rainfed rice ecologies. On-farm research on rice-fish farming expanded in 1991. In addition to research, there were production programs in Thailand and Indonesia.

Indonesia. Rice-fish farming is expanding rapidly in Indonesia. The target expansion area of 25,000 ha in 1989 increased to 40,000 ha in 1990 in 11 provinces of the country. On-farm trials among 24 cooperators showed that productivity was highest from rice + fish - rice + fish - fish (R+F-R+F-F) or rice + fish - fish - rice + fish - fish (R+F-F-R+F-F). R+F-R+F-F increased the efficiency of inputs particularly fertilizer, herbicides, and insecticides. During WS, application of these inputs was about 32, 92, and 46% lower than for rice - rice - fallow, and about 27, 58, and 32% lower than the same systems during DS. Fish raised together in R+F-R+F-F reduced the hours for weeding by about 23 during WS and 22% during DS. Fish also increased rice yield by 51% in R+F-R+F-F and by 27% compared with rice - rice - fish and rice - rice - fallow. Net income was 90 and 60% higher, respectively.

China. In Hunan, research activities on rice - azolla - fish systems continued with emphasis on rice - rice/azolla/fish or rice/azolla/fish. Rice - fish - azolla with a yield of 13.36 t/ha, which is 6.3% higher than that of rice monoculture, was the most popular. Fish yield was 795 kg/ha. The ecology experiment on the rice - fish - azolla showed that it increased soil fertility and rice and fish yields.

Bangladesh. Deepwater rice-based farming systems research key sites at Mirzapur, Tangail, were started in 1990. That represents a large extrapolation area of about 2.4 million ha. Because of the risk of flood damage, the area remains virtually fallow from July to November. The area of productivity can be increased through the introduction of transplanted deepwater rice and fish. On-farm trials using nylon net enclosures, bamboo cages and bamboo enclosures showed that nylon net enclosures were the most promising, with fish yield of 1.47 t/ha. In 1991, the polyculture of Thai sarputi, common carp, and grass carp was very promising, with yields of 5 t/ha. Thai sarputi and common carp performed equally well under monoculture and polyculture systems. The two species made good use of natural weed and azolla that grow in the open water. CARE International, which provided material support for the experiments, will expand the project in other areas. The trials have drawn the attention of researchers, administration extension workers, and farmers.

Korea. Rice-fish farming systems, with loach and catfish as the predominant species, are becoming popular in Korea. Rice-fish farming households increased by about 47% within 2 yr. Research activities are concentrated on culture methods in rice-fish farming systems using catfish, loach, and mud snails and in the establishment and production techniques of the fingerlings during winter months. Weed control was 28% more effective in rice-fish culture than with herbicide application. The system increased

rice yields by about 5%, compared with rice monoculture plus herbicides. An experiment on catfish *Parasilurus asotus* showed that feeding cost is lower if carp fodder is used for 4 mo compared with eel fodder.

Philippines. Rice-fish farming systems activities are carried out at five key sites. Studies in the irrigated lowland rice areas using the trench and pond refuge systems showed no significant difference in rice yields between the two systems compared with the monoculture rice yield on both WS and DS. Fish yield was slightly higher in the pond than in the trench refuge systems (388 vs 379 kg/ha). Economic analysis showed that the pond refuge was more efficient and profitable. Farmers also planted different kinds of vegetables along the dikes of the rice-fish systems. The highland irrigated ecosystem in Mountain Province showed that rice production in the rice-fish systems was higher (4.08 t/ha) than 3.5 t/ha under farmers' practice. Total fish production was 250 kg/ha. Economic analysis showed a marginal benefit:cost ratio of 6.30 in the rice-fish systems.

Thailand. Tilapia *Tilapia nilotica*, common carp *Cyprinus carpio*, and common silver carp *Puntius gonionotus* are the most common fish species grown. With a stocking rate of 1:2:2 (3,750 fishes/ha), 212.5 kg/ha was produced. Consequently, rice yield increased by 14.5% with KMDL and RD6 rice varieties as the most promising. Production of fingerlings from 1987 to 1990 has increased to 116.8%, with silver carp (44.4%) and common carp (39.1%) having the greatest demand. Systems involving the use of twin ponds, and the use of nursery cages in farmers' ponds and reservoirs are under study. In the deepwater rice areas, the aquatic environment was found to be naturally rich in fish food organisms. Fifty-nine species of phytoplankton, eight species of zooplankton, and 16 species of aquatic plants were identified. Water quality such as depth, transparency, temperature, pH, dissolved oxygen, and NH_4 concentration were found to be conducive to fish culture.

In Ayutthaya, a deepwater rice-fish system was studied by Rajamangala Institute of Technology in 35- × 45- × 2-m ponds. Silver bard and tilapia in a 1:1 ratio were stocked at different rates (5,000 and 10,000 fingerlings). Deepwater rice + fish (10,000 fingerlings) showed the highest gross value, with a fish yield of 274 kg/ha. Rice yield was relatively higher than that without fish.

In another experiment, three systems—monocrop deepwater rice (control), mungbean + deep water rice/fish, and deepwater rice/fish—were tested in Huntra Experiment Station, Ayutthaya. Mungbean yield was 500 kg/ha; deepwater rice suffered from drought and most plants died because of a rapid surge of water. Fish yield was high in mungbean + deepwater rice/fish system, although the fish was smaller than marketable size. The more intensive system guarantees higher yields of upland crops and fish than does the monocrop deepwater rice; thus the former reduces the risk of total production loss.

Vietnam. In the Mekong Delta, rice-shrimp systems continued to attract many farmers. In 1990, 119 farming families were monitored to evaluate the systems' performance with different rice varieties and the degree to which farmers accepted the new technology. Sixty-two percent of all farmers used fertilizer correctly. Rice yields were 4.7 t/ha during winter-spring crop, 4.5 t/ha during summer-autumn crop, and 4.3 t/ha for traditional rice during the main season. Shrimp yield ranged from 13 to 364 kg/ha. Studies on land allocation in the systems showed that 56-71% is occupied by rice, 14-23% by trenches and furrows, and 14-25% by surrounding dikes. Abundance of microflora and feeds was positively correlated with the growth and yield of shrimps. Research continues with emphasis on the effect of pesticide and other biological pest control measures on shrimp culture.

Rice - wheat cropping systems

One of the major cropping systems in subtropical countries is rice - wheat. The major objective of the collaborative research is to identify 1) profitable rice - wheat systems in different rice environments, and 2) best wheat and rice varieties that satisfy the crop rotation needs of rice - wheat farmers. Research on rice - wheat has been conducted in Bangladesh, Nepal, Myanmar, and China.

Myanmar. Rice - wheat cropping pattern trials in three locations in Myanmar were compared with other cropping patterns. Rice - wheat gave 83% higher net returns than sesame - rice in Yezin, 58% higher than monocrop wheat in Wetlet, and 297% higher than monocrop wheat in Pale. The introduction of the rice - wheat cropping pattern has a significant impact on the expansion of the rice - wheat area in Sagaing Division. Farmers usually grow only one crop of wheat, but through repeated rice - wheat trials and demonstrations with field

days, the acreage of rice - wheat dramatically increased from 623 ha in 1986-87 to 3,653 ha in 1990-91. Constraints to wheat production identified especially in the rainfed lowland fields are pest, rust diseases, and moisture and temperature stresses.

Nepal. The rice - wheat systems research was continued at two farming systems research sites, Bhairawa and Naldung. The rice - wheat cropping pattern trials were conducted under partially irrigated lowland ecosystem to evaluate the economic returns against farmers' rice - wheat cropping pattern. To improve the existing farmers' rice - wheat cropping pattern, improved management practices using a recommended dose of fertilizer and high-yielding varieties of rice and wheat were incorporated in the trial. Analysis showed that the percentage increase in return above variable cost of improved practice in comparison to the farmers' practice was 58% in Bhairawa and 42% in Naldung.

China. In China, the present rice - wheat cropping systems have entered a relatively stable stage. The 1989 national statistical data showed that average yields were 12.84 t/ha for wheat - rice - rice and 9.35 t/ha for wheat - rice; those are 28.5 and 43.9% higher than those for green manure - rice - rice and single rice, respectively. However, economic analysis of data from long-term trials conducted at the Hangzhou farming systems sites showed that net returns obtained from the new cropping patterns of barley - melon - rice were higher than those from wheat-rice, barley - rice - rice, and rice - rice. To ensure high and stable yield from the rice - wheat cropping systems, improved management practices were recommended for different soil and climatic conditions, along with component technology for each crop. For instance, the conservation of perfect irrigation and drainage systems in ricefields during the wheat-growing season is necessary. Optimum time of sowing plant population and fertilizer usage, protection from pests and diseases are some of the basic requirements for obtaining high and stable rice or wheat yield.

Bangladesh. Rice - wheat cropping systems trials were conducted by the Bangladesh Rice Research Institute in farmers' fields in Meherpur district. Farmers grew traditional local aus rice, but for the recommended management level the researcher used BR20 and BR21 as direct seeded, high-yielding aus rice. Wheat variety Kanchan was used at both recommended and farmer management levels. Data indicated that BR20 and BR21 produced more than 1.0 t higher yield/ha than farmers' traditional varieties in both years. Wheat yield was the same under both management levels.

Impact of farming systems research

Bangladesh. The Bangladesh Rice Research Institute studied the extent to which rainfed lowland rice cropping systems technologies have been adopted and the impact that it has had on resource use, productivity, income, and expenditure patterns in two key farming systems sites, Sitacunda and Kumarganj. Results show that households have adopted the technology in varying degrees, with relatively small farmholdings being high adopters. This group of households have higher input outlays per hectare and therefore obtained the highest productivity compared with the relatively well-off farmers with bigger landholdings. Adoption of the technology increased rice yield by 1.1-1.4 t/ha per yr over the existing cropping systems. Indirectly, adoption of the more intensive cropping patterns has generated additional employment opportunities within and outside the household.

Indonesia. The Central Research Institute for Food Crops of Indonesia focused a study on the degree to which rice-fish farming has increased household real income and how it has affected the quality of consumption through increased purchasing power. The study also measured the extent to which introduced technology has affected the marketable surplus of rice. Farmers who adopted the intensive rice-fish culture have smaller landholdings compared with nonadopters. The introduction of fish with rice has increased the efficiency of chemical input use, reduced labor use, and increased yield. The annual rice yield and rice yield equivalent of fish increased by about 20-50% over the less intensive double-cropping of rice alone. The availability of fish within the farm has led to higher fish consumption for the household. A significant change in nonfood expenditure, education in particular, was also observed across farm groups.

Nepal. The Nepal Agricultural Research Council conducted a case study on hill farmers, which focused on the degree of adoption of recommended farming systems research technologies in Pumdi Bhumdi, a rainfed midhill rice area. Results indicated that farmers adopted improved varieties of major crops and their cultural practices. Some par-

cels of land were shifted to vegetable production. Better quality forage grasses and fodder tree species were adopted by the farmers. The availability of suitable feedstuff for cattle increased milk production substantially. Adoption of these farming systems technologies has improved farmers' nutritional status because of consumption of home-grown vegetables and milk and milk products. Surplus milk and milk products provided additional income.

Sri Lanka. The Department of Agriculture in Sri Lanka examined the relative efficiency of resource use under traditional and new technologies, impact on income and on other non-quantifiable benefits in Uva Paranagama. Results indicate that adoption of farming systems research-developed technologies has caused structural changes in the production processes on each of the three major crops rice, vegetables, and potatoes. This resulted in changes in functional income distribution and value added of all those crops. While personal income distribution from rough rice and vegetables changed in favor of the adopters, the nonadopters were favored in potato crops. Systemswide, there was no significant difference in functional and personal income distribution between the two groups of farmers. Neither were there significant differences in other related welfare indicators, i.e., farm and household capital accumulation, nutrition, expenditure, and savings.

Thailand. The Farming Systems Research Institute of the Department of Agriculture and Chiang Mai University looked at the impact of mungbean before rice and direct seeding of rice in northern Thailand. Many farmers suffered yield losses due to waterlogging. The average mungbean yield was 250-300 kg/ha—55-70% lower than expected yield levels. While mungbean provided additional income and enhanced soil fertility, it can create delays and potential losses to subsequent rice crops, direct seeded rice in particular. Direct seeding of rice became popular only from 1990 onwards when rainfall was inadequate for transplanting and wage rates were high at peak periods. Mechanical seeders introduced along with direct seeding substantially reduced labor costs. Although many farmers have acquired seeders as a result, income increases from the new technology seem inadequate to slow down migration of the young to urban centers.

Philippines. The Farming Systems and Soil Research Institute of the University of the Philippines at Los Baños studied two farming systems research sites. The KABSAKA site in Iloilo Province was used to refine the methodology on the classification of farmers according to degrees of adoption or nonadoption. The Laguna Province site used a case study to determine the impact of farming systems research technology on household cash flows. Results of the study on methodology show that the application of cluster analysis can classify technology adopters, particularly when dealing with the adoption of a package of technology. Clusters of farmers differed in the levels of technology used, productivity, and cash flows. At the other site, the study revealed the economic benefits from adoption of the rice - watermelon cropping systems. Cash flow analysis showed that the technology benefited the farm household not only in terms of absolute cash income but also in meeting demands of monthly household expenditures. Farm workers also benefited from the additional employment generated in watermelon production.

An IRRI study considered the importance of nutritional aspects of farming systems research along with other welfare measures such as changes in income and purchasing power, as well as assets and capital accumulation. The study site in Isabela Province in northeastern Philippines has two distinct landforms: the rice-based area is rainfed lowland and the maize-based area is rainfed upland. The average farm household cultivates about 3 ha distributed almost equally between the two landforms. All households therefore have the opportunity to grow lowland and upland crops.

The study categorized its sample farms into three levels of adoption. Results indicate mixed impact on the different household welfare measures. While medium and high adopters were observed to have significantly higher farm receipts from the different crop enterprises, the low adopters compensated for their low farm income through other means, thus putting them at par with high adopters as far as total household income was concerned. Maize crops in the upland contribute about 80% of farm cash earnings for all the farming households, remaining the single most important source of income. The contribution of lowland crops rice and mungbean to total income remains insignificant.

The inability of the farming households to satisfy their required daily allowance on energy and protein cuts across adoption levels and seasons. Medium and high adopters, however, tend to have higher nutrient

intake than low adopters. Similarly, the prevalence of moderate malnutrition among preschoolers cuts across adoption levels and seasons.

Data management for on farm trials

The Data Management for on-farm trials aims to develop and make available to national programs, a computer-based data management system that would enhance efficient management and proper utilization of data from on-farm trials for technology verification. The three major activities are 1) development of a generalized microbased data management system, IRRIOFT, to support on-farm trials for technology verification; 2) development of a simple analytical tool for identifying the recommendation domain of a promising technology; and 3) evaluation of the applicability of IRRIOFT and the analytical procedures through training of and on-site testing by on-farm trial workers in national programs.

Three collaborating countries, each with two test sites, are involved: Indonesia (a tidal wetland farming systems and a rice-fish farming system site), Philippines (a crop-animal farming systems and a cropping systems site), and Thailand (a cropping systems and a rice-fish farming systems site).

Twenty participants from three countries were in two training programs on "Data Management for On-Farm Trials" conducted at SEARCA, 19 Feb-16 Mar 1990 and 11 Mar-12 Apr 1991. Three modules were studied: prescription, form generation, and data entry/editing. A fourth module has been finished: data analysis, summary, and presentation.

Extrapolation of agricultural technologies using geographic information systems (GIS)

This computer-based GIS approach to technology mapping is relatively new. The activity will be conducted at farming systems key sites: three in the Philippines, two in Thailand, three in Indonesia, and one in Vietnam. Several scientists from key sites of ARFSN were trained on the principles, procedure, application of GIS, and how to use the PC ARC/INFO GIS facilities. Each trainee prepared a project proposal that will be implemented in 1992.

Engineered equipment for timeliness of intensive cropping

The hydrotiller developed by IRRI was tested in South Vietnam in collaboration with the University of Cantho to control the problematic *Eleocharis* weeds in acid sulfate soils of Mekong Delta. Results were promising as the hydrotiller uprooted the weeds completely with the rhizomes while simultaneously tilling the field. Estimates show that users can save as much as 70% of the costs of weeding and land preparation.

The vertical metering slit seeder developed at IRRI attracted interest at Jiangsu Academy of Agricultural Sciences where collaborative use of this equipment in rice - wheat crop seeding will be undertaken. The evaluation was satisfactory and tractor multirow application was jointly made. Evaluation of the slit seeder in Pitchi, Thailand, was very promising. Yield of soybean after rice was higher than that with broadcasting and hand seeding.

Hulling continues to be a major source of income for rural women. A model was designed incorporating a hull cleaner or aspirator. The huller with aspirator is fitted with 3.5 HP gas engine and has a capacity of 4-5 sacks/h. The other model, which was reduced in size, weighs 15 kg. The unit with aspirator enables users to obtain clean grain and without the burdensome task of manual winnowing.

Two models of IRRI-designed micro rice mills were introduced to farm villages of Camarines Sur, Ilocos, Isabela, Kalinga Apayao, Leyte, Pangasinan, Quirino, and Sorsogon in the Philippines through the initiative of PhilRice and IRRI Women in Rice Farming Systems (WIRFS) and the Engineering Division of IRRI. The models can mill from 1-1 1/2 sacks of palay/h, with a milling recovery of 67%. The equipment enables women particularly in remote villages to process their own products.

Sri Lanka has started producing the centrifugal huller with aspirator for promotion. Units of the micro rice mill (Engelberg type) were sent to Indonesia and Nepal. Tests in collaboration with WIRFS are being undertaken.

Varietal testing of upland crops after rice

A regular yield trial of three upland crops—mungbean, cowpea, and peanut—with 12 entries each, and a replicated screening trial of 206 lines or cultivars of cowpea for early maturity, high grain yield and high fodder yield were conducted. The trials were conducted after the main rice crop under high tillage condition. No fertilizer was applied except on peanut (40-30-30 kg NPK/ha).

Three mungbean cultivars gave a bean yield of more than 1 t/ha. VC 2719 from the Asian Vegetable Research and Development Center yielded 1.40 t/ha followed by IPB M82-16-70 (1.24 t/ha) and IPB M82-17-52 (1.03 t/ha). They also produced the highest fresh fodder yield after two pickings of dry pods. These cultivars mature in 60-65 d.

Cowpea gave very low yields of 0.21 to 0.44 t/ha. CES 81-6 and CES 41-6, entries from IPB, were the highest yielders and All Season, the local check, was the lowest. A very high degree of pest infestation (beanfly and pod borer) and the effect of low temperature accounted for the low bean yield.

Five cultivars yielded more than 10 t fresh fodder. All Season gave the highest yield (11.33 t/ha) followed by IT83S-774-1 (11.30 t/ha) and TVx-3381-02F (11.03 t/ha). Maturity ranged from 65 to 71 d. The highest bean yielders CES 81-6 and CES 41-6 were the earliest maturing cultivars.

Peanut cultivars IPB PN 42-14, UPL PN-2, and IPB PN 48-75 yielded the most shelled bean and fresh fodder: 2.25-2.04 t shelled beans/ha and 13.77-12.97 t fresh fodder/ha. EG PN-18 and Tainan, however, were the most resistant to Cercospora leaf spot disease, which occurred at the late reproductive growth stage of the crop.

In the cowpea screening trial, 20 lines or cultivars with high grain yield and fodder yield were selected for a preliminary yield trial next cropping season. Four entries—TVx 4677-082E, TVx 2939-09D, IT 83S-979, and IT 83F-794-3—were also identified as suitable for grain and fodder purposes (dual-purpose types). For early maturity (81 d under Guimba condition, November planting), 30-40 entries with potential were identified.

Rice integrated pest management network

In IRRI's Five-Year Work Plan (1990-94), pest management research will try to fill knowledge gaps and design management strategies that will promote and sustain low pest populations, utilizing principles of integrated pest management (IPM). While research activities at IRRI will address strategic issues in broader perspectives, more country-specific issues are being promoted through the Rice IPM Network. The network provided the forum for national scientists, extension specialists, and policymakers to analyze country-specific pest management research and extension needs, and to develop activities to fill the gaps. This was carried out through a series of diagnostic workshops, where a set of analytical frameworks for analyzing complex problems were used by participants. Among the frameworks used were historical profiles, seasonal profiles, interaction matrices, analysis of policy options, knowledge structuring frameworks, and tactic discrimination profiles.

Farm surveys designed to provide information in current scenarios of farmers' pest management practices are useful tools. In the Philippines, a survey was conducted in collaboration with the Visayas State College of Agriculture (VISCA) in Leyte to investigate farmers' insecticide use patterns. A large proportion of the insecticide sprays were applied at the tillering and booting stages. The 300 farmer respondents applied a total of 840 sprays in 1991 WS: 37% at tillering and 25% at booting stage. The main pest targets were the rice bugs and leaf-feeding insects like armyworms and rice leaffolders.

The insecticides used by farmers for various pest targets raise questions on farmers' pest management knowledge. Methyl parathion, endosulfan, and monocrotophos were the main chemicals used. Rice bugs, leaf-feeding insects, and snails were the main targets.

Since these pests are highly visible, farmers tend to overestimate the damage they cause. That may account for their misuse of highly toxic chemicals. The results suggest the need for more information that will help farmers' overcome extreme fear of such pests.

International programs
Training

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Training

IRRI assists and strengthens national agricultural research systems (NARS) through various activities, one of which is training. The IRRI training program encompasses research-oriented activities and group training courses aimed at developing scientists to solve rice production and utilization problems and to transfer appropriate technology.

The goal of IRRI's training program is the development of human resources in NARS and is accomplished through collaboration with national rice research systems, universities, and affiliated institutions.

Subprogram I: Degree and postdegree training

Management of degree and postdegree training

IRRI's degree and postdegree training programs assist national programs by increasing the number of trained professionals at key strategic national institutions in each NARS. Collaboration is strengthened among IRRI scientists, university professors, and national rice research scientists.

IRRI's degree program provides opportunities for scholars to conduct MS or Ph D thesis research under the guidance and supervision of an IRRI senior scientist. The research may be undertaken at IRRI or at a key collaborative location in the country. IRRI has established formal Memoranda of Agreement with more than 30 selected universities worldwide where scholars take course work for their degree programs prior to beginning research. Nondegree research-oriented programs enable scientists to undertake tutorial or on-the-job training in various disciplines under the supervision of IRRI scientists. The training is designed to impart job-specific research/training skills. IRRI administers the following types of scholarships as well as a Type V scholarship (short-term group training courses):

Type I—Thesis/dissertation research only
Type II—Course work and thesis/dissertation research
Type III—Tutorial or on-the-job training
Type IV—Collaborative research

In 1991, 171 scholars from 28 countries in Africa, Asia, Europe, the Americas, and Oceania participated in IRRI's degree and nondegree research training programs (Table 1). Among the 171, 72 completed their training programs during 1991.

Postdoctoral research and midcareer training

The program serves as a reorientation for senior scientists of national research organizations and agricultural universities who pursue in-depth research on problems related to mutual objectives of IRRI and the respective NARS. Opportunities are provided for exchange of scientists from research and academic institutions in countries where IRRI has established formal collaborative research agreements. A balance is achieved between IRRI's needs to bring in research expertise and provide professional development to NARS, and representation of the various NARS.

During 1991, 63 scientists and fellows from 19 countries in Asia, E[illegible] and the Americas participated in IRRI's co[illegible]ative research and fellowship programs (Table 2). These scientists and fellows conducted their research activities in eight

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Table 1. Research scholars by region, country, and type. IRRI, 1991.

Region and country	Scholars (no.)								
	Type I		Type II		Type III	Type IV			Total
	MS	Ph D	MS	Ph D		MS	Ph D	Non-degree	
Africa									
Ghana	-	-	1	1	-	-	-	-	2
Madagascar	-	-	4	2	-	-	-	-	6
Somalia	-	1	-	-	-	-	-	-	1
Tanzania	-	-	1	2	-	-	-	-	3
Subtotal	-	1	6	5	-	-	-	-	12
Asia									
Bangladesh	-	3	3	9	5	-	-	-	20
Bhutan	-	-	1	-	-	-	-	-	1
Cambodia	-	-	1	-	-	-	-	-	1
China	1	-	1	10	5	-	-	-	17
India	-	4	-	-	2	-	-	-	6
Indonesia	-	1	1	1	1	-	-	-	4
Iran	-	-	-	2	1	-	-	-	3
Japan	-	3	-	-	2	-	-	-	5
Korea		1	-	4	5	-	-	-	10
Myanmar	-	-	4	-	-	-	-	-	4
Nepal	2	5	3	6	1	-	-	-	17
Pakistan	-	2	-	1	-	-	-	-	3
Philippines	2	8	-	1	4	-	-	-	15
Sri Lanka	1	-	-	5	4	-	-	-	10
Thailand	1	-	1	4	2	-	-	-	8
Vietnam	1	-	11	3	7	-	-	-	22
Subtotal	8	27	26	46	39	-	-	-	146
Europe									
Denmark	-	1	-	-	-	-	-	-	1
France	-	-	-	-	-	-	1	-	1
Germany	1	-	-	-	-	-	1	-	2
Netherlands	-	-	-	-	-	-	-	1	1
United Kingdom	-	1	-	-	1	-	-	-	2
Subtotal	1	2	-	-	1	-	2	1	7
The Americas									
Canada	-	-	-	-	-	-	2	-	2
USA	-	2	-	-	-	1	-	-	3
Subtotal	-	2	-	-	-	1	2	-	5
Oceania									
West Samoa	-	-	-	-	1	-	-	-	1
Subtotal	-	-	-	-	1	-	-	-	1
Grand total	9	32	32	51	41	1	4	1	171

divisions, two centers, two networks, and a unit at IRRI headquarters (Table 3).

Scholars, scientists, fellows, and nondegree trainees who participated in IRRI training programs in 1991

The following degree scholars, scientists, fellows, and nondegree trainees participated in training programs at IRRI in 1991. The list is categorized into Types I-IV scholars/trainees, research fellows, collaborative research scientists, and collaborative research fellows.

(Note: An asterisk indicates participants who completed their training program during 1991.)

■ Type I—Thesis research scholarship (MS)

Qinfang Wang, China
Brigitte Kranz*, Germany
Nagendra Raj Sharma*, Nepal
Ramesh Raj Pokharel*, Nepal
Arthur R. Baria, Philippines
Giselle Maurene P. Bombay, Philippines
V. Vingnanakulasingam*, Sri Lanka
Raschanee Suvaparp, Thailand
Nguyen Tri Khiem, Vietnam

Table 2. Distribution of scientists and fellows by region and country. IRRI, 1991.

Region, country	Scientists and fellows[a] (no.)			
	RF	CRS	CRF	Total
Asia				
Afghanistan	1	-	-	1
Bangladesh	3	-	-	3
China	4	-	-	4
Egypt	1	-	-	1
India	12	2	-	14
Indonesia	1	-	-	1
Japan	1	-	-	1
Korea	3	-	-	3
Pakistan	1	-	-	1
Philippines	8	-	-	8
Sri Lanka	1	-	-	1
Thailand	2	-	-	2
Vietnam	1	-	-	1
Subtotal	39	2	-	41
Europe				
Belgium	1	-	2	3
East Germany	-	2	1	3
Netherlands	-	-	6	6
United Kingdom	-	-	7	7
West Germany	-	1	-	1
Subtotal	1	3	16	20
The Americas				
USA	2	-	-	2
Subtotal	2	-	-	2
Grand total	42	5	16	63

[a]No visiting scientists in 1991. RF = research fellow, CRS = collaborative research scientist, CRF = collaborative research fellow.

■ Type I—Thesis research scholarship (Ph D)

A. Motaleb Bhuiyan*, Bangladesh
Abdul Quddus*, Bangladesh
Md. Fokhrul Islam, Bangladesh
Hans Hestvang Jorgensen*, Denmark
B.D. Medhi*, India
D.N. Medhi*, India
C.P. Dorairajan, India
Marappa G. Maheswaran, India
Fahmuddin Agus, Indonesia
Nobuya Kobayashi, Japan
Satomi Yoshimura*, Japan
Takashige Ishii, Japan
Sang Yeol Kim, Korea
An S. Bhandari, Nepal
Jay Bahadur Singh Karki, Nepal
Resham B. Thapa*, Nepal
Surya L. Maskey*, Nepal
Regmi Sushil Kumar, Nepal
M. Akram*, Pakistan
Usman Mustafa*, Pakistan
Presquito A. Aurin, Philippines
Edgar M. Dilla, Philippines
Cesar M. Limbaga, Philippines
Bimbo Mandras*, Philippines
Rex L. Navarro, Philippines
Leocadio S. Sebastian*, Philippines
Carlito Solera, Philippines

Table 3. Distribution of scientists and fellows by division or center. IRRI, 1991.

Division, center, or unit	Scientists and fellows[a] (no.)			
	RF	CRS	CRF	Total
Division				
Agricultural Engineering	1	-	3	4
Agronomy, Plant Physiology, Agroecology	11	-	2	13
Entomology	3	-	1	4
Plant Breedin, Genetics and Biochemistry	11	1	-	12
Plant Pathology	6	2	4	12
Soil Microbiology	2	2	2	6
Social Sciences	2	-	1	3
Soil and Water Sciences	2	-	2	4
Center				
Information Center	1	-	-	1
Training Center	1	-	-	1
Network				
ARFSN	-	-	1	1
INGER	1	-	-	1
Unit				
Project Management Systems and Biometrics	1	-	-	1
Total	42	5	16	63

[a]No visiting scientists in 1991.

Tolentino Moya*, Philippines
Abdulahi Omer Egeh*, Somalia
Aurora Garcia*, United Kingdom
Erik Bloom*, USA
Scott Templeton*, USA

■ Type II—Course work and thesis research scholarship (MS)

Md. A. Khan*, Bangladesh
Abu Saleque, Bangladesh
Md. Ayub Ali, Bangladesh
G.B. Chettri, Bhutan
Seng Tek Leng, Cambodia
Wang Hongyong, China
Vitus Ayingayure*, Ghana
I. Wayan Laba*, Indonesia
Berojo A. Rabarimandimby, Madagascar
Daniele Marie Ramiaramanana, Madagascar
Fidelis Justin Andrianilana, Madagascar
Pierre Rasolofo*, Madagascar
Moe Moe Shein, Myanmar
Soe Hlaing, Myanmar
Tun Winn, Myanmar
Marlar Oo, Myanmar
Anant Prasad Regmi, Nepal
Hem Singh Bhandari, Nepal
Raj Kumar Shrestha, Nepal
Moses N. W. Mnzava*, Tanzania
Duangjai Suriya-Arunroj, Thailand
Bui Duc Quy, Vietnam
Cam Loan Le, Vietnam
Duc Thach Tran, Vietnam
Le Thi Chau Dung, Vietnam
Pham Van Chuong, Vietnam
Vien Tran Ngoc, Vietnam
Do Van Xe*, Vietnam
Pham Cong Voc, Vietnam
Phan Ti Cong, Vietnam
Phan Ti Giac Tam, Vietnam
Tran Ngoc Lam, Vietnam

■ Type II—Course work and thesis research scholarship (Ph D)

Jiban Krishna Biswas, Bangladesh
A.W. Julfiquar, Bangladesh
Hafiz Uddin Ahmed, Bangladesh
M.A. Rashid, Bangladesh
M. Islam, Bangladesh
M.R. Ahmed, Bangladesh
Md. A. Sattar, Bangladesh
Md. Abdul Mazid, Bangladesh
S.B. Naseem, Bangladesh
Chuanyin Wu, China
Chen Dahu, China
Liu Xiaoqui, China
Liu Zhanwen, China
Mao Changxiang, China
Wang Guoliang, China
Wu Chuan Yin, China
Wu Ping, China
Zhang Shiping, China
Teng Shibiao, China
Roger Chris Dekuku*, Ghana
Dwidjono Hadi Darwanto, Indonesia
Tahereh Azhiri Sigari, Iran
Ghorban Ali Nematzadeh, Iran
Hyun Soon Kim, Korea
Kwang Hu Park*, Korea
Sang Eun Lee*, Korea
Tae Shik Park*, Korea
Abel Ratovo, Madagascar
Zafera Antoine, Madagascar
Bhaba Prasad Tripathi, Nepal
Khem Raj Sharma, Nepal
Lakshman Pun, Nepal
Pitambar Gautam*, Nepal
Tika Adhikari*, Nepal
Shyam Krishna Poudel, Nepal
Saeed Zahid, Pakistan
Irma C. Tandingan, Philippines
Sivaluxmy Sriyoheswaran, Sri Lanka
Lakshman L. Ranasinghe, Sri Lanka
Lionel Nugaliyadde, Sri Lanka
R.M.T. Rajapakse, Sri Lanka
Wipula K.B. Elkaduwa, Sri Lanka
Ashura Kihupi, Tanzania
Z.L. Kanyeka*, Tanzania
Charuwan Bangwaek, Thailand
Patchanee Chaiyawat, Thailand
Paiboon Ratnapradipa, Thailand
Somsong Chotechuen, Thailand
Nguyen Van Huynh, Vietnam
Phan Hieu Hien, Vietnam
Nguyen Manh Don, Vietnam

■ Type III—In-service, on-the-job training (non-degree) scholarship

A.Q. Mozumder†, Bangladesh
Md. Abu Nasir*, Bangladesh
Md. Abdur Rauf Meah*, Bangladesh
Habib Abul Quayyum*, Bangladesh
Debi Narayan Rudra Paul, Bangladesh
Fang Wang*, China
Huang Kaihong*, China
Lin Birun*, China
Minggao Shen*, China
Xiong Jianhua, China
D.K. Sharma*, India

Naweed Isaak Naqvi*, India
Syahril Darwis*, Indonesia
Behzad Gharehyazi*, Iran
Shao Yang Lin*, Japan
Seiji Yanagihara*, Japan
Seong Sook Han*, Korea
Hung Goo Hwang*, Korea
Kyung Ho Kang*, Korea
Dong Soo Ra*, Korea
Chung-Don Choi*, Korea
Lucy Malla*, Nepal
Thelma A. Alegado*, Philippines
Marita I. Galinato*, Philippines
Lualhati M. Noriel*, Philippines
Paulino Sanchez*, Philippines
Anura Hettiarachchi*, Sri Lanka
M.M.A.S.K. Abeysekara*, Sri Lanka
A.K. Wagarachchige, Sri Lanka
M.U.N. Puhpa Kumara, Sri Lanka
Manit Lauhatiranonda*, Thailand
Nopharat Muangprasert*, Thailand
Fleur May*, United Kingdom
Ngo Ngoc Hung*, Vietnam
Le Van Nha*, Vietnam
Duong Duc Ngu*, Vietnam
Ngo Thoi Tuyen*, Vietnam
Pham Hoan*, Vietnam
Duong Ngoc Thanh*, Vietnam
Tran Thuc Son, Vietnam
Sadang Ebais*, West Samoa

■ Type IV—Collaborative research scholarship (MS)

Pamela Dee Roberts*, USA

■ Type IV—Collaborative research scholarship (Ph D)

Caroline Begg, Canada
Henry Klein Gebbinck, Canada
O. Panaud*, France
Matthias Halwart, Germany

■ Type IV—Collaborative research scholarship (nondegree)

Marco C.S. Wopereis, Netherlands

Research fellowship

Gul Ahmad Khalidi, Afghanistan
Nurul Islam Faridi, Bangladesh
G.C. Ghosh Biswas, Bangladesh
Abdul Fazal M. Saleh, Bangladesh
Wilfried Theunis, Belgium
Dai Qui Jie, China
Huang Jikun, China
Xin-Xiang Peng, China
Xinyou Yin, China
Abd El-Salam Ebaid Draz, Egypt
Mahendra K. Satapathy, India
U.S. Singh, India
Rachhpal Singh, India
Saroj Kumar Sanyal, India
Swati Sen Mandi, India
Harbans Lal Sharma, India
Harbir Singh, India
Jawahar Lal Dwivedi, India
Chhabi Nath Chaubey, India
Vinoy N. Sahai, India
Tej N. Chaudhary, India
Pradeep Kumar Sharma, India
Zainuddin Harahap, Indonesia
Takashiqe Ishii, Japan
Chung-Don Choi, Korea
Young Tae Lee, Korea
Yoo Han Song, Korea
M.S. Khan Rana, Pakistan
Julia O. Bader, Philippines
Emerlito Borromeo, Philippines
Cesar Demayo, Philippines
Arnulfo G. Garcia, Philippines
Luciana M. Villanueva, Philippines
Ireneo Manguiat, Philippines
Genaro O. San Valentin, Philippines
Felix Librero, Philippines
Gerard D. Fernando, Sri Lanka
Chintana Chantachaeng, Thailand
Tawee Kupkanchanakul, Thailand
Michael C. Champoux, USA
Peter Reimers, USA
Do Van Cat, Vietnam

Collaborative research scientists

Matthias Becker, Germany
Hans Pinnschmidt, Germany
Ekkehard Kuerschner, Germany
Thomas George, India
Dilbagh Singh Multani, India

Collaborative research fellows

Bart Cottyn, Belgium
Benoit Van Coppenole, Belgium
Matthias Halwart, Germany
Hugo D. van der Gon, Netherlands
Eduard C. Roumen, Netherlands
Don M. Jansen, Netherlands
Marco C. S. Wopereis, Netherlands
Jacobus de Kraker, Netherlands
Premchand S. Bindraban, Netherlands
Ian C. Simpson, United Kingdom
John L. Gaunt, United Kingdom

Mark B. M. Douthwaite, United Kingdom
Charles Blessley, United Kingdom
Hilary Warburton, United Kingdom
Tim Chancellor, United Kingdom
Dylan Winder, United Kingdom

Subprogram II: Group training

The subprogram consists of short-term training courses held at IRRI, courseware development and production that supplements and complements group training courses, language laboratory and learning resources, and collaborative in-country training activities with national systems.

Short-term courses

Development and implementation of short-term group training courses are linked intrinsically to technologies developed and generated by IRRI and national rice research programs. IRRI has developed a diversity of training courses designed to be responsive to the evolving needs and rice-related problems of national systems. Group training courses aim to assist NARS scientists in enhancing their rice research competence and in disseminating appropriate technology to end-users in national systems.

IRRI offers regular and special short-term courses from 2-wk to 4-mo duration. The training methodology focuses on learning that blends theoretical and practical activities. About 50% of training time is devoted to "hands-on" laboratory work and field exercises and demonstrations while the remainder of the time is devoted to lectures, discussion and problem-solving sessions, case studies, and, when applicable, the use of self-learning courseware.

During the year, 286 trainees from 27 countries in regions of Africa, Asia, the Americas, and Europe participated in 6 regular and 12 special group training courses, one of which (RSHTC) was offered twice. Regularly offered courses in 1991 included engineering in rice agriculture, genetic evaluation and utilization, farming systems research, sustainable rice farming systems, irrigation water management, and training and technology transfer. Special courses emphasized topics in research techniques in

Table 4. Participants in regular short-term group courses. IRRI, 1991.

Region, country	Participants (no.)						
	ERAC	FSR	GEU	INSURF	IWTC	T3C	Total
Africa							
Madagascar	-	1	-	-	-	5	6
Nigeria	-	-	-	1	-	-	1
Tanzania	-	-	-	-	1	-	1
Subtotal	-	1	-	1	1	5	8
Asia							
Bangladesh	2	-	-	-	1	1	4
Cambodia	1	3	3	-	1	2	10
China	2	1	-	2	-	-	5
India	2	4	3	1	3	2	15
Indonesia	-	1	-	3	-	2	6
Iran	-	-	-	1	1	-	2
Korea	2	-	-	1	-	-	3
Myanmar	-	-	-	1	-	-	1
Nepal	2	1	-	1	2	-	6
Philippines	2	2	-	-	5	-	9
Sri Lanka	-	-	-	1	-	-	1
Thailand	-	-	-	4	2	-	6
Vietnam	2	1	-	1	2	-	6
Subtotal	15	13	6	16	17	7	74
The Americas							
Latin America	1	-	-	-	-	-	1
Surinam	-	-	-	-	1	-	1
Subtotal	1	-	-	-	1	-	2
Grand total	16	14	6	17	19	12	84

Table 5. Participants in special short-term group courses, by region and country. IRRI, 1991.

Country	Participants (no.)												
	RM Consortia	GIS	QRTPE	MLETC	RMTC	RSHTC	SRPTC	RPTC	GAT	RBTC	HRSP	SARP	Total
Africa													
Burundi	-	-	-	-	-	-	1	-	-	-	-	-	1
Madagascar	-	-	-	-	2	-	10	-	-	-	-	-	12
Malawi	-	-	-	-	1	-	-	-	-	-	-	-	1
Nigeria	1	-	-	-	-	-	-	2	-	-	-	-	3
Subtotal	1	-	-	-	3	-	11	2	-	-	-	-	17
Asia													
Bangladesh	2	-	-	14	5	1	-	-	-	1	-	2	25
Bhutan	-	-	-	-	-	-	3	-	-	-	-	-	3
Cambodia	-	-	-	-	4	1	7	3	-	-	-	-	15
China	-	-	1	-	-	1	-	2	-	-	-	6	10
Egypt	-	-	-	-	1	-	-	-	-	-	-	-	1
India	5	-	-	-	-	-	-	3	-	3	-	13	24
Indonesia	1	3	1	-	-	-	-	3	3	2	-	5	18
Iran	-	-	-	-	-	-	-	2	-	-	-	-	2
Korea	-	-	-	-	-	-	-	1	-	-	-	-	1
Laos	-	-	-	-	2	-	-	-	-	-	-	-	2
Malaysia	-	-	-	-	-	-	-	-	-	-	-	2	2
Myanmar	-	-	-	-	2	-	2	1	-	-	-	-	5
Nepal	3	-	-	-	-	-	-	1	-	1	-	-	5
Pakistan	2	-	-	-	-	-	-	-	-	1	-	-	3
Philippines	2	-	-	-	-	2	-	15	6	1	10	1	37
Sri Lanka	-	-	-	-	-	1	-	-	-	2	-	2	5
Thailand	1	1	2	-	-	-	-	4	4	2	-	3	17
Vietnam	-	-	-	-	2	-	-	1	-	2	1	-	6
Subtotal	16	4	4	14	16	6	12	36	13	15	11	34	181
Europe													
Netherlands	-	-	-	-	-	-	-	1	-	-	-	-	1
United Kingdom	-	-	-	-	-	-	-	3	-	-	-	-	3
Subtotal	-	-	-	-	-	-	-	4	-	-	-	-	4
Grand total	17	4	4	14	19	6	23	42	13	15	11	34	202

pest ecology, rice seed health, biotechnology, geographic information systems, and simulation/systems analysis. Tables 4 and 5 list training participants by course and country.

The Project Management Services and Biometrics Unit continued to conduct in-house biometrics training courses to enhance the expertise of IRRI researchers and scholars in experimental design, analysis, and interpretation. A total of 312 researchers and scholars participated in 10 courses held from January to September 1991.

REGULAR COURSES

Engineering for Rice Agriculture Course (ERAC). This 6-wk course is designed to enhance the agricultural engineering capability of cooperators in IRRI's engineering mechanization development program. This was formerly entitled Agricultural Engineering Course (AEC), a 3-wk course that covered all aspects related to design, operation, manufacture, maintenance, and field testing of IRRI-designed machines. With the new name and duration, the course broadened its coverage to include the application of engineering principles to sustainable farming systems, engineered pest control, and postharvest practices.

Farming Systems Research Course (FSRC). This 17-wk course aims to develop knowledge and skills in conducting farming systems research (FSR) and extension as these relate to research in rice production and sustainability of rice ecosystems. The course includes a training and technology transfer component with emphasis on developing training teams to implement FSR activities within an institution or region.

Genetic Evaluation and Utilization (GEU). This 16-wk course is designed to enhance the basic skills essential in operating and managing rice germplasm improvement programs. The course complements IRRI's genetic evaluation and utilization work, and is supported by UNDP as part of the seed improvement network. The course will be discontinued after 1991 to allow for development of other upstream, specialized IRRI courses.

International Network on Soil Fertility and Sustainable Rice Farming (INSURF). This 16-wk course aims to provide theoretical and practical aspects on soils, fertilizers, and experimental techniques to researchers and technicians of national programs involved in the INSURF program. The course focuses on ecological and economic sustainability issues related to soil fertility and fertilizer management in rice ecosystems.

Irrigation Water Management Training Course (IWMTC). Designed to enhance participants' concepts, understanding, knowledge, and skills in effective and efficient management of irrigation water, this course emphasizes technical, soil-plant, economic and socio-institutional factors that individually and interactively determine water use efficiency in irrigated agriculture. A 10-d field exercise in a Philippine irrigation system provides first-hand experience in the application of improved management concepts and practices.

Training and Technology Transfer Course (T3C). Designed to provide knowledge in the latest concepts and skills used in human resources development and extending technology, this course relates modern principles of educational and information technology to designing methods and materials that have immediate application in training and technology transfer. It promotes a team concept in training and trains participants to disseminate information and skills in farmer or institutional settings.

SPECIAL COURSES

Advanced Workshop in Research Management for Rainfed Lowland Rice Consortium and the International Collaboration on Rice/Wheat Program (RM Consortia). This 8-d advanced workshop cum training provides management theories, framework, and skills applicable for consortia site coordinators to implement the rice research work plans and projects at key sites in various ecosystems. The program emphasizes enhancing managerial competence associated with effective and efficient operations of rice research programs.

Geographic Information Systems (GIS) Training on Extrapolation of Agricultural Technologies. This 2-wk course measured the impact of environmental parameters to increase food production, income, and livelihood. Participants are provided with knowledge and skills in extrapolation of agricultural technologies.

Quantitative Research Techniques in Pest Ecology (QRTPE). This 8-wk course imparts a working knowledge of quantitative research techniques in pest (insect and disease) ecology research. It includes theory and practice of methods for measuring insect populations and disease intensity; field sam-

pling techniques, monitoring techniques for ecological attributes in rice-pest systems, and use of microcomputers to analyze research data on pest ecology.

Managerial Leadership Enhancement Training Course (MLETC). With the objective of assisting national research and development organizations in building their management leadership capabilities, this 3-wk course was designed to strengthen the analytical ability, skills, knowledge, and commitment of Noakhali Rural Development-II (NRD) project officers from Bangladesh. The course was developed and conducted in collaboration with the Department of Development Management, College of Economics and Management, UP at Los Baños.

Research Management Training Course (RMTC). This 3-wk course was designed to enhance leadership and managerial competence of mid-senior level leaders and managers of research institutions in national rice research systems. It aims to assist in building national research and development organizational and management expertise so participants can assume effective leadership roles in their countries' rice research and development programs. The course was developed and implemented in collaboration with the Research Management Center, UP at Los Baños.

Rice Seed Health Training Course (RSHTC). This 4-wk course trains laboratory technicians and seed specialists in detecting and identifying seed-borne pathogens of rice. It focuses on seed health testing methods and techniques to detect fungi, bacteria, nematodes, weed seeds, and insects infesting rice seeds.

Special Rice Production Training Course (SRPTC). This 14-wk course provided theory and practical experiences in rice production, irrigation systems management, farming systems research, and technology transfer/extension. It exposed trainees to participatory management through a 2-wk training conducted by the College of Engineering, Central Luzon State Univesity, Nueva Ecija, Philippines.

Two-week Rice Production Course (2-wk RP). This 2-wk course was conducted for junior researchers, extension workers, and innovative farmers to update their knowledge and skills on the new techniques of wetland rice culture. It covers the basic concepts of the rice plant and improved cultural practices with emphasis on skills in rice production.

Gender Analysis and its Application to Farming Systems Research (GA). This 2-wk course aimed to enhance participants' understanding of gender analysis and its application in technology development, extension, and training in a farming systems framework. It focuses on women's roles and concerns in agricultural research and development work as well as provides opportunities to strengthen linkages between biological and social scientists in responding to gender issues.

Rice Biotechnology Training Course (RBTC). This 8-wk course familiarized rice scientists from developing countries with new biotechnology tools and their potential to solve problems encountered in modern rice improvement programs.

Hybrid Rice Seed Production Course (HRSPC). This 3-wk course focused on hybrid rice technology that involves raising commercial rice crop from F_1 seeds and was designed to develop the skills necessary in producing and processing hybrid rice seeds. Adoption of seed production technology can be partly accomplished through training personnel and rice seed growers involved in hybrid rice seed production. The course was funded by a grant from the Italian Government through its Seed Technology and Tissue Culture Research for Economic Production of Hybrid Rice Project. This course was offered twice in 1991.

Systems Analysis and Simulation in Rice Production (SARP). This 8-wk course aimed to develop expertise and capabilities to implement systems analysis and simulation of rice production. It emphasized modeling as a tool to improve research and extension activities in rice production. Funds for this course were provided by the Centre for Agrobiological Research (CABO), Netherlands.

PARTICIPANTS IN GROUP TRAINING COURSES IN 1991

Regular courses

Engineering for Rice Agriculture Course (ERAC)

M. Abul Quasem, Bangladesh
M. Abdul Quddus Miah, Bangladesh
Chhim Bunsan, Cambodia
Xuan Hong, China
We Hualiang, China
Satya Pal, India
Satyanarayan Mohanty, India
Kwang-pyo Hong, Korea
Ki-cheol Seong, Korea
Andre Leury, Latin America

Merina Pradhan, Nepal
Okendre Budhathoki, Nepal
Jaime Batocabe, Philippines
Cyprian Torralba, Philippines
Diem Nguyen The, Vietnam
Si Tram Nguyen, Vietnam

Farming Systems Research Course (FSRC)
Meng Chheang, Cambodia
Nam Sam, Cambodia
Sak Choeun, Cambodia
Xiaodi Wei, China
Singh Om Prakash, India
Dilip N. Shindey, India
Chandra Vir Singh, India
Wagle Sudhir Mahohar, India
Djamaluddin Sahari, Indonesia
Martin F. Rakotondrasata, Madagascar
Babu Ram Banstola, Nepal
Wilfredo B. Balatibat, Philippines
Rolando O. Retales, Philippines
Hoang Thi Xuan Dau, Vietnam

Genetic Evaluation and Utilization Course (GEU)
Chhim Sarin, Cambodia
Sin Sovith, Cambodia
Sok Heng, Cambodia
S.S. Rao, India
D.K. Hore, India
Habibollah Arefi, India

International Network on Sustainable Rice Farming Systems (INSURF)
Jia Feng, China
Yanging Zhang, China
SP. Ramanathan, India
Gustami, Indonesia
Rahayu Tejasarwana, Indonesia
Anicetus Wihardjaka, Indonesia
Naser Saadati Sheyadeh, Iran
Jong Sik Lee, Korea
Khin Maung Tint, Myanmar
Bharat Mani Adhikari, Nepal
Isah Abdullahi Gatawa, Nigeria
Jayasundera Bandara, Sri Lanka
Seree Chaiyapanthu, Thailand
Suwat Jearakongman, Thailand
Panjaporn Lertrat, Thailand
Somkiat Wattakawigran, Thailand
Thuan Duc Nguyen, Vietnam

Irrigation Water Management Training Course (IWMTC)
Abu Turab Mohd. Ali Choudhury, Bangladesh
Tout Saravout, Cambodia
Dinesh Chandra, India
V. Rajendran, India
Giri Raj Singh, India
Manzoor Saremi, Iran
Purnedu Shekhar Sharma, Nepal
Mahendra Kumar Yadav, Nepal
Arsenio Moreno Araco, Philippines
Sesinando Constantino, Philippines
Baldwin Jallorina, Philippines
Felix Jose, Philippines
Ronald Vinegas, Philippines
Lila August Wilfred, Surinam
Affman Othman Maalim, Tanzania
Sa-ngob Arunthong, Thailand
Ekjit Tripakvasin, Thailand
Pham Si Cuong, Vietnam
Pham Thi Dung, Vietnam

Training & Technology Transfer Course (T3C)
Muhammad Nasir, Bangladesh
Mak Solieng, Cambodia
Van Kim San, Cambodia
Ramgopal Singh, India
B.S.N. Reddy, India
Zadry Hamsah, Indonesia
Arif Musaddad, Indonesia
Olga Razafinirina, Madagascar
Jeanine Ravatomanga, Madagascar
Victor Rakotoniaina, Madagascar
Desire Andrianorosoa, Madagascar
Ravalitera Andriamalanto, Madagascar

Special courses
Advanced Workshop in Research Management for Rainfed Lowland Rice Consortium and the International Collaboration on Rice/Wheat Research Program
Liakat Ali, Bangladesh
A. Motaleb Bhuiyan, Bangladesh
S. Mallik, India
Braja Bhoosan Singh, India
Y. Singh, India
R.K. Singh, India
S.P. Karwasra, India
Suprapto, Indonesia
Keshab Datta Joshi, Nepal
Ghana Shyam Giri, Nepal
Dambar Bahadur Tamang, Nepal
Franklin Jacob Abamu, Nigeria
Md. Munir, Pakistan
Md. Sarfraz Iqbal, Pakistan
Pompe Sta. Cruz, Philippines
Teresita Marcos, Philippines
Poonsak Mekwattanakarn, Thailand

Geographic Information Systems (GIS) Training on Extrapolation of Agricultural Technologies
Zainal Arifin, Indonesia
Djojosoegito Marsoedi, Indonesia
Khairiah, Indonesia
Narong Hutanuwatr, Thailand

Quantitative Research Techniques in Pest Ecology (QRTPE)
Wen Lizhang, China
Yanfirwan Yanuar, Indonesia
Parkpian Arunyanart, Thailand
Narong Chantaraprapha, Thailand

Managerial Leadership Enhancement Training Course (MLETC)
Ahmed Humayun Kabir, Bangladesh
Md. Abdullah, Bangladesh
Jacinta Gonsalves, Bangladesh
Samar Prasad Das, Bangladesh
Rezaul Karim Chowdhury, Bangladesh
Mohammad Mohsin, Bangladesh
Md. Masud Hossain, Bangladesh
Ferdousi Sultana, Bangladesh
Zainab Akhter, Bangladesh
Md. Abul Hashem, Bangladesh
A.B. Mukhlesur Rahman, Bangladesh
Md. Abdullah Sani, Bangladesh
Munir Ahmed, Bangladesh
Luis Herrera, Bangladesh

Research Management Training Course (RMTC)
Nazira Quraishi Kamal, Bangladesh
Md. Anwarul Islam, Bangladesh
Khairul Alam Billah, Bangladesh
Zahurul Haque, Bangladesh
Nurul Islam Bhuiyan, Bangladesh
Try Meng, Cambodia
Cheng Phan, Cambodia
Samreth Pech, Cambodia
Ouk Phal, Cambodia
Fawzi Naiem Mahrous, Egypt
Viengsavanh Manivong, Laos
Chounthavong Bounliep, Laos
Rakotonirainy, Madagascar
Rakotonjanahary, Madagascar
Austin Suzgo Kunwenda, Malawi
John Ba Maw, Myanmar
Khin Than Nwe, Myanmar
Din Van Cu, Vietnam
Bui Chi Buu, Vietnam

Rice Seed Health Training Course (RSHTC)
A.K.G. Md. Enamul Haque, Bangladesh
Xie Guang Lin, China
Suon Chhim, Cambodia
Myrna dela Cruz, Philippines
Lorelie Agbagala, Philippines
G.M. Chandrasena, Sri Lanka

Special Rice Production Training Course (SRPTC)
Tandin Dorji, Bhutan
C.P. Rai, Bhutan
Nima Weezer, Bhutan
Felix Ntahomvukiye, Burundi
Sothy Hout, Cambodia
Iv Phirun, Cambodia
Visarto Preap, Cambodia
Kim Sereikith, Cambodia
Kuch Kallya, Cambodia
Houl Meng Lee, Cambodia
Moul Phat, Cambodia
Daniel Rabenitary, Madagascar
Alisoa Rachelle Olive Raharison, Madagascar
Soldier Salomon Rahetlah, Madagascar
Dieudonne Rakotomampianina, Madagascar
Thomas Rakotonirina, Madagascar
Andrianasolo Rakotonierana, Madagascar
Arsene Randrianantenaina, Madagascar
Victor Fidele Razanadrakoto, Madagascar
Jose Elysee Solofomampionona, Madagascar
Ignace Lonyaule Stefiarison, Madagascar
U.N. Naw Gyi, Myanmar
U Than Tun, Myanmar

Two-week Rice Production Course (2-wk RP)
Chim Sarin, Cambodia
Sin Sovith, Cambodia
Sok Heng, Cambodia
Jia Feng, China
Zhang Yanging, China
S.S. Rao, India
D.K. Hore, India
Ramanathan Subbiah, India
Gustami, Indonesia
Rahayu Tejasarwana, Indonesia
Anicetus Wihardjaka, Indonesia
Habib Allah Arefi, Iran
Naser Saadati Sheyadeh, Iran
Jong-sik Lee, Korea
Khin Maung Tint, Myanmar
Bharat Mani Adhikari, Nepal
Premchand Bindraban, Netherlands
Abdullahi Isah Gatawa, Nigeria
J.M.P. Bandara Jayasundera, Nigeria
Arlene Baulita, Philippines
Byron Candole, Philippines
Cecilia Depositario, Philippines
Carlos Huelma, Philippines

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Armel Maligaya, Philippines
Arielo Manila, Philippines
Robert Ona, Philippines
Hilary Warburton, UK
David Dawe, Philippines
Reynaldo Padilla, Philippines
Esperidion Sales, Philippines
Redentor A. Natividad, Philippines
Rolando Bugayong, Philippines
Adriano Sapin, Philippines
Jose Mari Valmayor, Philippines
Seree Chaiyapantu, Thailand
Suwat Jearakongman, Thailand
Panjaporn Lertrat, Thailand
Somkiat Wattakawigran, Thailand
Charles Blessley, United Kingdom
Mark B.M. Douthwaite, United Kingdom
DeeAnna Kay Adkins, USA
Nguyen Duc Thuan, Vietnam

Gender Analysis and its Application to Farming Systems Research
Wafiah Akib, Indonesia
Siti Dewi Indrasari, Indonesia
Cahyati Setiani, Indonesia
Emelita Reyes, Philippines
Genevieve Falag-ey, Philippines
Rosalina Velasquez, Philippines
Minda Agarao, Philippines
Rosalinda Balse, Philippines
Nida de Guzman, Philippines
Benjaratna Sawantrat, Thailand
Pachanee Niamsrichand, Thailand
Sukum Khunyean, Thailand
Banjongsak Pakdee, Thailand

Rice Biotechnology Training Course (RBTC)
Md. Safiullah Pathan, Bangladesh
G.J.N. Rao, India
K.G. Bhat, India
Harsh Raman, India
Muhammad Herman, Indonesia
Alberta Ambarwati, Indonesia
K.R. Regmi, Nepal
Emily Corpuz, Philippines
Azra Qureshi, Pakistan
Merennga Hector Mendis, Sri Lanka
Bangamuwage Dharmadas Pathinayake, Sri Lanka
Kingkarn Pitchayakurn, Thailand
Rongrong Visessuwan, Thailand
Doan Thi Binh, Vietnam
Ngo Huu Nhi, Vietnam

Hybrid Rice Seed Production Training Course (HRSP)
Jimmy Abarabar, Philippines
Marie Ablaza, Philippines
Roselyn Argumento, Philippines
Imelda dela Cruz, Philippines
Jesusa Curioso, Philippines
Rogelio Escobar, Philippines
Nancy Gawat, Philippines
Winfred Libunao, Philippines
Eleuterio Ortega, Philippines
Romualdo Ortuste, Philippines
Levan Nha, Vietnam

Systems Analysis and Simulation in Rice Production (SARP)
Md. Aminul Haque, Bangladesh
Md. Musherraf Hussein, Bangladesh
Chen Zhongxiao, China
Ma Jufa, China
Zhu Defeng, China
Wu Yunying, China
Pan Deyun, China
Yan Li Jiao, China
R.N. Dash, India
M.V.R. Murthy, India
P.R. Reddy, India
B. Mishra, India
R.K. Pathak, India
R.A. Singh, India
S. Mohandass, India
V. Narasimhan, India
S. Palanisamy, India
N. Kalra, India
K. Palanisami, India
S. Ramasamy, India
M. Selvarajan, India
Abdul Karim Makarim, Indonesia
Sutoro, Indonesia
Susanto Tirtowirjono, Indonesia
Aan Daradjat, Indonesia
Rahayu Tejasarwana, Indonesia
Md. Norowi Hamid, Malaysia
A. Rajan, Malaysia
Jesusita Orno, Philippines
G.A. Gunatilaka, Sri Lanka
Dalmi Wickremasinghe, Sri Lanka
Sirichai Kanlayanarat, Thailand
Krirk Pannangpeth, Thailand
Weena Mekwattanakarn, Thailand

Courseware development

IRRI-developed courseware documents technical rice-related information in self-learning, multimedia formats. Research has shown that properly designed courseware can enhance learning by 30 to 50% over conventional instruction and can assist in overcoming language problems.

The Training Center is intensifying efforts in producing relevant courseware, especially for more advanced, upstream training courses. Concurrently, we assist the weaker NARS by providing IRRI-developed courseware that can be readily transferred, adapted, and translated, if necessary. IRRI courseware has become an essential component of course development and implementation and an essential entity in collaborative training activities with national systems.

In 1991, 48 courseware titles in multimedia formats were developed and produced for short-term courses in Rice Production (RP), Training and Technology Transfer (T3C), Farming Systems Research (FSR), Systems Analysis and Simulation in Rice Production (SARP), Genetic Evaluation and Utilization (GEU), and general promotion of training. The multimedia formats included 27 print-on-paper, 17 slide/tape modules with accompanying self-learning and test booklets, 1 interactive computer-aided instruction, and 3 video instruction. In addition, 7 courseware titles were in various phases of completion as of 31 Dec 1991 (Table 6).

The Training Center and IRRI's Communication and Publications Services (CPS) jointly initiated development of video instruction on certain rice research and production skills. Video format provides sound, motion, and rich visual experiences to enhance learning. Another collaborative courseware development project was undertaken with the Systems Analysis and Simulation in Rice Production Project (SARP). A 15-module courseware package was developed and produced; it consisted of slide sets, taped narration, and booklets. This courseware package was field-tested in SARP training courses held at IRRI headquarters and in India.

During the year, 37 IRRI-developed courseware were adapted and translated into the Khmer language (Table 7). These training materials were used to support in-country training courses held in Cambodia on Rice Production (RP), Training and Technology Transfer (T3C), and Standard Evaluation System for Rice (SESR).

Table 6. IRRI-developed courseware, Training Center, 1991.

Courseware lines and areas	Titles (no.)	
	Produced	In pipeline as of 31 Dec
Print-on-paper (POP)		
• Objectives manuals		
RP	3	
• Basic skills booklets		
T3C	7	
RP		1
• Guidebooks		
FSR	2	
T3C	2	1
• Brochures		
General (training)	13	
Slide-tape modules (STM)		
T3C	1	1
RP	2	
FSR	4	2
SARP	10	1
Interactive computer-aided instruction (ICAI)		
RP	1	
Video instruction (VI)		
RP	1	
GEU	1[a]	
General (briefing)	1	
Pesticide use (briefing)		1

[a]In U-matic and V-8 format.

Table 7. IRRI-developed courseware adapted or translated into Khmer.

Courseware lines	Titles (no.)
Print-on-paper	
Skills booklet series	
• RP	33
• T3C	1
• SESR	1
Objectives manual	
• RP	1
• T3C	1

Language laboratory and learning resources

The English as a Second Language (ESL) Learning Resources facility began operation in 1991. The facility provides self-learning and tutorial courses to assist IRRI scholars and trainees improve their English proficiency skills. An additional function is to organize and implement technical writing courses to assist scholars in improving their scientific writing skills. Software is being developed to support both activities.

Coupled with this facility, the IRRI English Exam has been developed to screen candidates for IRRI training in research-oriented degree/nondegree programs and short-term group training courses. The IRRI English Exam consists of two parts: Vocabulary and Reading Comprehension, and Listening Comprehension. The exam is administered in-country at least 2 mo before the training program begins. Examination forms are made available to IRRI in-country representative scientists in collaborating NARS.

Collaborative in-country training

IRRI continues to assist in strengthening the training capabilities of NARS through collaborative in-country training activities. Upon request, IRRI assists in organizing and implementing group training programs in collaboration with in-country teams, most of whom are IRRI alumni. IRRI also provides specialists to complement the existing NARS scientists and personnel in conducting in-country training courses. In 1991, Bhutan and Cambodia requested IRRI assistance to establish their own in-country training programs in rice production through a training of trainers approach.

During the year, 347 NARS rice scientists from 8 Asian countries participated in 13 short-term group training courses. These courses focused on integrated pest management, rice production, training and technology transfer, teaching improvement skills, standard evaluation for rice, gender analysis, research data analysis, and computerization of agroeconomic data. Courses were designed, developed, and implemented to address specific training needs of rice scientists in the requesting NARS.

To further strengthen NARS training capabilities, a Collaborative Training Workshop was held at IRRI in October 1991. Invitees were selected participants from key NARS universities and national rice research institutes in China, India, Indonesia, Philippines, and Thailand. Workshop objectives were to identify regional priority training needs and strengths of participating NARS universities/rice research institutions and explore ways to

- enhance collaboration in Ph D degree training, and
- establish an innovative regional rice research training program involving collaboration and division of labor in offering short-term group training courses to international participants.

As a result of the workshop, a generic memorandum of agreement has been prepared to be signed by each participating NARS university or rice research institute and IRRI. Operational guidelines and procedures have been set up for implementing a collaborative Ph D degree program and regional group training course programs and a grant proposal was developed for submission to donors to effect these training activities.

Conclusion

Significant changes in focus and perspective for IRRI's training program were evident in 1991. Two new internationally recruited staff joined the Training Center: the Head and a Training and Courseware Specialist. The management developed and approved an organizational structure and staffing pattern that will allow the Center to accomplish its mandate and objectives indicated in the 5-yr strategic work plan.

During June 1991, an external peer review of IRRI's training program and operations was conducted. The 3-member external review team assessed

- progress, present orientation, and future direction of IRRI's training program;
- linkages between the training program and IRRI research programs, and IRRI scientists' role and responsibilities in training activities;
- the relevance of IRRI training programs in meeting the needs of NARS; and
- subprograms and administrative operations of the Training Center including its organizational chart, staffing pattern, and responsibilities.

The review team generally agreed with the goals and focus of IRRI's training program as outlined in the 5-yr strategic work plan. The team also concurred with the Training Center's planned activities to implement the subprograms degree/postdegree and group training. The team submitted 19 recommendations to IRRI; most of them have been accepted by management for implementation.

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Country and regional projects

During 1991, IRRI continued to work closely with national rice programs in the implementation of country and regional projects. IRRI scientists collaborated with national scientists in 16 countries in South and Southeast Asia, Africa, and Latin America. The activities continue to focus on facilitating and undertaking research to generate and disseminate rice-related knowledge and technology, and strengthening the rice research capacity and capabilities of national agricultural research systems (NARS).

Bangladesh

Continued funding from the U.S. Agency for International Development and the Canadian International Development Agency to the Bangladesh Rice Research Institute (BRRI)-IRRI Rice Research and Training Project enabled the research systems specialist/IRRI representative and the rice farming systems specialist to continue work with the project through December 1991. Support was provided for training, networking, and procurement. In addition, BRRI and IRRI scientists worked together on 13 collaborative research projects funded by IRRI and BRRI.

BRRI scientists started collaborative research in the rainfed lowland rice consortium and on rice - wheat systems. This research complements the Rainfed Rice Research Project that the International Fund for Agricultural Development funds through IRRI. In this project, environmental analysis, varietal improvement, soil-crop management, and rice cropping systems research are carried out in four rainfed rice ecosystems in Bangladesh.

BRRI and IRRI continued to collaborate on deepwater rice (DWR) systems research. The DWR area covers more than 2.8 million ha, only 0.9 million ha of which is planted to DWR. The area has potential as a rich inland fisheries resource since about 80% is submerged from mid-June to November. Where irrigation facilities are not available, a cropping pattern of early season rice (aus) followed by DWR and winter crops (rabi) is a common agricultural practice. In irrigated areas, however, winter rice (boro) is widely planted.

During 1991, the BRRI Rice Farming Systems Division introduced fish culture in DWR fields and in open water where nylon nets were used to develop a pen culture. Thai Sarputi, common carp, and grass carp were very promising, producing as much as 5 t of fish/ha. Performances of Indian carp such as Rohu, Catla, and Mrigal were disappointing. Thai Sarputi and grass carp did equally well in monoculture and polyculture systems; both species can make good use of the natural weed vegetation and azolla that grow in the open water. The trials have drawn the attention of researchers, extension workers, and farmer cooperators.

BRRI and IRRI collaborate on varietal improvement through networking among scientists, exchange of germplasm, and INGER. BRRI scientists conduct varietal improvement research for irrigated winter rice (boro), rainfed upland (direct seeded aus), rainfed or partially irrigated lowland (T. aus), rainfed lowland (T. aman), and deepwater (B. aman) rice ecosystems. During 1991, several advanced breeding lines were proposed to the National Seed Board (NSB) for release as varieties. BR4290-3-3-5 and BR425-189-1-6-2-1-1 were approved by the NSB as BR24 (Rahmat) for direct seeded aus and BR25 (Naya Pajam) for T. aman season.

BR24 is about a meter tall and matures in 100-105 d with a yield of 2.5-3.0 t/ha. Its medium slender grains have good milling recovery and acceptable cooking and eating qualities. BR25 is an improved Pajam (Mahsuri), but grows taller, has earlier maturity and higher grain yield, and is more tolerant of diseases than Pajam.

Three more breeding lines—IR4495-70-2-2-3 for T. aus, and BR850-22-1-4 and BR1725-13-7-1-6 for T. aman—were proposed to the NSB and field evaluation was completed. These lines have additional advantages over the existing varieties as regards yield, disease resistance, and grain quality.

Rice production in Bangladesh has steadily increased, from about 9.5 million metric tons of milled rice in 1971 to 18.3 million metric tons in 1991. A recent study on the economic impact of rice research in Bangladesh showed an estimated marginal productivity of 36.4, which is the average expected return from one unit (taka) increase in research investment.

The BRRI-IRRI farming systems specialist has developed a computer software program called FARMACTION to assist in the analysis of relevant aspects of small farm operations for on-farm research. The software provides a format for systematic collection, storage, analysis, and comparison of data for farming systems research. The software is being used for ex ante analysis of existing farming systems and for developing farm plans for on-farm research within the major rice ecosystems in Bangladesh.

Bhutan

Research in Bhutan focused on rice varietal improvement and improved crop management. IR20913 was recommended as a second crop because it escaped the cold temperature at flowering. Direct seeded rice gave yields comparable with that of transplanted rice and reduced the necessity of raising seedlings under polyethylene tunnels.

Research arrived at the following conclusions. Dhaincha as prerice green manure increased rice yield by about 30%. Chinese milk vetch performed well in high and medium altitudes. Optimum crop establishment periods were identified. Under Wangdi-Punakha conditions, IR64 and local Zakha are best transplanted in June. At medium altitudes, IR20913 and Milyang 54 should be transplanted between mid-June and mid-July; and local Verna, between end-May and end-June. At lower altitudes, Milyang 54 and E18 should be transplanted from end-May to mid-June while IR20913 can be delayed up to early August.

Cambodia

Phase III of the Australian Government (Australian International Development Assistance Bureau)-funded project in Cambodia commenced in July after a 5-yr extension was approved. The initial amount granted was 1.5 million Australian dollars per year, but this is expected to increase in 1992 after an Australian mission reappraises country expenditures.

At the end of 1991, three IRRI staff members (two scientists and one administrative assistant) were stationed in Cambodia. The soil scientist's position has yet to be filled. In addition, the project had a core-funded postdoctoral fellow working on the plant breeding program.

Cambodia was devastated by floodwaters off the mountains of Cambodia and rising water from the Mekong River and Tonle Sap Lake. An estimated 200,000 ha of riceland was destroyed, in addition to damaged properties, research facilities, and research trials. Nevertheless, the Cambodia-IRRI Rice Project was able to pursue several activities (training, infrastructure and equipment development, rice ecosystems analysis, and technology transfer) and to coordinate an extensive research and germplasm conservation program.

Translation and publication of training materials

The project continued to translate and print technical booklets for extension purposes. Ten thousand copies each of nine Skills Development Series booklets were translated into Khmer and printed. *A Farmer's Primer on Growing Rice* (in Khmer) was also reprinted (10,000 copies). In addition, four baseline surveys (200 copies each) and the 1989 Research Report (500 copies) in English were printed for distribution to cooperators. Translated and ready for printing is *Techniques for Field Experiments with Rice* while a technical glossary is being translated.

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Infrastructure and equipment development

Earthwork started at the Cambodian Rice Research and Development Institute site during the first semester, but ceased with the onset of the wet season. Earth moving and compaction will recommence at the beginning of 1992. Funding for major building constructions is being requested from UNDP.

Rice ecosystems analysis

Provincial rice ecosystem maps (1:250,000 scale) and a national map (1:1,000,000 scale) were prepared by the land use consultant during the year. In 1992, the maps will be finalized, printed, and copies distributed to provinces for research, extension, and data collection purposes.

Baseline surveys conducted by the project technology transfer specialist were finalized and printed during the year. They have proven extremely popular among Cambodian and expatriate researchers.

Field research

Many of the research programs were permanently damaged by floods in August and September. However, more than 100 researchers continued to be actively involved in the design, planning, management, and reporting of the research. This hands-on approach and frequent visits by IRRI personnel and senior counterpart staff members have dramatically improved the quality of research conducted in many provinces. The research can be classified under 1) integrated nutrient management, and 2) the varietal improvement program.

Integrated nutrient management. Research conducted during the year revealed that raising the organic matter of the soil would improve rice yields. At the farm level, growing green manure *Sesbania rostrata* before rice increased yields by an average of 40%. Applications of phosphate rock had positive long-term effects on the acid soils of Cambodia. The initial dramatic yield increases after application were tempered over time. However, dry matter yields were 100% higher at 1,200 kg phosphate rock/ha than the control after three seasons. The different elemental requirements on various soils also were further defined through the conduct of inorganic fertilizer experiments.

Difficulties of working in the rainfed lowland environment were encountered with the apparent failure of organic fertilizer in the form of cow manure to increase rice yields. In addition, upland crops in the rainfed lowlands frequently were inundated.

Varietal improvement program. The varietal improvement program included components of germplasm collection and conservation, the development of breeding material, varietal trials, and seed multiplication.

Germplasm collected during 1989 and 1990 was evaluated for 52 characters. The results have been summarized into a catalog that will be finalized early in 1992 when photoperiod sensitivity data have been collected. A duplicate set of the 1,358 varieties stored in the Cambodia-IRRI Rice Project rice genebank was sent to IRGC in Los Baños. A fresh set of 1,600 accessions was collected and, after duplicates were discarded, 373 new varieties were grown for future evaluation.

In addition to 27 F_2 populations, 151 F_1 hybrids (CIR32-CIR182) were grown. Three populations were advanced in Los Baños under rapid generation advance with the help of the deepwater program. An additional 90 F_2 populations of Cambodian DWR were grown at Huntra in Thailand. Two male sterility facilitated composites were created, using the best locally adapted traditional medium- and late-flowering rainfed lowland rices. The genetic male sterility of IR36 is being transferred to late flowering, photoperiod-sensitive varieties to speed up composite breeding, using a modified backcross technique. All 266 breeding lines of an F_6 started at Los Baños were also planted for final selection.

More than 3,000 rice lines were tested in 39 trial designs. For evaluation in 15 provinces, 133 on-station experiment sets and 263 sets of on-farm trials were packaged. The four-tiered trial system including observational yield trials, preliminary yield trials, advanced yield trials, and on-farm adaptive trials addressed the four ecosystems. Eight varieties have been released: early varieties IR66, IR72, and KRU; Don, Khao Tak Petch, and Tewada for the deepwater ecosystem; and Rimke and Sita for the rainfed upland ecosystem. Early varieties that outyield controls by more than 23% under farmer management have been the most successful.

Seed multiplication in Cambodia is still in its infancy. The Cambodia-IRRI Rice Project is the only organization currently producing breeder and foundation seed for multiplication. Included in the program this year are the varieties released by the project in addition to some promising lines. Good

seed production will form an increasingly important part of the project as the breeding program releases improved material.

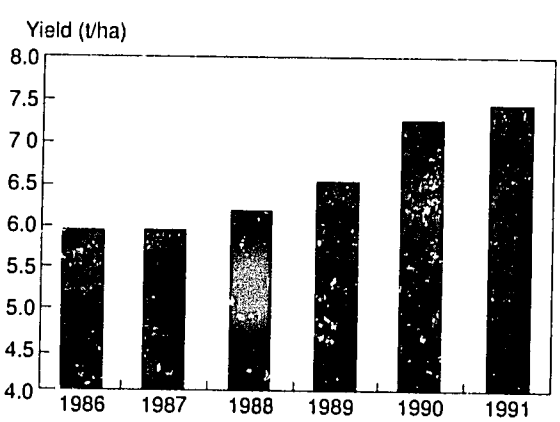
Egypt

Rice production in Egypt followed the trend for record yields. The national average farm yield of 7.31 t/ha in 1991 represents a 35% increase from 1986 (Fig. 1). The yield increase in this very stable, favorable agroclimate is due to multidisciplinary research efforts, and an annual national rice production campaign, under which rice research scientists visit different farms to identify and overcome production constraints. The campaign has resulted in increased farmer acceptance of recommended cultural practices, indicated by a shift toward more recently released, shorter stature, higher yielding, blast-resistant varieties such as GZ175, GZ176, and GZ181. Although these yields are high, they represent only 60% of the 10.5 t/ha average of the technology transfer component's on-farm demonstration.

The Egypt Rice Program works in close collaboration with IRRI through a contract funded by a grant from USAID. The contract was amended to extend through December 1993 and to include an agronomist-program manager, a plant breeder, and a weed scientist from IRRI to act as collaborating scientists.

Research initiatives

In collaboration with IRRI, research on tissue culture started during an Egyptian scientist's postdoctoral fellowship at IRRI was continued. The 2,000 lines developed in Los Baños were planted at Sakha and 66 lines were retained for further evaluation. Currently, IRRI is assisting the Rice Research and Training Center in establishing a tissue culture laboratory with adequate equipment and facilities.



1. Egypt's annual rice yields.

One hundred and twenty introductions from IRRI were planted as potential donors of tolerance for soil salinity, and resistance to blast, or for wide compatibility. Of 70 lines retained for further evaluation, nine with blast resistance and modern plant type were judged particularly suitable for Egypt. Eight originated from Korea—Chulweon 35, IRI 373, IRI 353, Milyang 55, Milyang 60, Suweon 349, Suweon 258, and Suweon 287—while the best indica line is IR5853-198-1-2-1E-P1. They will be tested in the 1992 summer season in Sakha.

The weed science section undertook a farm-level survey of rice weeds and control practices. The survey indicated the most predominant weed species were *Echinochloa crus-galli* (L.) P. Beauv., *Cyperus difformis* L., *Echinochloa colona* L., and *Ammannia baccifera* L. The survey showed an increase in the use of herbicides, particularly with direct seeded rice, and indicated that most farmers applying herbicides would mix the commercial liquid chemical with sand or dust for broadcast application. Granular formulations of the herbicides, if available, would reduce direct contact between the skin and the chemical, and increase the safety of handling them.

Egypt's breeding component participated in six INGER nurseries containing 661 entries. Of that number, 102 lines were selected for further evaluation. Egypt also submitted 10 lines for inclusion in next year's INGER nurseries. IRRI continued to support the program with the winter nursery, which currently has 200 lines.

Eastern, Central, and Southern Africa

A project design document for a proposed collaboration on "Rice Research and Training in the SADCC Region and Neighboring Countries" between the Southern African Center for Cooperation in Agricultural Research (SACCAR) and IRRI was completed. The draft was sent to SACCAR for concurrence before funding from a potential donor is requested.

India

In 1991, the Indian Council of Agricultural Research-IRRI Collaboration, with support from the International Fund for Agricultural Development

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and the Ford Foundation, focused on the analysis of major rice agroecosystems, identification and development of varieties with high and stable yields, comprehensive rice crop management practices for each major environment, and the development of rainfed cropping systems.

Rice ecosystems analysis

Rapid rural appraisal, agroecosystems mapping, and diagnostic surveys were conducted to characterize rice ecosystems. Each site was classified into agroecological zones using maps, charts, and transects. Farmers and scientists together conducted all activities in the environmental analysis.

Upland ecosystem. Two types of uplands are common in eastern India: the Chhotanagpur plateau subecosystem with undulating topography and minimal possibility of water accumulation, and the Ganga and Brahmaputra alluvial plains in Uttar Pradesh and Assam States where water accumulates.

Lowland ecosystem. The rainfed lowland ecosystem is divided into three subecosystems: drought-prone, drought- and submergence-prone, and submergence-prone. Rainfed lowland rice is found in alluvial plains of the Ganga, Brahmaputra, and Mahanadi Rivers where soils become flooded with the onset of the monsoon as a result of slow surface drainage. Submergence at 30-70 cm is related to local rainfall (1,200-2,300 mm) and to flood levels of rivers during June-September. Soil moisture deficits occur most often at the beginning of the season when the monsoon is late.

Deepwater ecosystem. The deepwater ecosystems are represented by river basins, deltas, and low-lying areas prone to waterlogging in the rainy season when flooding varies from 50 cm to more than 2 m. Topography is concave to flat, and flooding that begins in June-July continues until October-February.

Crop management

Farmers in uplands were responsive to the introduction of new genotypes; however, they adopted management packages reluctantly. The farmers of Bihar and eastern Uttar Pradesh adopted pest management methods readily because they perceived that losses due to pest infestation were high.

In the rainfed lowlands, rice crop establishment methods differed widely with rainfall pattern, internal and surface drainage characteristics, and cropping sequence of the sites. Among the various systems, random transplanting and dry seeding are common. In the drought-prone lowlands of Madhya Pradesh, farmers traditionally grow long-duration, tall, and photoperiod-sensitive rice varieties. Broadcasting is followed by *bushening*, a cultivation practice also locally known as *biasi*. A sharp decrease in plant population after biasi is a major constraint to rice productivity. A 2-yr study revealed that broadcast seeding with intense gap filling (improved bushening) increased the grain yield by 15-23% over the traditional method.

On-farm trials demonstrated that rice yields and profitability can be increased with improved crop management practices. Improved bushening through the use of in-field nurseries, improved stand and yields of dry seeded rice, application of inorganic or organic fertilizers, and good weed management increased yields of improved varieties under most conditions.

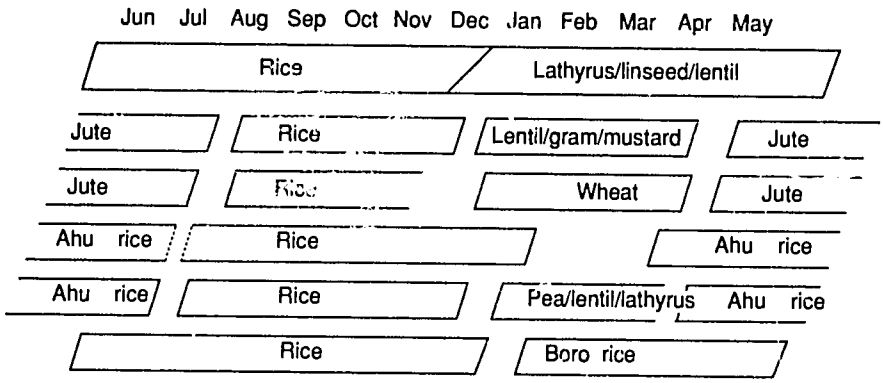
Appropriate tillage, sowing methods, seed rates, dates of sowing, fertilizer management, and crop protection appear to produce fairly high and stable rice yields in deepwater ecosystems.

Cropping systems

Upland areas in eastern India are traditionally monocropped. Rice and millet are the major crops grown during the wet season (June-September/October). In some areas, short-duration cereals, pulses, and oilseed crops are also grown. In Assam, ahu rice is grown during March-June. Fields left fallow after ahu rice (July-October) are planted with a rabi crop, usually toria, in November.

In the upland rice areas of Bihar, farmers follow a well-defined 4-yr crop rotation of pulses, upland rice, minor millet, and fallow. Intercropping had apparent advantages in enabling the farmers to grow an additional crop at economic levels without much added input. Intercropping also reduces the risk of total loss if the rice crop fails in a severe drought year.

Farmers' cropping systems in the rainfed lowland ecosystem depend on local rainfall and hydrology. Among them, rice - lathyrus/linseed, rice - lentil/gram/mustard, rice - wheat, jute - rice - wheat, rice - rice (boro), and rice (ahu) - rice are practiced widely (Fig. 2). The choice of different rice-based cropping systems in the rainfed lowland usually depends on the time of recession of floodwater, soil type, topography, and resourcefulness of the farmers. In Chin-



2. Some common farmers' cropping patterns in eastern India.

surah and Kendrapara, a three-crop system involving jute - rice - wheat or lentil gave the best returns. In Assam, Bihar, Uttar Pradesh, and Madhya Pradesh, two-crop sequences of rice - lentil, rice - gram, rice - mustard, and rice - pea increased profits.

Considerable progress has been made in identifying new rice genotypes and cropping patterns that are more remunerative than farmers' current practice. There is a need to further strengthen on-farm testing of suitable crops and improved varieties, e.g., wilt-resistant chickpea and low-toxin lathyrus, from national and international research programs.

Lao PDR

More than 98% of the cultivated rice area in the Lao PDR is under rainfed conditions (59% rainfed lowlands and 39% rainfed uplands). Total annual production of approximately 1.4 million t is usually sufficient to meet local needs only. Unseasonal dry conditions and, to a lesser extent, flooding can often result in severe rice deficits, particularly on a local area basis. The current national policy relating to rice production in the Lao PDR has two major components: improved rice production to ensure self-sufficiency, with emphasis on increasing the productivity of areas of rainfed lowland cultivation; and stabilization of areas of rainfed upland rice production. Important in implementing these policies has been the relatively recent movement away from a centrally planned economy and toward a market-based economy.

Research network development

The Lao PDR-IRRI Project is supported by the Swiss Development Cooperation. In its first year of operations, the project focused on establishing a network of rice research stations and sites, and a network of personnel. In 1991, this network encompassed 7 of the 17 provinces in the country. The network will be expanded to include three more provinces during 1992. However, not all research disciplines are currently represented in the network activities because there are staffing constraints.

Rainfed lowland research

During the 1991 wet season, a program of on-farm and on-station research was initiated in the three provinces with the largest areas of rainfed lowland rice production (Vientiane municipality, Savannakhet, and Champassak). The program reflected the regional priorities of identifying improved rice varieties and developing specific fertilizer recommendations for the major soil types. A benchmark agroeconomic survey was undertaken in selected villages of Savannakhet Province to measure the impact of improvements in rice production technology in the longer term. The average per capita annual cash income in the villages surveyed was about US$50; only 40% of households surveyed were producing sufficient rice for more than 6 mo consumption, highlighting the critical shortage of rice production in many areas.

Rainfed upland research

A northern regional research base for the national rice research program was established under the project in the former royal capital of Luang Prabang.

This center will serve to coordinate research activities in provinces just south of the Vietnamese and Chinese borders, where more than 70% of the areas of rainfed upland rice cultivation are to be found. A program of seed collection has been initiated throughout this area to evaluate and preserve the diverse genepool of local rice varieties that exists; almost 100% of the upland varieties used are traditional. At a small research center, which the project is developing in Luang Prabang Province, studies initiated in the 1991 wet season started to examine the range of factors that affect both the productivity and stability of production in the rainfed upland areas. Relatively poor accessibility will limit the number of provinces that can be incorporated in the upland research program network.

Cooperative research links

Collaborative research links have been established between the national rice research program, and other national and international research agencies. A joint research program had been developed with the Australian Centre for International Agricultural Research to examine ways of improving the productivity of rainfed lowland rice in drought-prone areas of the Lao PDR. Participation in the International Network on Soil Fertility and Sustainable Rice Farming and the Asian Rice Farming Systems Network has also been initiated.

Training

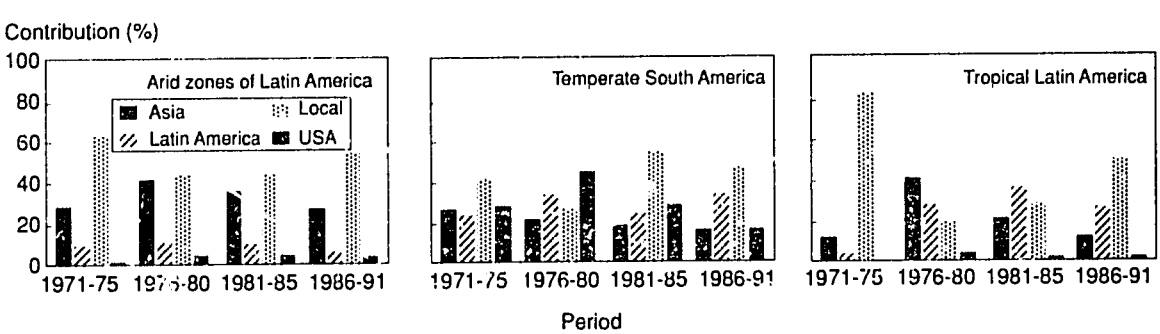
To enable rice research staff to benefit from training available through IRRI in the Philippines, and to be able to participate in international conferences and meetings, efforts were geared toward improving the English language proficiency of all the senior Lao staff in the national rice research program. The similarity between the languages of Thailand and the Lao PDR enables IRRI to sponsor training programs for Lao scientists in Thailand and to invite IRRI-trained scientists in Thailand to conduct training courses in the Lao PDR.

Latin America

The rice crosses made for the irrigated and favored upland environments by 10 Latin American programs during 1971-90 were used to evaluate the way different rice germplasm sources are combined to develop rice cultivars in Latin America. Seventy rice cultivars released by the 10 programs were classified by year of release and region of origin and used to assess the effectiveness of breeding programs.

The number of parents used in the crossing programs and their contribution according to origin are summarized in Figure 3. The materials generated by the local programs gave the largest number of parents and genetic contribution, with the maximum average participation observed in the arid zones. The second most important germplasm source varied according to the environment; IRRI was the most important source for the arid zones, other Latin American programs for tropical Latin America, and USA for the southern zone. In the last two environments, the two respective sources indicated were even more important than local materials during 1976-80.

Additional evidence suggesting a concentration on a limited number of parents for varietal development comes from our estimations of the contribution to the genetic constitution of the populations from the top 5% of the parents used in crosses (Fig. 4). It appears that 5% of the parents contributed at least 25% of the genes from 1971-90. The percentage has steadily increased for the arid zones, reaching nearly 50% during 1986-90. This might indicate that, al-



3. Origin and contribution of parents used in rice crossing programs in Latin America.

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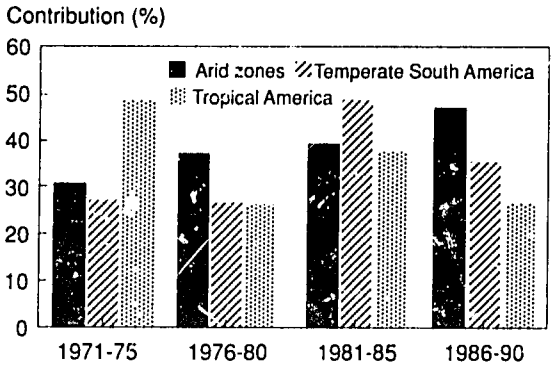
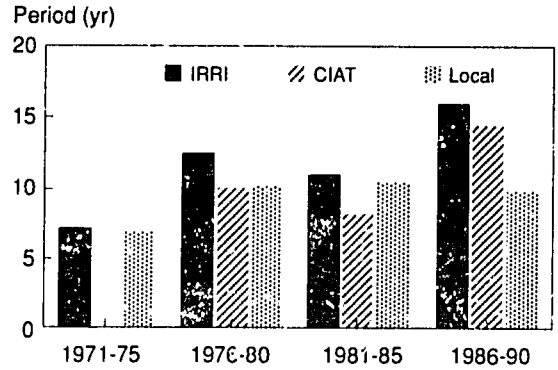


4. Total contribution of the top 5% of the parents used in crossing programs in Latin America, 1971-90.



5. Number of years from cross to varietal release in Latin America according to origin of population, 1971-90.

though the number of parents per cross is the highest for this environment, dependence on the basic genetic core for further improvements is now higher.

The most popular rice varieties in the countries studied tended to be at least 10 yr old, and some were as old as 20 yr. Although varieties reportedly have major weaknesses in the form of susceptibilities to diseases, farmers seem willing to manage them with nongenetic means as long as their yield potential is high. The interest in stress resistance has been suggested as a possible cause for the yield plateau observed.

Surprisingly, the sharpest increase in time from cross to varietal release has been observed in materials introduced from international centers (Fig. 5). It has been suggested that current breeding efforts are working around the IR8 paradigm, which seems to have exhausted its yield improvement potential. A new approach to varietal improvement is needed if further yield increases are to be realized. IRRI is assessing new plant types with potential for initiating a new era in rice breeding.

Madagascar

Rice, the principal food crop of Madagascar, is cultivated on about 1.2 million ha in diverse environments. Technical constraints to rice production include low temperature in the highlands, poor water control, pests, diseases such as blast (*Pyricularia oryzae*) and fungal sheath rot (*Sarocladium oryzae*), and adverse soil conditions including P deficiency and Fe toxicity. Socioeconomic constraints (poor resource base, low food prices, high input costs, poor road infrastructure, and transport) add to the technical problems. With financing from USAID, the Madagascar-IRRI Project has been working with FOFIFA (National Center of Applied Research for Rural Development) since 1984 to improve national rice research capability, and to develop and diffuse improved rice production technologies. Salient research findings of this project in 1991 are discussed below.

Improved rice varieties for the high plateau

The High Plateau accounts for 20% of all wetland rice and is the largest rice-growing region in Madagascar. Rice, grown from 800 m to 1,800 m above sea level, is cultivated in valleys, floodplains, and in bunded ricefields on terraced slopes. Fields are generally rainfed and depend on seepage water from adjoining hills.

To identify varieties suitable for the High Plateau, introduced varieties and local materials were evaluated for cold tolerance, resistance to major diseases, and overall agronomic potential. Screening for Fe toxicity was done in a well-known Fe-toxic field in Manjakandriana (about 60 km from Antananarivo); screening for P deficiency was done at the FOFIFA Rice Research Station at Mahitsy. Tolerance for Fe toxicity was observed from visual symptoms that include leaf discoloration (bronzing), reduced tillering, and growth or death of plants. For P-deficiency tolerance, growth and tillering were compared in test materials grown in P-deficient soils with and without added P.

From 500 varieties and lines tested, 27 were found agronomically desirable and were tolerant of Fe toxicity. Seventeen entries were tolerant of P

deficiency. The most promising varieties, identified as tolerant of Fe toxicity and P deficiency, were NR10073-167-3-1-1 from Nepal, IR15579-24-2 and IR15579-135-3 from IRRI, and the local selection Latsika 112-1. The three introduced lines were originally entries in the International Rice Cold Tolerance Nursery. Several years of on-station and on-farm testing confirmed the good performance of IR15579-24-2 and IR15579-135-3 which are also early maturing, high yielding, and resistant to major diseases in the High Plateau. The two lines are now under extensive farmers' participatory trials before they are released as varieties. Grain yield and other characteristics are shown in Table 1.

Efficiency of phosphorus root dip for rice in problem soils

P and N are the major nutrients limiting rice production in many soils of the High Plateau, which have low native P and high P fixation. P deficiency is coupled with low available K in Fe-toxic soils, and S and Zn deficiencies in isolated areas. Early research, conducted from the 1940s to the 1960s, used high P levels (100-300 kg/ha) to alleviate P deficiency. With increasing fertilizer costs and low rice prices, Malagasy farmers cannot afford high levels of input for rice production. Therefore, it is imperative to develop cost-effective fertilization methods that will improve nutrient use efficiency and increase farmers' profits.

An efficient method of P fertilization developed by the project involves coating rice roots with a phosphate-soil slurry. This method is called P root dipping. One part P fertilizer is dissolved in two parts water. Two parts red or clayey soil are added to the fertilizer solution to make a thin paste or slurry. Roots of rice seedlings are washed and the seedlings are placed on bunds to dry. The roots are then dipped in the slurry to thoroughly coat them.

This method concentrates the fertilizer P near the roots, minimizes P absorption by the soil, and thus increases P use efficiency. At an application rate of 13 kg P/ha, root dipping was found to be consistently superior to broadcast P (Table 2). To produce an equivalent grain yield by broadcasting, twice the amount (26 kg/ha) of P was required. In Fe-toxic soils, root dipping was observed to improve P uptake and reduce the severity of Fe toxicity.

Soluble P fertilizers (triple superphosphate or dicalcium phosphate) are ideal in making the slurry. When simple P fertilizers are not available, compound fertilizers (15-15-15 or 11-22-16) can be used at low P rates (about 8 kg/ha). However, higher concentrations of soluble N and K may scorch roots and kill the seedlings.

Rice yellow mottle virus

A survey of virus-like diseases in the central high plateau of Madagascar (Fianarantsoa and Antananarivo) confirmed the presence of a rice virus disease. Enzyme-linked immunosorbent assay and mechanical transmission tests were conducted to identify the causal agent. Pieces of infected samples were fixed in glutaraldehyde and brought to IRRI for electron microscopy.

All of the results indicate that the yellowing disease of rice in Madagascar is caused by rice yellow mottle virus. The disease was observed in locations where it has not been previously reported, which indicates that it is widespread in Madagascar.

Myanmar

IRRI-Agricultural Research Institute (ARI) collaborative research includes those of INSURF, INGER, ARFSN, rice germplasm collection, and Myanmar-IRRI Farming Systems (MIFS) Project. IDRC is supporting the following components of the MIFS

Table 1. Grain yield and other characteristics of IR15579-24-2 and IR15579-135-3.

Selection	Grain yield[a] (t/ha)	Plant height (cm)	Maturity[b] (d)			Tillers[c] (no./hill)	Spikelet fertility (%)	1000-grain wt (g)
			Early	Intermediate	Main crop			
IR15579-24-2	5.6	110	140	130	130	7	89	27
IR15579-135-3	5.4	100	145	130	130	6	90	24

[a]Mean of 6 trials from 1987 to 1990. [b]From transplanting to maturity. Planting seasons in the High Plateau are early (Vary Aloha): seeding Apr-May, transplanting Aug-Sep; intermediate (Siha): seeding Jun-Aug, transplanting Sep-Nov; main crop (Vakiambiaty): seeding Oct-Nov, transplanting Dec-Jan. [c]Spacing 20 × 20 cm.

Table 2. Rice yield response to methods and rates of P application in a P-deficient and Fe-toxic soil at Sambaina, Manjakandriana, Madagascar, 1985-89.

NPK[a] (kg/ha)	P application method	Grain yield (t/ha)				
		1985-86	1986-87	1987-88	1988-89	Mean
0-0-0	-	2.5 d	0.8 c	0.9 c	1.1 d	1.4
60-0-50	-	3.7 c	0.8 c	1.1 c	1.6 c	1.8
60-13-50	Broadcast	3.9 bc	1.3 b	2.3 b	2.2 b	2.4
60-13-50	Root-dip	4.2 ab	2.0 a	3.0 a	2.6 a	3.0
60-26-50	Broadcast	4.4 a	1.4 b	2.4 b	2.2 b	2.6

[a]N as urea, P as triple superphosphate, and K as KCl.

Project: 1) research on rice-based cropping patterns, varietal improvement of crops in rice farming systems, and development of implements for rice farming; and 2) manpower development through degree and nondegree training and participation of Myanmar agricultural scientists in scientific conferences and international meetings.

Site characterization

A diagnostic survey was conducted in six new rice farming system sites in Myanmar to understand favorable rainfed lowland (Taikkyi and Hlegu), deepwater (Danubyu and Thanatpin), and upland (Aungban, Kyaukme, and Kyaingetung) rice ecosystems and associated farmers' practices and technical knowledge. Other objectives were to identify and prioritize causes of low rice yields, and to identify appropriate research to address such problems. Problems in the rainfed lowland included lack of labor for transplanting, lack of fertilizer, and excess water in lower areas. Farmers who wet seeded rice faced problems of insect pests, poor crop establishment, flooding, and weeds in upper fields. DWR problems were unfavorable water conditions, weeds (wild rice), soil physical problems, and pests (stem borer, crabs). Farmers fallowed or switched to late-season transplanted rice as a solution to rapid onset of rains, stem borer, and wild rice infestations. Upland rice problems included weeds, low soil fertility, insects, drought, soil erosion, and poor crop establishment in some areas. A new rice variety has to meet farmers' requirements and growing conditions.

Farmers' evaluations and new selections (FENS)

No new rice selections were released for 1991, but the following were found promising based on the 1990 FENS tests; YN83-8, IR24410-RRYN6, YN114-7, and YN257-4 for lowland ecosystems; IR13146-45-1 and IR29109-RR-36-2-2 for rainfed lowland; YN92-17 for upland; and YN32-8 for saline areas. Most of these were from INGER trials. For 1991, 29 INGER nurseries were distributed in 13 sites in Myanmar.

Table 3. On-farm cropping pattern trial involving sesbania green manure at Pyinmana, Myanmar, 1991-92.

Cropping pattern[a]	Rice yield (t/ha)
TPR - cowpea	3.7
Peanut - TPR	4.4
Sesbania - TPR	5.7
TPR with urea[b]	4.1

[a]TPR = transplanted rice. [b]57 kg N/ha.

Rice germplasm collection

The second wild rice collection mission was jointly undertaken by ARI and IRRI scientists on 24 Nov-12 Dec 1991. Ninety-one samples were collected from Bago, Ayeyarwaddy, Magway, and Mandalay Divisions and Shan State; there were 44 *O. sativa*, 11 *O. nivara*, 5 *O. rufipogon*, 17 *O. spontanea*, 11 *O. officinalis*, and 3 *O. granulata*. This is the first time *O. granulata* was collected in Myanmar. Comprehensive sets of traditional varieties were collected in Aungban and Kyaukme of Shan State.

Green manure program

Sesbania rostrata was considered the best among several green manure legumes tested earlier as N source for lowland rice. In Pyinmana on-farm trials, rice yield was 5.7 t/ha in a cropping pattern with sesbania seeded at 15 kg/ha and incorporated 60 d after emergence. This was the highest yield obtained from the patterns tested. Related studies showed that optimum seed rate was 25 kg/ha and the best cultiva-

tion method was one plowing and one harrowing before broadcasting the sesbania seeds before the monsoon. Premonsoon sowing of sesbania seeds without tillage overcame land preparation problems and corrected poor green manure stand usually caused by heavy rain immediately after sowing. Soaking seeds in recently boiled water for 5 min corrected seed dormancy and increased germination from 17% to 52%. Sesbania was also propagated by stem cuttings for on-farm seed increase.

CONSUMERS' RICE GRAIN QUALITY PREFERENCE
Consumers' grain quality preferences in five domestic markets were estimated. Rice retail price was treated as the dependent variable and percent broken, length:width ratio, elongation ratio, amylose content, protein content, shape, gelatinization temperature, gel consistency, and alkali digestion as independent variables. Multiple correlation analysis of these parameters indicated that the variability of rice retail price was influenced negatively by percent broken rice, grain length:width ratio, protein content, and shape, and positively by cooking elongation ratio to a level of 59%. In Myanmar, the most popular rice is Pathein Nga Kywe, which has bold grains but a very high elongation ratio when cooked.

Sri Lanka

Cooperation in research and training between IRRI and the Department of Agriculture, Sri Lanka (DOASL), continued in 1991 with financial assistance from the Swedish Agency for Research Cooperation with Developing Countries (SAREC).

Germplasm conservation activities were completed, and evaluation of the collection begun. IRRI provided necessary materials and information to aid DOASL in the management of rice genetic resources.

DOASL identified six elite lines for seed multiplication and release. These varieties will cater to the needs of some specific rice-growing environments in Sri Lanka.

Collaboration with IRRI resulted in the identification of appropriate lines for a hybrid rice development program and advanced lines with tolerance for Fe toxicity. DOASL contributed 21 advanced lines for inclusion in specific irrigated and rainfed lowland nurseries of INGER.

IRRI continued to assist DOASL in identifying varieties tolerant of tungro virus disease for use in the hybridization program. Long-term collaborative experiments to study the effects of crop residues on fungal disease were established. A comprehensive review of IRRI-DOASL collaboration for 1989-91 was undertaken in December 1991.

Socioeconomic investigations revealed that bridging the gap between actual and potential rice yields should receive major research attention.

Vietnam

Research under phase 3 of Vietnam-IRRI collaboration focused on integrated nutrient management, integrated pest management, and improved water management. Research results on the integrated use of urea and farmyard manure (FYM) indicated that the latter affected the optimal timing for the first urea application. In the absence of FYM, rice yields for the early and delayed split were similar; but with application of FYM, the delayed split increased yield by 10%.

Other NARS-IRRI collaboration

BRUNEI DARUSSALAM
Only about 4% of the rice needs of Brunei Darussalam is produced in the country. Based on average figures reported between 1985 and 1989, the land area harvested was 1,116 ha and production was 1,436 t of unhusked rice; thus, the average yield during the same period was only 1.3 t/ha. The total rice requirement is 21,165 t husked rice/yr.

The Government of Brunei Darussalam aims to produce at least 15% of its rice needs. To meet this demand without expanding the rice area means that the current yield of 1.3 t/ha must be increased to 4.2 t/ha.

The Kilanas Agricultural Research Center of the Department of Agriculture of Brunei Darussalam is involved in testing rice varieties or lines introduced from IRRI and elsewhere and in developing appropriate agronomic management practices like pest control. During the year, IR841 was released as a variety because of its good eating quality and high yield (av 4.0 t/ha). However, IR841 was observed to be somewhat sensitive to Fe toxicity, which is an important soil problem in most of the rice-growing areas of the country.

Indonesia

Because of the severe drought in Indonesia, rice production in 1991 is forecast to decline by 2.3% from that of 1990; production is expected to be 44 million t of unhusked rice, compared with 45 million t in 1990. As a consequence, the government is importing 600,000 t of rice, the first time since 1984. The government is also encouraging the participation of large business conglomerates in developing new ricefields on the other islands to offset the loss of ricefields to industrial and housing estates, which is one of the reasons why rice production has stagnated.

Early in the year, the biennial Agency for Agricultural Research and Development (AARD)-IRRI Collaborative Research Planning Meeting was held in Bogor. Ten projects were reported completed. The group agreed to continue 12 on-going collaborative projects in addition to 10 new projects. Activities under the four international networks—ARFSN, INGER, IPMN, and INSURF—coordinated by IRRI also continued.

Collaborative research activities focused on biological control of rice diseases; data management for on-farm trials; characterization of *Pyricularia grisea*; soil fertility and fertilizer management in rainfed lowland and upland rice, rainwater conservation and utilization, breeding rice for and development of appropriate amelioration techniques for problem soils, integrated pest management focusing on rice stem borer, nematode studies in upland rice systems, machinery development and testing, and genetic mapping of javanica-type rice cultivars. Under the international networks, AARD continued to conduct several INGER nurseries such as IIRYN-E, IRRYN-M, IIRON-VE/E, IURON-E, IURON-M, IRLON-E, ITRON, IRCTN, IRDTN, IRSSTON, IRBN, IRBBN, IRTN, and IRBPHN. AARD, on the other hand, contributed Indonesian-developed cultivars to the various international nurseries such as IRBPHN, IRBBN, IRBN and IRSSTON. For the ARFSN, AARD continued research on rice-fish farming systems, impact of rice-fish system, and women's role in agriculture. INSURF activities included integrated nutrient management in rainfed lowland and upland rice and long-term soil fertility trials in irrigated and rainfed lowland rice. AARD and IRRI also continued to jointly undertake the following activities: germplasm conservation and dissemination; exchange of germplasm for varietal improvement of irrigated, rainfed, upland, and deepwater rice; and exchange of germplasm and information for hybrid rice development.

Research activities under the Rainfed Lowland and Upland Rice Research Consortia were started during the year. The two major research activities in the Upland Rice Consortium are soil fertility management with four sub-activities, and upland rice-based farming system with four sub-activities. The consortium key site for upland rice is in Sitiung, West Sumatra. For the Rainfed Lowland Rice Consortium, five activities are being undertaken: drought alleviation by rainwater collection and conservation, screening breeding materials for drought tolerance, potassium transformation in rice-based cropping systems, alternative means of weed control and their benefits in *gogo rancah* and *walik jerami* rices, and nitrogen dynamics and nitrogen use efficiency.

An IRRI research fellow in Soils/Agronomy has been stationed in Sitiung since late 1990 and is assisting in carrying out the core-funded collaborative activities on upland rice in Sitiung with focus on enhancing the productivity of newly opened areas and ameliorating abandoned acid upland soils grown to rice.

The Indonesia Minister of Agriculture released eight new rice varieties; three are IRRI-bred IR19661-131-1-3-1-3 (Barumun), IR11288-B-B-69-1 (Sei Lilin), and IR32453-20-3-2-2-M-1 (IR74). Two azolla strains (Acc. nos. 4074 and 4138), both *A. microphylla*, were growing vigorously at many sites. Because of their wide adaptability, they will be included in the rice-fish system as supplementary feed for the fish.

An important activity in IRRI's country programs is the visit of IRRI internationally recruited staff (IRS) or nationally recruited staff (NRS) to discuss and implement joint activities with their colleagues in the national research systems and the attendance of NARS scientists in IRRI-sponsored conferences, workshops, symposia, and training. Twenty-five IRRI IRS and seven NRS, one research fellow, and seven affiliated research staff visited Indonesia and spent 386 d in the country. On the other hand, 29 Indonesian scientists were invited to 24 IRRI-sponsored workshops, conferences, and symposia, and 30 Indonesian junior researchers participated in short-term formal and informal training sessions at IRRI headquarters.

Malaysia

As of 1988-89, the average yield of rice in Peninsular Malaysia was 3.4 t/ha (unhusked rice); that for the entire country is 2.8 t/ha. The Government of Malaysia maintains its policy of producing rice at 60% self-sufficiency level. Despite this policy, however, the need to increase rice yields is imperative, especially if the present land area devoted to rice is not expanded. Because cost of production is increasing, rice farmers are encouraged to mechanize land preparation and harvesting and to adopt direct seeding.

Collaboration with the Rice Research Center of the Malaysian Agricultural Research and Development Institute (MARDI) is continuing in the following areas: biological control of pests and diseases, hybrid rice development, and management of direct seeded rice. Likewise, MARDI is actively participating in the international networks INGER, INSURF, and IPMN. Ten MARDI scientists were invited to participate in IRRI-sponsored workshops, conferences, and symposia. In 1991, MARDI released two new rice varieties, MR123 and MR127.

The assistance extended to the Departments of Agriculture in the two eastern states of Sarawak and Sabah is the exchange of germplasm and information and visits by IRRI IRS. Promising IRRI lines were sent to the research centers of the two states. Sabah released one of the IRRI lines (IR8192) as a variety and named it Lumayan.

Thailand

Collaboration with Thailand continues through departments and institutes of the Ministry of Agriculture and Agricultural Cooperatives. To mark the 30th anniversary of collaboration between Thailand and IRRI, a symposium was held, the theme of which was the role of IRRI in strengthening rice research in Asia—achievements from the past and collaboration for the future.

H.R.H. Princess Maha Chakri Sirindhorn of Thailand visited IRRI headquarters in the Philippines on 29 Aug 1991. During her visit, Thailand and IRRI signed a Memorandum of Understanding to establish a new joint research and training program in DWR. As a result, a major part of IRRI's DWR breeding program will be transferred to Thailand. Thai and IRRI researchers will jointly develop and distribute plant breeding materials and the associated technology for improved DWR production in Southeast Asia. The new plant breeding activities join other IRRI core DWR research that has been based in Thailand for many years.

The IRRI DWR agronomy project continued collaborative research activities with the Prachinburi Rice Research Center and Huntra Experiment Station. Research focuses on cropping systems, herbage production, rice-fish culture, and fertilizer response of DWR. Other research studied new methods for assessing the elongation capacity of DWR varieties, N transformation in the dry and flooded phases of DWR soils, leaf canopy development as a measure of productivity, and long-term effects of P application.

The two final issues of the newsletter *Deepwater and Tidal Wetlands Rice* were published by the IRRI Bangkok office. Future research reports on these crops will be in the *International Rice Research Newsletter*.

Two rice research consortia sites commenced collaborative research activities in 1991. The Rainfed Lowland Rice Consortium site at Ubon Rachatani conducted research on integrated nutrient management and soil fertility, soil physics, and management practices to improve effectiveness of rainfall, P placement, weed ecology, and evaluation of rice varieties. Two Thai IRRI research assistants are employed at the site to work with an IRRI visiting scientist on physical aspects of soil productivity.

An Upland Rice Consortium site was established at Samoeng in the northern highlands with responsibility for research on upland rice management for sustainable production on steep lands, intercropping legume and nonlegume crops, and soil fertility studies.

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Research support services

Analytical service laboratories

The Analytical Service Laboratories (ASL) comprise four units—the Chemical Analysis Laboratory, the Mass Spectrometry and Radioisotope Laboratories (added in 1981), and the Pesticide Residue Laboratory (transferred to ASL in 1991). The laboratories continued to provide analytical services and special laboratory facilities to IRRI programs.

Analytical services. In 1991, the laboratories completed more than 76,000 analyses, ranging from pH to mass spectrometric ^{15}N determinations. Material for analysis came from the research and international programs and special projects (Table 1).

Other services. Nonanalytical support services were also provided for radiotracer users in the following activities:

- assay of soluble starch synthase (^{14}C);
- research on seed and embryo vigor (^{14}C);
- tagging the segregation of bacterial blight (BB) *xa-5* and *xa-8* resistance genes using restriction fragment length polymorphism (RFLP) on F_2 populations from crosses between IR24 and BB isolines (^{32}P);
- RFLP evaluation of a representative world collection from the conserved rice germplasm (^{32}P);
- salt tolerance gene tagging in *Oryza sativa* by RFLP (^{32}P);
- study of polymorphism for heterosis survey in rice varieties using RFLPs (^{32}P);
- tagging the wide compatibility genes (S-5) in *Oryza sativa* using RFLPs (^{32}P);
- DNA fingerprinting of Azolla section Rhizosperma (^{32}P);
- RFLP mapping of doubled haploid population derived from a Azucena/IR64 cross (^{32}P);
- survey of polymorphism among possible parents of a drought-tolerant population (^{32}P);
- tagging and mapping of genes for resistance to blast and BB (^{32}P).
- effect of *Rhizoctonia solani* levels and N concentration on the growth, photosynthesis rate, translocation process, and yield of IR72 grown in the greenhouse (^{14}C);
- evaluation of the uptake and utilization of organic and inorganic C in rice (^{14}C);
- assay for 1-aminocyclopropane-carboxylic acid (^{14}C);

Table 1. Analyses completed in 1991.

Analyses	Determinations[a] (no.)							
	IR	RL	UR	DT	CE	NT	Special projects	Total
Soil and plant analyses	15,258	12,369	6,191	904	2,637	16,558	16,414	70,331
^{15}N determination	204	3,011					462	3,677
Radioactivity counting	128	16			105	166	112	527
Pesticide residue and organic analyses	416					733	604	1,753
Total	16,006	15,396	6,191	904	2,742	17,457	17,592	76,288

[a]IR = Irrigated Rice Ecosystem, RL = Rainfed Lowland Rice Ecosystem, UR = Upland Rice Ecosystem, DT = Deepwater and Tidal Wetlands Rice Ecosystem, CE = Cross-Ecosystems Research, and NT = Networks.

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- effect of tubificids on the decomposition of ^{14}C-labeled organic material under submerged greenhouse condition (^{14}C);
- P depletion in soil near growing rice roots (^{33}P); and
- Southern blot analysis of transgenic IR58 (^{32}P).

Monitoring IRRI waterways. Since 1984, the Pesticide Residue Laboratory has been monitoring the waterways that flow through the IRRI Central Research Farm. From the initial sampling protocol of a grab sample from two outfall sites, the project was expanded in 1986 to five sampling times per day for 3-4 d at 12 sites. In 1991, the activities decreased to two 24-h samples from each of six outfall sites and two irrigation sources for 3 d during peak spraying periods in the dry and wet seasons (Fig. 1). The samples were analyzed for eight pesticides used by IRRI researchers: isoprocarb, BPMC, carbofuran, diazinon, chlorpyrifos, butachlor, monocrotophos, and carbaryl. Organochlorines are not used at IRRI.

IRRI waterways ultimately empty into Laguna de Bay. The maximum allowable limit for synthetic organic chemicals is 500 ppb for Class C waters, the category under which Laguna de Bay is classified. Although no information is available on limits of the abovementioned pesticides under tropical conditions, the maximum allowable concentration can be estimated from lethal concentration (LC_{50}) values. LC_{50} is the concentration which kills 50% of test organisms exposed for 96 h. Table 2 shows the peak readings at IRRI and the maximum allowable concentration derived (MAC) from LC_{50} values. Although peak values are sometimes higher than MACs, there is no cause for concern because the mean total pesticide levels for the six outfalls sampled throughout the monitoring period were less than 1 ppb (Table 3) and do not present a danger to the environment.

Table 2. Observed peak residue values and estimated maximum allowable concentrations (MAC).

Pesticide	Maximum reading[a] (ppb)	MAC[b] (ppb)
BPMC	3.8	25.2
MIPC	2.1	0.8
Carbofuran	0.6	0.8
Diazinon[c]	1.1	3.0
Chlorpyrifos[c]	0.4	0.14
Butachlor	0.4	0.6
Monocrotophos[c]	nil	6.1
Carbaryl	nil	24.0
Acephate	nil	100.0

[a]Taken from data covering 1988 dry season to 1991 wet season.
[b]Calculated as follows:
$MAC = LC_{50}/5^* \times 0.01$
For organophosphates: $MAC = LC_{50}/8.5^* \times 0.01$
* = factor for temperature correction.
[c]Organophosphates.

Central research farm

The Central Research Farm (CRF) observed closed season from 15 May to 1 July and 1 November to 15 December, primarily to reduce pest and disease outbreaks.

During 1991, we achieved simultaneous land preparation of experimental plots for the first time.

Culverts have been installed in 90% of the main and drainage canals in the old and new lowland areas. The installation will eliminate rat breeding grounds and minimize breeding areas of golden snails.

Table 3. Mean total pesticides found in six outfalls and two irrigation water sources.

Sampling site	1984 Dec	1985 Jan	Mean total level (ppb)											
			1986		1987		1988		1989[a]		1990		1991	
			DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS
1	1.5	0.5	0.8	1.00	1.20	0.9	1.2	2.7	1.4	2.0	0.8	0.08	0.70	0.02
3	-	-	0.3	0.05	0.30	0.2	0.2	0.9	0.07	0.3	0.004	0.04	0.20	0.06
4	-	-	0.3	0.10	0.20	0.2	0.9	0.1	n.d.	0.2	0.2	0.50	0.10	0.03
8	-	-	0.5	0.20	0.10	0.3	0.3	0.3	n.d.	0.2	0.2	0.06	0.20	0.30
10	-	0.2	0.4	0.20	0.04	0.2	0.3	-	2.0	0.3	0.7	0.20	0.08	0.02
12	-	-	0.3	0.08	0.10	0.3	0.4	-	2.5	0.8	0.3	0.10	0.90	0.03
6[b]	-	-	-	-	-	-	-	-	-	-	-	-	0.10	0.01
9[c]	-	-	-	-	-	-	-	-	-	-	-	-	0.08	0.03

[a]n.d. = not detectable by the analytical procedure used. [b]The reservoir at Block K. [c]The entry point of the National Irrigation Administration canal into the IRRI farm.

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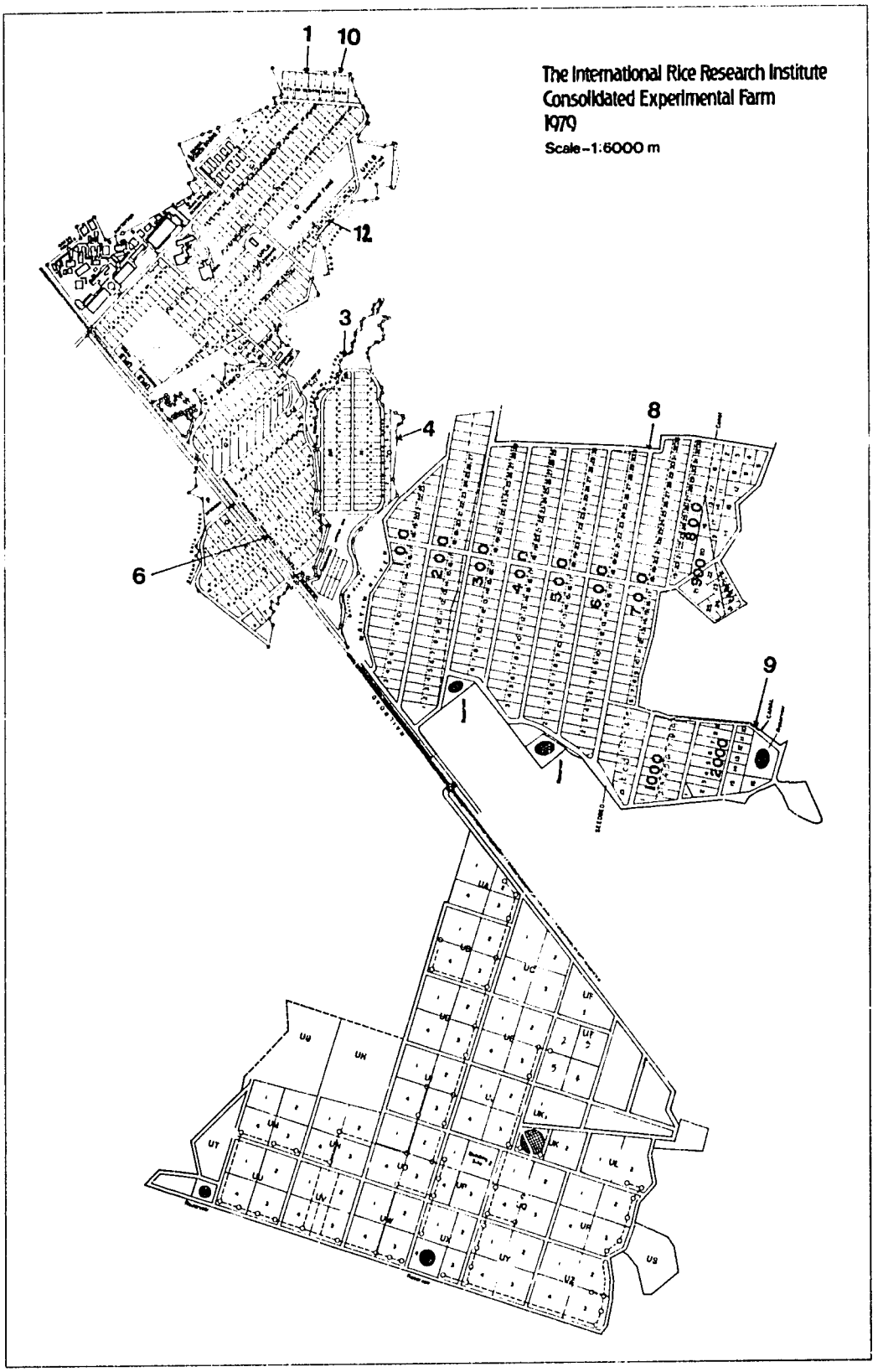

1. Sampling sites.

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Land development included consolidation and leveling of blocks 500, 600, and UA in the upland area. Underground PVC irrigation pipes were installed in block UA.

The first centralized seedbeds were built at series 100 and 200 during the wet season. During the dry season, UJ-2, UJ-3, and UP-1 were prepared with a modified tractor-powered rototiller. This reduced manual labor for preparing seedbeds, seeding, and covering seeds with soil. The seedbeds were irrigated by sprinkler. A few seedbeds were built in UJ-2 with a Landmaster hand tractor attached to a moldboard plow. To decrease soil needed for covering the seedbeds and to protect the seeds from birds and rats, we tried plastic sheeting and brown wrapping paper covers with some success.

Of the 229.6 ha prepared and planted, 16.7 ha were used for seed production and multiplication of IR841, IR50504-57, IR54950-181, IR72, IR74, PSB-CR_1 (Makiling), PSB-CR_2, and PSB-CR_4.

During the year, 27,823 rats were killed by flame throwing, mowing, baiting, and live trapping. Flame throwing, mowing, and live trapping will continue.

Contract labor in 1991 cost $413,382.52: 4% ($16,385.24) was paid for land preparation, 75% ($310,319.10) for planting and weeding, and 21% ($86,678.18) for birdboys. Contract labor expenses will decrease when all laborers from the other divisions are transferred to CRF.

We harvested, threshed, dried, and cleaned 94,743 kg of rough rice, which is stocked at the Materials and Control Division.

The Plant Growth Facilities (PGF) Unit of CRF provided centralized support services for the phytotron, greenhouses, and the planned Containment Facility.

Phytotron

Forty-seven experiments conducted at the phytotron involved 66 research staff from the Agronomy, Plant Physiology, and Agroecology (APPA); Soil Microbiology; INGER; Plant Breeding, Genetics, and Biochemistry (PBGB); IRGC; Plant Pathology; Soil and Water Sciences; and Entomology Divisions.

The experiments lasted from 2 to 320 d. Humidity was set from 60 to 80% in the various growth chambers. Artificially lit cabinets required 10 to 30 klx.

The requested temperature settings were 12-45 °C. Temperature control studies on rice growth were combined with various subjects: low light intensity, effects of ultraviolet-B (UV-B) on rice, salinity tolerance, drought resistance, photosynthesis, assimilate translocation, anthesis, leaf senescence, grain filling, seedling vigor inheritance, germination and direct seeding physiology, water use efficiency, phytohormones, volcanic ash, azolla growth and maintenance, rice blast, bacterial blight, nematodes, brown planthopper, decomposition dynamics of green manure species, nodulation and N_2 fixation by rhizobia, N mineralization potential, roots with Fe and P in submerged soils, root NA oxidation, rooting characteristics, phosphatase activity of roots, interspecific hybrid production, cytoplasmic male sterile lines, marker stocks, primary trisomics, embryo rescue of *Oryza sativa* and wild rice accessions, wide hybridization, and RFLP linkage mapping and tagging of genes.

The phytotron also serviced more than 180 requests for cold rooms, leaf area meter, oven, balances, and incubator.

Information and orientation services were given to new research staff users, graduate students, and 204 visitors.

The HNL growth cabinet and Conviron growth bench were used continuously by the Soil Microbiology Division to maintain the azolla germplasm collection. The glasshouses were greatly utilized (Table 4). More than 95% of the space in all growth chambers (except the five darkrooms) was reserved at the start of the growing period. As in the previous years, the five darkrooms were the least utilized facilities. Two of the darkrooms will be converted into a balance room and a cold room when the phytotron is renovated.

No major problems were encountered during the 1991 operations. Eleven scheduled and unscheduled power interruptions totaled 48.7 h. Most interruptions lasted 1 h; the longest was 13 h on 11 June. The two 500-KVA standby generators allowed all experiments to proceed without fluctuations in the controlled environments. The old chart recorders were continually maintained, although difficulties were experienced in procuring replacement parts. This made calibration of monitoring devices laborious and time-consuming. Although plants were sprayed before entering the phytotron, some eggs survived, hatched, and spread. The CRF-Plant Protection and Surveillance group ordered a new miticide, and is studying other control measures. Glass-

Table 4. Occupancy rates of growth rooms. IRRI phytotron, 1991.

Plant growth rooms	Total floor area (m^2)	Mean monthly space utilization (%)	Requested range of temperature setting (°C)	
			Min	Max
6 glasshouses (naturally lit)	240	85	21	29
12 SA-L cabinets (naturally lit)	19	65	15	41
4 KB cabinets (naturally lit)	2	71	25	40
11 KG cabinets (artificially lit)	16	72	12	45
1 Conviron bench (artificially lit)	4	91	21	26
1 HNL cabinet (artificially lit)	3	98	18	26
5 darkrooms	32	40	17	30

houses will be sprayed with insecticides after maintenance operations just before new plant materials are accepted.

CO_2 control and regulation mechanisms were installed in six naturally lit 3-SAL units. The roof of the demineralizer and power substation was replaced. Chilled water pipe insulation was changed from styropor with canvass cover to fiberglass with fiberglass reinforced plastic cover. The mezzanine office was renovated. Automatic irrigation systems were installed in the glasshouses. This minimized the labor for watering potted experiments in the glasshouses.

A computer program was developed to keep track of space allocation and maintain the history of facility use. A data base of current and previous experiments is maintained. Plans were made to computerize control and monitoring of the growth chambers.

The thermometers used in calibrations were checked with National Institute of Science and Technology standard thermometers and verified with the IRRI Climate Unit and the Philippine Atmospheric, Geophysical, and Astronomical Services Administration.

Dynamic space allocation, proper timing of cooling units, and efficient mechanical operations lowered energy requirements for this year: 2,316,800 kW-h were used in 1991, 2,523,200 in 1990, and 2,738,400 in 1989. This saved at least 206,400 kW-h ($11,040.32).

The phytotron closed for annual maintenance from 4 November to 20 December. All motors, cooling units, generators, and control units were serviced. New procedures during the shutdown reduced overtime by at least 334 h and used pooled staff rather than contract workers.

Greenhouses. IRRI has more than 72 greenhouses and screenhouses, with 26,219 m^2 (2.62 ha) of floor area. In 1991, more than 90% of greenhouse space was used for 187 rice research experiments. More greenhouse space is needed to serve new research. Centralized support services for IRRI's greenhouses include maintenance of the physical structures, allocation of space to users, and centralization of common supplies used by research staff. Greenhouse renovation in the west area commenced during February.

Routine activities included replacement of 506 glass roof panels, collection and centralization of 10,788 pots, and supply of 176 t ground or pulverized soil for pots and greenhouses. We installed automatic irrigation systems for pots in the upland screenhouses and started making concrete beds in the east greenhouses. A continuous water flow system installed above one of the glasshouses helped reduce temperature by 4-6 °C during peak solar radiation.

Containment facility. The design and operation of containment facilities from around the world were studied and design plans for the IRRI containment facility were proposed.

Communications support

The Information Center provides in-house communications support services to IRRI programs, administration, and other entities. The support includes editorial, typesetting, artwork, design, printing, photography, and audiovisual services.

The Information Center printed 14.5 million pages of text in-house in 1991 (not including IRRI books and periodicals, which are contracted out). More than 33,000 original slides were produced, 42,000 slides were duplicated, and 56,200 black-and-white photographs were developed. About 2,400 black-and-white artworks were drawn, and 8,000 pages laid out. Fifty posters were prepared.

We edited an additional 93 journal and miscellaneous papers (conference papers, proposals, etc.) totaling about 2,000 pages.

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The other work of the Information Center—library services, scientific publication, data bases, conferences and workshops, and public awareness—is program-driven and is reported under the Information and Knowledge Exchange program (p. 226).

Project management services and biometrics

The Project Management Services and Biometrics (PMSB) Unit assumed the duties and responsibilities of the Department of Statistics beginning in January 1990. It provides biometrics expertise and related services in support of research and international programs. The computational services, a key function of the previous Statistics Department, have been discontinued.

Biometrics consultation. PMSB provides consultation services and training in biometrics to IRRI researchers, scholars, fellows, and trainees. There were 318 walk-in consultations in 1991; most (77%) pertained to statistical analysis and interpretation of research data, and the rest dealt with experimental design and field plot techniques.

Biometrics training. Since IRRI researchers must perform their own statistical analyses, PMSB concentrated on the in-house biometrics training programs. In 1991, PMSB offered 10 training cum workshop programs (a total of 212 course hours), which had 312 participants:

- field plot techniques,
- principles of experimental design and commonly used designs for rice experiments,
- analysis of variance,
- regression and correlation analysis for experimental data,
- interpretation and presentation of research results,
- chi-square test,
- multivariate analysis,
- SAS basics,
- genetic Analysis via SAS, and
- IRRISTAT.

PMSB staff also provided biometrics lectures and a practicum in nine Institute short-term training courses involving 200 total class hours.

In consonance with the Institute's recent focus on sharing training responsibilities with national programs, PMSB staff participated as resource persons in several training programs coordinated by national or regional centers in 1991. These include

- Research Data Analysis and Management course held in Bhutan, 29 Apr-7 May 1991, and
- Data Management for On-farm Trials course offered jointly with SEARCA, 11 Mar-12 Apr 1991.

Development of IRRISTAT. IRRISTAT, a micro-based statistical software developed in-house, is designed to assist agricultural researchers (particularly rice researchers) with experiment layout, plot sampling, data collection, data management, statistical analysis of data, and presentation of results. The first IRRISTAT version (90-1) was released in January 1990 and the second (91-1) in April 1991. There are more than 400 registered IRRISTAT users in 45 countries.

Research. PMSB staff undertook two research activities in 1991.

Development of field plot techniques for rainfed lowland rice. We reviewed and evaluated existing techniques. With members of the Rainfed Lowland Rice Research Consortium, we planned 1991 wet season field studies on field plot techniques. The studies were conducted at two Consortium key sites: Polba-Chinsurah, West Bengal in India, and Ubon Ratchathani in Thailand.

Data management for on-farm trials. PMSB staff coordinated project activities and worked on the development of IRRIOFT, a generalized micro-based data management system for on-farm trials for technology verification. By the end of 1991, three of five IRRIOFT modules had been completed. They are being tested at two pilot sites per country in three collaborating countries (Indonesia, Philippines, and Thailand). The five modules are Variable Prescription, Form Generation, Data Entry/Editing/Display/Discard, Data Analysis/Summary/Presentation, and Information Storage and Retrieval.

Publications and seminars

Under **Institute publications** are listed the 18 major books in English (1 is a computer edition, on diskette), 11 translations of 6 books in 7 languages, 7 monographs in the IRRI Research Paper Series, and 5 periodicals published by IRRI in 1991. Seven of the translations were produced by national organizations with assistance from the Institute.

Subsequent sections list, by division, the output of individual scientists and additional bibliographies produced by the Library and Documentation Center.

Institute publications

Books

Training and technology transfer course: performance objectives manual. 1991.

World rice statistics 1990. 1991.

IRRI 1990-1991: a continuing adventure in rice research. 1991.

Rice grain marketing and quality issues. 1991.

Direct seeded flooded rice in the tropics. 1991.

Rice blast modeling and forecasting. 1991.

World bibliography of rice stem borers 1794-1990. Z.R. Khan, J.A. Litsinger, A.T. Barrion, F.F.D. Villanueva, N.J. Fernandez, and L.D. Taylo. 1991. 415 p.

Program report for 1990. 317 p.

Rice genetics II. 1991. 844 p.

A handbook for weed control in rice. Kwesi Ampong-Nyarko and S.K. De Datta. 1991. 113 p.

A primer on organic-based rice farming. R.K. Pandey. 1991. 201 p.

Home chefs of the world: rice and rice-based recipes. 1991. 252 p.

Human geography of rice in Southeast Asia. R.E. Huke and E.H. Huke. 1990. This set updates the 1982 map and data.

Editing and publication: a training manual. I. Montagnes. 1991.

Editing and publication: a handbook for trainers. I. Montagnes. 1991.

Basic procedures for agroeconomic research (revised). 1991.

Rice production skills development series (RP3-01 to 33). 1991. (booklets)

Publications of the international agricultural research and development centers: 1990 computer edition. (on diskette)

Translations

Field problems of tropical rice [Lao edition].

Helpful insects, spiders, and pathogens: friends of the rice farmer [Bangla edition], by B.M. Shepard, A.T. Barrion, and J.A. Litsinger.

A farmer's primer on growing rice. 2d Vietnamese edition, in southern region dialect (1st ed. was published in northern region dialect).

A farmer's primer on growing upland rice [Bicol and Cebuano (Philippines) editions], by M.A. Arraudeau and B.S. Vergara.

A farmer's primer on growing cowpea on riceland [Bicol (Philippines), French, and Bahasa Indonesia editions], by R.K. Pandey. 218 p.

A farmer's primer on growing soybean on riceland [French, Cebuano (Philippines), and Bahasa Indonesia editions], by R.K. Pandey.

Research Paper Series

145. A generalized model of economic constraints on crop turnaround time, by A. Orr. 12 p.
146. Dual-purpose legumes in the rainfed lowland rice-based system in the Philippines, by N.U. Ahmed, P.E. Hildebrand, and V.R. Carangal. 13 p.
147. Rice production trends in selected Asian countries, by M.D. Pathak and K.A. Gomez. 14 p.
148. Crop establishment *(Beusani)* in Cuttack district, India, by S. Fujisaka, K.T. Ingram, and K. Moody. 9 p.
149. Rice herbage, by T. Kupkanchanakul and B.S. Vergara. 23 p.

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150. Methods for studying blue-green algae in ricefields: distributional ecology, sampling strategies, and estimation of abundance, by P.A. Roger, R. Jimenez, and S.S. Ardales. 19 p.
151. Systems simulation at IRRI, by F.W.T. Penning de Vries, M.J. Kropff, P.S. Teng, and G.J.D. Kirk. 67 p.

Periodicals

International rice research newsletter, Vol. 16, nos. 1-6 and IRRN subject and variety indexes 1990

IRRI reporter, 1/91, 2/91, 3/91, 4/91

Rice literature update, Feb, Apr, Jun, Aug, Oct, Dec

IRRI hotline

This week at IRRI

Agricultural Engineering

Douthwaite B, Quick G R (1991) Rotary combing stripper harvester for small area farming. *In* Proceedings of the International Agricultural Mechanization Conference, Beijing, October 1991.

Quick G R (1991) Engineering development for small scale rural industry in the rice world—the IRRI experience. *In* Proceedings of the Regional Seminar on Technology for Rural Industry, Chiang Mai, Thailand, 24-25 July 1991.

Quick G R (1991) Engineering for the low-income sector of the rice world—the IRRI experience. *In* Proceedings of the International Agricultural Mechanization Conference, Beijing, October 1991.

Quick G R (1991) Rice postharvest technology and the IRRI position on intellectual property (WIPO). *In* Proceedings of the Asian Regional Seminar on the Use of Industrial Property and Technology Transfer Agreement, Beijing, 8-11 April 1991.

Quick G R, ed. (1991) Rodents and rice. Report and proceedings of an expert panel meeting on rice rodent control, Los Baños. September. 132 p.

Wang Hongyong, Quick G R (1991) Hand-operated seeder for precision seeding. *In* Proceedings of the International Agricultural Mechanization Conference, Beijing, October 1991.

Agronomy, Plant Physiology, and Agroecology

Aragones D A, Senmandi S, Seshu D V, Yamauchi M (1991) Varietal difference in growth and grain yield of broadcast-seeded short duration rice plants with special reference to seed vigor. Philipp. J. Crop Sci. 16 (suppl. 1):15.

Bastiaans L (1991) Quantification of the effect of leaf blast on leaf photosynthesis, crop growth, using an ecophysiological model for crop growth. Pages 89-99 *in* Rice blast modeling and forecasting. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Bastiaans L (1991) Ratio between virtual and visual lesion size as a measure to describe reduction in leaf photosynthesis of rice due to leaf blast. Phytopathology 80, 81:611-615.

Becker M, Diekmann K H, Ladha J K, De Datta S K, Ottow J C G (1991) *See* **Soil Microbiology.**

Bhuiyan M A, Garrity D P, Centeno G (1991) *See* **Soil and Water Sciences.**

Bossio D A, Cassman K G (1991) Traditional rainfed barley production in the Andean highlands of Ecuador: soil nutrient limitations and other constraints. Mt. Res. Dev. 11:115-126.

Buresh R J, De Datta S K (1991) Nitrogen dynamics and management in rice-legume cropping systems. Adv. Agron. 45:1-59.

Buresh R J, De Datta S K, Samson M I, Phongpan S, Snitwongse P, Fagi A M, Tejasarwana R (1991) Dinitrogen and nitrous oxide flux from urea basally applied to puddled rice soils. Soil Sci. Soc. Am. J. 55:268-273.

Calendacion A N, Garrity D P, Batugal P, De Datta S K (1991) Increased productivity and profitability through potato-wet seeded rice cropping systems. Philipp. J. Crop Sci. 16:121-127.

De Datta S K, Buresh R J, Samson M I, Obcemea W N, Real J G (1991) Direct measurement of ammonia and denitrification fluxes from urea applied to rice. Soil Sci. Soc. Am. J. 55:543-548.

Dingkuhn M, Cruz R T, O'Toole J C, Turner N C, Doerffling K (1991) Responses of seven diverse rice cultivars to water deficits. III. Accumulation of abscisic acid and proline in relation to leaf water-potential and osmotic adjustment. Field Crops Res. 27:103-117.

Dingkuhn M, Farquhar G D, De Datta S K, O'Toole J C (1991) Discrimination of 13C among upland rices having different water use efficiencies. Aust. J. Agric. Res. 42:1123-31.

Dingkuhn M, Penning de Vries F W T, De Datta S K, van Laar H H (1991) New plant type concepts for direct seeded flooded tropical rice. Pages 17-38 *in* Direct seeded flooded rice in the tropics. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Dingkhun M, Schnier H F, De Datta S K, Dorffling K, Javellana C (1991) Relationships between ripening-phase productivity and crop duration, canopy photosynthesis and senescence in transplanted and direct-seeded lowland rice. Field Crops Res. 26:327-345.

Elahi Nur-E, Furoc R E, Carangal V R, Parder W D (1991) *See* **Asian Rice Farming Systems Network.**

Elliot P C, Moody K (1991) Influence of weed-control practices in the first crop on the tillage requirements for the succeeding crops in an upland rice-maize-cowpea cropping sequence. Crop Prot. 10(1):28-33.

Fujisaka S, Garrity D P (1991) *See* **Social Sciences.**

Garcia A G, Garrity D P (1991) Simulation of phosphorus fertilizer requirement of upland rice in two acid upland sites in the Philippines. Pages 19-32 *in* Simulation and systems analysis for rice production (SARP). F.W.T. Penning de Vries, H.H. van Laar, and M.J. Kropff, eds. PUDOC, Wageningen.

Garrity D P, Sajise P E (1991) Sustainable land use systems research in Southeast Asia: a regional assessment. Pages 59-76 *in* Proceedings of an International Workshop on Sustainable Land Use Systems Research. New Delhi, India.

Ingram K T, Dingkuhn M, Novero R P, Wijangco E J (1991) Growth and CO_2 assimilation of lowland rice in response to timing and method of N fertilization. Plant Soil 132:113-125.

Janiya J D, Moody K (1991) Effect of water deficit on rice-weed competition under greenhouse conditions. J. Plant Prot. Trop. 8(1):25-35.

Kropff M J, Spitters C J T (1991) A simple model of crop loss by weed competition from early observations on relative leaf area of the weeds. Weed Res. 31:97-105.

Kupkanchanakul T, Vergara B S (1991) Rice herbage as animal feed in deepwater areas. Rice Farming Syst. Tech. Exch. 1(2):19-22.

Moody K (1991) Crop-weed complexity in lowland rice. Pages 15-26 *in* Proceedings of the 13th Asian-Pacific Weed Science Society Conference, Jakarta, Indonesia.

Moody K (1991) Weed control in upland rice with emphasis on grassy weeds. Pages 164-178 *in* Tropical grassy weeds. F.W.G. Baker and P.J. Terry, eds. CASAFA Report Series No. 2. CAB International, Wallingford, Oxon 0X10 8DE, U.K.

Moody K (1991) Weed management in rice. Pages 301-328 *in* Hand book of pest management in agriculture. D. Pimentel, ed. 2d ed. CRC Press, Inc., Boca Raton, Florida, USA.

Navarez D C, Moody K (1991) Effects of weed control and tillage in a rice - mungbean crop rotation. J. Plant Prot. Trop. 8(1):13-23.

Osuna-Canizalez F J, De Datta S K, Bonman J M (1991) Nitrogen form and silicon nutrition effects on resistance to blast disease of rice. Plant Soil 135:223-231.

Pablico P P, Moody K (1991) Effect of fentin acetate on wet-seeded rice, *Pistia stratiotes* and *Azolla pinnata*. Crop Prot. 10(1):45-47.

Peng S, Krieg D R (1991) Single leaf and canopy photosynthesis response to plant age in cotton. Agron. J. 83:704-708.

Peng S, Krieg D R, Girma F S (1991) Leaf photosynthetic rate is correlated with biomass and grain production in grain sorghum lines. Photosynthesis Res. 28:1-7.

Penning de Vries F W T, Spitters C J T (1991) The potential for improvement in crop yield simulation. *In* Climatic risk in crop production: models and management for the semi-arid tropics and subtropics. Commonwealth Scientific and Industrial Research Organization, 1990. R.C. Muchow and J.A. Bellany, eds. CAI International, U.K.

Penning de Vries F W T, van Laar H H, Kropff M J, eds. (1991) Simulation and systems analysis for rice production (SARP). Selected papers presented at workshops on crop simulation of a network of national and international agricultural research centers of several Asian countries and the Netherlands, 1990-1991. PUDOC, Wageningen. 366 p.

Rashid M A (1991) Simulation of potential production and nitrogen response of IR72. Pages 5-11 *in* Case studies in growth simulation. February 1990-1991. IRRI/CABO/TPE.

Sanyal S K, De Datta S K (1991) Chemistry of phosphorus transformations in soil. Adv. Soil Sci. 16.

Satrusajang A, Snitwongse P, Buresh R J, Friesen D K (1991) Nitrogen-15 and sulfur-35 balances for fertilizers applied to transplanted rainfed lowland rice. Fert. Res. 28:55-65.

Senanayake N, De Datta S K, Naylor R E L, Thompson W J (1991) Lowland rice apical development: stages and cultivar differences detected by electron microscopy. Agron. J. 83(6):1013-1023.

Timsina J (1991) Drought and waterlogging of food legumes: a review of effects, tolerances and implications for simulation. Pages 261-276 *in* Simulation and systems analysis for rice production (SARP). F.W.T. Penning de Vries, H.H. van Laar, and M.J. Kropff, eds. PUDOC, Wageningen.

Timsina J (1991) Simulation models as tools for yield prediction and extrapolation: an example for cowpea. Pages 53-59 *in* Simulation and systems analysis for rice production (SARP). F.W.T. Penning de Vries, H.H. van Laar, and M.J. Kropff, eds. PUDOC, Wageningen.

Vergara B S, Venkateswarlu V, Janoria M, Ahn J K, Kim J K, Visperas R M (1991) Rationale for a low-tillering rice plant type with high-density grains. Pages 39-53 *in* Direct seeded flooded rice in the tropics. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Williams W A, Graves W L, Cassman K G, Miller P R, Thomsen C D (1991) Nitrogen fixation versus estimated water usage by berseem clover. Calif. Agric. 45(4):30-32.

Xia J Y, Penning de Vries F W T, Litsinger J A (1991) *See* **Entomology.**

Entomology

Barrion A T, Litsinger J A, Last H (1991) A new species of *Hesperus* (Coleoptera: Staphylinidae) and other rove beetles associated with rice agroecosystems. Philipp. Entomol. 8(4):1075-1080.

365

Barrion A T, Litsinger J A, Medina E B, Aguda R M, Bandong J P, Pantua P C, Jr., Viajante V D, dela Cruz C G, Vega C R, Soriano J S, Camañag E E, Saxena R C, Tryon E H, Shepard B M (1991) The rice *Cnaphalocrocis* and *Marasmia* (Lepidoptera: Pyralidae) leaffolder complex in the Philippines: taxonomy, bionomics, and control. Philipp. Entomol. 8(4):987-1074.

Bottrell D G (1991) Limitations to low-input pest management in developing countries. Pages 143-146 *in* International plant protection: focus on the developing world. Proceedings of the 11th International Congress of Plant Protection, October 5-9 1987, Manila, Philippines. E.D. Magallona, ed. Vol. 1. International Congress of Plant Protection, Manila. 581 p.

Demayo C G, Khan Z R, Saxena R C (1991) Genetic differences between two leaffolder species, *Cnaphalocrocis medinalis* Guenee and *Marasmia patnalis* Bradley (Lepidoptera: Pyralidae) associated with rice. Pages 332-335 *in* International plant protection: focus on the developing world. Proceedings of the 11th International Congress of Plant Protection, October 5-9 1987, Manila, Philippines. E.D. Magallona, ed. Vol. 2. International Congress of Plant Protection, Manila. 363 p.

Heong K L (1991) Modeling in the analysis of pest management strategies. Pages 35-38 *in* Systems simulation at IRRI. F.W.T. Penning de Vries, M.J. Kropff, P.S. Teng, and G.J.D. Kirk, eds. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Heong K L, Aquino G B, Barrion A T (1991) Arthropod community structures of rice ecosystems in the Philippines. Bull. Entomol. Res. 81:407-416.

Heong K L, Saad Bleih, Rubia E G (1991) Prey preference of the wolf spider, *Pardosa pseudoannulata* (Boes et Strand). Res. Popul. Ecol. 33:179-186.

Khan Z R, Litsinger J A, Barrion A T, Villanueva F, Fernandez N, Taylo L (1991) World bibliography of rice stem borers. International Rice Research Institute, P.O. Box 933, Manila, Philippines. 415 p.

Litsinger J A (1991) Crop loss assessment in rice. Pages 1-65 *in* Rice insects: management strategies. E.A. Heinrichs and T.A. Miller, eds. Springer-Verlag, New York, USA.

Litsinger J A, Hasse V, Schmutterer H (1991) Response of *Ostinia furnacalis* (Guenee) (Lepidoptera, Pyralidae) to intercropping. Environ. Entomol. 20(4):988-1004.

Mochida O, Guevarra H T, Litsinger J A, Basilio R P (1991) Golden apple snail *Pomacea canaliculata*: an introduced pest of rice. Pages 86-89 *in* International plant protection: focus on the developing world. Proceedings of the 11th International Congress of Plant Protection, October 5-9 1987, Manila, Philippines. E.D. Magallona, ed. Vol. 1. International Congress of Plant Protection, Manila. 581 p.

Norton G A, Holt J, Heong K L, Cheng J, Wareing D R (1991). Systems analysis and rice pest management. Pages 287-321 *in* Rice insects: management strategies. E.A. Heinrichs and T.A. Miller, eds. Springer-Verlag, New York, USA.

Roger P A, Heong K L, Teng P S (1991) *See* **Soil Microbiology**.

Saxena R C, Barrion A A (19[illegible]) Limitations of host plant resistance: insect biotypes. Pages 541-549 *in* International plant protection: focus on the developing world. Proceedings of the 11th International Congress of Plant Protection, October 5-9 1987, Manila, Philippines. E.D. Magallona, ed. Vol. 1. International Congress of Plant Protection, Manila. 581 p.

Saxena R C, Demayo C G, Barrion A A (1991) Allozyme variation among biotypes of the brown planthopper *Nilaparvata lugens* in the Philippines. Biochem. Genet. 29(3/4):115-123.

Saxena R C, Khan Z R (1991) Electronic recording of feeding behavior of *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae) on resistance and susceptible rice cultivars. Ann. Entomol. Soc. Am. 84(3):316-318.

Teng P S, Bottrell D G (1991) *See* **Plant Pathology**.

Velusamy R, Saxena R C (1991) Genetic evaluation for resistance to rice thrips (Thysanoptera:Thripidae) in leafhopper- and planthopper-resistant rice varieties. J. Econ. Entomol. 84(2):664-668.

Way M O, Grigarick A A, Litsinger J A, Palis F, Pingali P L (1991) Economic thresholds and injury levels for insect pests of rice. Pages 67-105 *in* Rice insects: management strategies. E.A. Heinrichs and T.A. Miller, eds. Springer-Verlag, New York, USA.

Xia J Y, Penning de Vries F W T, Litsinger J A (1991) Model of population dynamics of *Scirpophaga incertulas* (Walker) (Lepidoptera: Pyralidae). Environ. Entomol. 20(3):832-840.

Zhang Z T, Saxena R C, Boncodin M E M (1991) Effect of neem oil on courtship signal and mating behavior of the female brown planthopper, *Nilaparvata lugens* (Stål) [in Chinese, English summary]. Acta Entomol. Sin. 34(1):1-6.

Zhang Z, Yin B, Chen L, Saxena R C (1991) The model of signal production and the simulation of female signals in rice brown planthopper, *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae). Chin. J. Rice Sci. 5(1): 29-36.

Plant Breeding, Genetics, and Biochemistry

Bainton S J, Plumb V E, Juliano B O, Perez C M, Roxas D B, Khush G S, de Jesus J C, Gomez K A (1991) Variation in the nutritional value of rice straw. Anim. Feed Sci. Technol. 34:261-277.

3(6

Brar D S, de los Reyes B G, Panaud O, Sanchez A, Khush G S (1991) Genetic mapping in rice using isozymes and RFLP markers. Pages 137-145 *in* Rice genetics II. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Constantino S V, Caballero P, Juliano B O, Ibabao M G B (1991) Epicuticular wax alkanes of rice leaf and hull. Kimika J. Chem. Soc. Philipp. 7:27-30.

Endo N, Bustos G A, Ogawa T, Khush G S (1991) Rice cultivar groups in Myanmar based on reaction to bacterial blight. Jpn. J. Breed. 41:289-300.

Huebner F R, Hussain A, Lookhart G L, Bietz J A, Bushuk W, Juliano B O (1991) Discrimination of sister-line IR rice varieties by polyacrylamide gel electrophoresis and reversed-phase high-performance liquid chromatography. Cereal Chem. 68:583-588.

Juliano B O (1991) Rice in human nutrition. Pages 31-34 *in* Cereals international. Proceedings of a conference, Brisbane, Australia, Sep 9-13 1991. D.J. Martin and C.W. Wrigley, eds. Cereal Chemistry Division, Royal Australian Chemical Institute, Parkville, Victoria 3052, Australia.

Juliano B O, Duff B D (1991) Rice grain quality as an emerging priority in national rice breeding program. Pages 55-64 *in* Rice grain marketing and quality issues. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Juliano B O, Duff B D (1991) Setting priorities for rice grain quality research. Pages 201-211 *in* Grain postharvest research and development: priorities for the nineties. Proceedings of the 12th ASEAN Seminar on Grain Postharvest Technology, Aug 29-31 1989, Surabaya, Indonesia. J.O. Naewbanij, ed. ASEAN Grain Postharvest Programme, Bangkok.

Juliano B O, Hussain A, Resurreccion A P, Bushuk W (1991) Interference of phytate with extraction of protein from brown rice using 5 M acetic acid. Cereal Chem. 68:317-318.

Juliano B O, Perez C M, Chang T T (1991) Storage longevity. Rice Biotechnol. Q. 6:21-22.

Juliano B O, Perez C M, Maranan C L, Abansi C L, Duff B (1991) Grain quality characteristics of rice in Philippine retail markets. Pages 256-265 *in* Grain postharvest research and development: priorities for the nineties. Proceedings of the 12th ASEAN Seminar on Grain Postharvest Technology, Aug 29-31 1989, Surabaya, Indonesia. J.O. Naewbanij, ed. ASEAN Grain Postharvest Programme, Bangkok.

Juliano B O, Perez C M, Villareal C P, Tonogai J, Biliaderis C G (1991) Role of amylopectin in varietal differences in hardness of cooked rice and starch gels: a status report. Pages 143-146 *in* Cereals international. Proceedings of a conference, Brisbane, Australia, Sep 9-13 1991. D.J. Martin and C.W. Wrigley, eds. Cereal Chemistry Division, Royal Australian Chemical Institute, Parkville, Victoria 3052, Australia.

Kaosa-ard M, Juliano B O (1991) Assessing quality characteristics of rice in selected international markets. Pages 351-371 *in* Grain postharvest research and development: priorities for the nineties. Proceedings of the 12th ASEAN Seminar on Grain Postharvest Technology, Aug 29-31 1989, Surabaya, Indonesia. J.O. Naewbanij, ed. ASEAN Grain Postharvest Programme, Bangkok.

Kaosa-ard M, Juliano B O (1991) Assessing rice quality characteristics and prices in selected international markets. Pages 23-35 *in* Rice grain marketing and quality issues. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Kaushik R P, Khush G S (1991) Endosperm mutants in rice: gene expression in japonica and indica backgrounds. Cereal Chem. 68:487-491.

Kaushik R P, Khush G S (1991) Genetic analysis of endosperm mutants in rice, *Oryza sativa* L. Theor. Appl. Genet. 83:146-152.

Khush G S, Kinoshita T (1991) Rice karyotype, marker genes, and linkage groups. Pages 83-108 *in* Rice biotechnology. G.S. Khush and G.H. Toenniessen, eds. CAB International, Wallingford, England, and International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Khush G S, Brar D S (1991) Genetics of resistance to insects in crop plants. Adv. Agron. 45:223-274.

Khush G S, Juliano B O (1991) Research priorities for improving rice grain quality. Pages 65-66 *in* Rice grain marketing and quality issues. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Khush G S, Singh R J (1991) Chromosome architecture and aneuploidy in rice. Pages 577-598 *in* Chromosome engineering in plants: genetics, breeding, evolution. Part A. P.K. Gupta and T. Tsuchiya, eds. Elsevier Science Publishers B.V., Amsterdam.

Khush G S, Toenniessen G H, eds. (1991) Rice biotechnology. CAB International, Wallingford, England, and International Rice Research Institute, P.O. Box 933, Manila, Philippines. 320 p.

Khush G S, Virmani S S (1991) Rice breeding strategies for the nineties. Pages 227-233 *in* Rice production on acid soils of the tropics. P. Deturck and F.N. Ponnamperuma, eds. Institute of Fundamental Studies, Kandy, Sri Lanka.

Lookhart G L, Juliano B O, Webb B D (1991) Effect of solvent extraction, environment, and genetic background on differentiating rice by reversed-phase high-performance liquid chromatography. Cereal Chem. 68:396-400.

Maranan C L, Duff B, Juliano B O (1991) *See* **Social Sciences.**

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McCouch S R, Khush G S, Tanksley S D (1991) Tagging genes for disease and insect resistance via linkage to RFLP markers. Pages 443-449 *in* Rice genetics II. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Ogawa T, Bustos G A, Tabien R E, Romero G O, Endo N, Khush G S (1991) Grouping of rice cultivars based on reaction pattern to Philippine races of bacterial blight pathogen (*Xanthomonas campestris* pv. *oryzae*). Jpn. J. Breed. 41:109-119.

Ogawa T, Yamamoto T, Khush G S, Mew T W (1991) Resistance and its inheritance to bacterial blight of IR8 rice cultivar group. Jpn. J. Breed. 41:211-221.

Ogawa T, Yamamoto T, Khush G S, Mew T W (1991) Breeding of near-isogenic lines of rice with single genes for resistance to bacterial blight pathogen (*Xanthomonas campestris* pv. *oryzae*). Jpn. J. Breed. 41:523-529.

Panlasigui L N, Thompson L U, Juliano B O, Perez C M, Yiu S (1991) Starch digestibility and glycemic response to extruded high amylose rice noodles. Trans. Natl. Acad. Sci. Technol. Manila 12:109-127.

Panlasigui L N, Thompson L U, Juliano B O, Perez C M, Yiu S, Greenberg G R (1991) Rice varieties with similar amylose content differ in starch digestibility and glycemic response in humans. Am. J. Clin. Nutr. 54:871-877.

Siscar-Lee J J H, Juliano B O, Tsuji S, Chikubu S, Faure J (1991) Viscosity and flow properties of cooked milled rice slurries. Starch 43:220-225.

Tang S X, Khush G S, Juliano B O (1991) Genetics of gel consistency in rice. J. Genet. 70:69-78.

Taura S, Ogawa T, Yoshimura A, Ikeda R, Omura T (1991) Identification of a recessive resistance gene in induced mutant line XM5 of rice to rice bacterial blight. Jpn. J. Breed. 41:427-432.

Vaughan D A, Sitch L A (1991) *See* **Genetic Resources Center**.

Villareal C P, Maranville J W, Juliano B O (1991) Nutrient content and retention during milling of brown rices from the International Rice Research Institute. Cereal Chem. 68:437-439.

Yu Z H, Mackill D J, Bonman J M, Tanksley S D (1991) *See* **Plant Pathology**.

Plant Pathology

Aswidinnoor H, Nelson R J, Dallas J F, McIntyre C L, Leung H, Gustafson J P (1991) Cloning and characterization of repetitive DNA sequences from genomes of *Oryza minuta* and *Oryza australiensis*. Genome 34:790-798.

Bonman J M, Estrada B A (1991) Assessment of blast disease and yield loss in susceptible and partially resistant rice cultivars in two irrigated lowland environments. Am. Phytopathol. Soc. 75(5). (abstr.)

Bonman J M, Estrada B A, Kim C K, Ra D S, Lee E J (1991) Assessment of blast disease and yield loss in susceptible and partially resistant rice cultivars in two irrigated lowland environments. Plant Dis. 75:462-466.

Ferris H, Prot J C (1991) Interpreting crop yield-nematode and nematode-nematode relationships from field data. J. Nematol. 23:528-529.

Gnanamanickam S S, Mew T W (1991) Interactions between *Sarocladium oryzae* and stem attacking fungal pathogens of rice. Plant Soil 138:213-219.

Hibino H, Ishikawa K, Omura T, Cabauatan P Q, Kogarezawa H (1991) Characterization of rice tungro bacilliform and rice tungro spherical viruses. Phytopathology 81:1130-1132.

James W C, Teng P S, Nutter F W (1991) Estimated losses of crops from plant pathogens. Pages 15-51 *in* CRC handbook of pest management. 2d ed. CRC Press, Boca Raton.

Khan M A, Hibino H, Aguiero V M, Daquioag R D (1991) Rice and weed hosts of rice tungro-associated viruses and leafhopper vectors. Plant Dis. 75:926-930.

Nutter F W, Jr., Teng P S, Shokes F M (1991) Disease assessment terms and concepts. Plant Dis. 75:1187-1188.

Ogawa T, Yamamoto T, Khush G S, Mew T W (1991) *See* **Plant Breeding, Genetics, and Biochemistry**.

Ogawa T, Yamamoto T, Khush G S, Mew T W (1991) *See* **Plant Breeding, Genetics, and Biochemistry**.

Osuna-Canizalez F J, De Datta S K, Bonman J M (1991) *See* **Agronomy, Plant Physiology, and Agroecology**.

Prot J C, Cuc N T T (1991) Nematodes in irrigated rice crop after DWR in the Mekong Delta. Deepwater Tidal Wetlands Rice 17:2-3.

Prot J C, Soriano I R S, Matias D M (1991) Control of upland and irrigated rice nematode pests with legume crops. Proceedings of the XIIth International Plant Protection Congress, Rio de Janeiro, Brazil, August 11-16, 1992. (abstr.)

Roger P A, Heong K L, Teng P S (1991) *See* **Soil Microbiology**.

Sakthivel N, Mew T W (1991) Efficacy of bacteriocinogenic strains of *Xanthomonas oryzae* pv. *oryzae* on the incidence of bacterial blight disease of rice (*Oryza sativa* L.). Can. J. Microbiol. 37:764-768.

Sama S, Hasanuddin A, Manwan I, Cabunagan R C, Hibino H (1991) Integrated management of rice tungro disease in South Sulawesi, Indonesia. Crop Prot. 10: 34-39.

Savary S, Elazegui F A, Teng P S (1991) Use of categorized information for crop loss analysis in tropical rice. Phytopathology 81:1156. (abstr.)

Teng P S (1991) Evolving concepts, principles, problems, and challenges of IPM in the Philippines: a reaction/response. Pages 59-70 *in* Proceedings of the 21st Anniversary and Annual Convention of the Pest Control Council of the Philippines. Pest Control Council of the Philippines.

Teng P S (1991) IPM activities at the International Rice Research Institute. Philipp. Pest Manage. 1:4-13.

Teng P S (1991) Modeling and non-modeling approaches to assessing the impact of field releases of bioengineered organisms. Phytopathology 81:1137-1142.

Teng P S, Bottrell D G (1991) Development of national IPM program: the U.S.A. experience. Pages 161-166 *in* Proceedings of the National Conference and Workshop on Integrated Pest Management in Rice, Corn and Selected Major Crops, 1-3 March 1990, National Crop Protection Center, UPLB, Los Baños. National Crop Protection Center, Los Baños, Philippines.

Teng P S, Calvero S B (1991) Computer simulation of tropical rice-leaf blast pathosystem using BLASTSIM. 2. Phytopathology 81:1143. (abstr.)

Teng P S, Klein-Gebbinck H, Pinnschmidt H (1991) An analysis of the blast pathosystem to guide modeling and forecasting. Pages 1-30 *in* Blast modeling and forecasting. International Rice Research Institute, P.O. Box 933, Manila, Philippines.

Yu Z H, Mackill D J, Bonman J M, Tanksley S D (1991) Tagging genes for blast resistance in rice via linkage to RFLP markers. Theor. Appl. Genet. 81:471-476.

Project Management Services and Biometrics

Bainton S J, Plumb V E, Juliano B O, Perez C M, Roxas D B, Khush G S, de Jesus J C, Gomez K A (1991) *See* **Plant Breeding, Genetics, and Biochemistry.**

Social Sciences

David C C (1991) Rural development problems and prospects in agriculture and the state: employment and poverty in developing countries. C.P. Timmer, ed. Cornell University Press, Ithaca, New York.

Fujisaka S (1991) A set of farmer-based diagnostic methods for setting post-green revolution rice research priorities. Agric. Syst. 36:191-206.

Fujisaka S (1991) Farming systems development in the uplands of Southeast Asia: social and economic issues. FAO Farm Manage. Notes Asia Far East 14:1-18.

Fujisaka S (1991) Improving productivity of an upland rice and maize system: farmer cropping choices or researcher CP trapezoids? Exp. Agric. 27:253-261.

Fujisaka S (1991) Targeting research to improve sustainability and productivity of shifting cultivation: Northern Laos. Agrofor. Syst. 13:95-109.

Fujisaka S (1991) The role and impact of socioeconomic and policy research in effecting technology adoption. *In* Technologies for sustainable agriculture on marginal uplands in Southeast Asia. G. Blair and R. Lefroy, eds. Australian Centre for Agricultural Research, Canberra.

Fujisaka S, Garrity D P (1991) Farmers and scientists: a joint effort in upland soil conservation research and technology transfer. Pages 221-231 *in* Conservation farming on hillslopes. International Society of Soil and Water Conservation, Taichung, Taiwan.

Fujisaka S, Wollenberg E (1991) From forest to agroforest and logger to agroforester: a case study. Agrofor. Syst. 14(2):113-130.

Huang J, David C C, Duff B (1991) Rice in Asia: is it becoming an inferior good? Comment. Am. J. Agric. Econ. 72(3).

Juliano B O, Duff B D (1991) *See* **Plant Breeding, Genetics, and Biochemistry.**

Juliano B O, Duff B D (1991) *See* **Plant Breeding, Genetics, and Biochemistry.**

Juliano B O, Perez C M, Maranan C L, Abansi C L, Duff B (1991) *See* **Plant Breeding, Genetics, and Biochemistry.**

Maranan C L, Duff B, Juliano B O (1991) Quality preferences for modern and traditional milled rice at the retail level: the Philippine case. Pages 230-255 *in* Grain postharvest research and development: priorities for the nineties. Proceedings of the 12th ASEAN Seminar on Grain Postharvest Technology, 29-31 August 1989, Surabaya, Indonesia. J.O. Naewbanij, ed. ASEAN Grain Postharvest Programme, Bangkok.

Pingali P L (1991) Agricultural growth and the environment: conditions for their compatibility in Asia's humid tropics. *In* Proceedings of the Conference on Agricultural Sustainability, Growth and Poverty Alleviation. International Food Policy Research Institute and Deutsche Stiftung fur Entwickslunder.

Pingali P L, Moya P F, Velasco L E (1991) Prospects for rice yield improvements in the post-green revolution Philippines. Philipp. Rev. Econ. Business 27(1):86-97.

Vo Tong Xuan, Pingali P L, Gerpacio R V (1991) Can Vietnam sustain its re-acquired rice exporter status. Pages 92-114 *in* Proceedings of the First Annual Meeting of the Vietnam Society of Agricultural Economists, 18-20 Dec, Hanoi, Vietnam. International Rice Research Institute and International Development Research Centre.

Way M O, Grigarick A A, Litsinger J A, Palis F, Pingali P L (1991) *See* **Entomology.**

Soil Microbiology

Becker M, Diekmann K H, Ladha J K, De Datta S K, Ottow J C G (1991) Effect of NPK on growth and nitrogen fixation of *Sesbania rostrata* as a green manure for lowland rice (*Oryza sativa* L.). Plant Soil 132:149-158.

Roger P A (1991) Reconsidering the utilization of blue-green algae in wetland rice cultivation. Pages 119-141 *in* Biological N_2 fixation associated with rice production. S.K. Dutta and C. Sloger, eds. Oxford & IBH Pub., New Delhi.

Roger P A, Heong K L, Teng P S (1991) Biodiversity and sustainability of wetland rice production: role and potential of microorganisms and invertebrates. Pages 117-136 *in* The biodiversity of microorganisms and invertebrates: its role in sustainable agriculture. Proceedings of the First Workshop on Ecological Foundations of Sustainable Agriculture (WEFSA 1), July 26-27, 1990, London. D.L. Hawskworth, ed. CAB International, UK.

Watanabe I (1991) Biological nitrogen fixation in sustainable rice farming. Pages 280-289 *in* Biological N_2 fixation associated with rice production. S.K. Dutta and C. Sloger, eds. Oxford & IBH Pub., New Delhi.

Watanabe I, Yoneyama T, Talukdar H, Ventura W (1991) The contribution of atmospheric N_2 to *Azolla* spp. grown in flooded soils. Soil Sci. Plant Nutr. 37: 101-109.

Yoneyama T, Uchiyama T, Sasakawa H, Gamo T, Ladha J K, Watanabe I (1991) Nitrogen accumulation and changes in natural ^{15}N abundance in the tissues of legumes with emphasis on N_2 fixation by stem-nodulating plants in upland and paddy fields. Soil Sci. Plant Nutr. 37:75-82.

Soil and Water Sciences

Bhuiyan M A, Garrity D P, Centeno G (1991) Simulation of soil-water balance and crop productivity of a rainfed sorjan system. Pages 211-224 *in* Case studies in growth simulation. February 1990-1991. IRRI/CABO/TPE.

Bhuiyan S I, Undan R C (1991) Pages 579-628 *in* Irrigation in tropical areas. Hoffman, Howell, and Solomon, eds. American Society of Agricultural Engineers, USA.

Ghani M A, Bhuiyan S I, Hill R W (1991) A model to evaluate intensive vs. extensive irrigation practices for irrigated rice production system in Bangladesh. Agric. Water Manage. 20(3):233-244.

Kirk G J D, Bouldin D R (1991) Speculations on the operation of the rice root system in relation to nutrient uptake. Pages 195-203 *in* Simulation and systems analysis for rice production. F.W.T. Penning de Vries, H.H. van Laar, and M.J. Kropff, eds. PUDOC, Wageningen.

Genetic Resources Center

INTERNATIONAL NETWORK FOR GENETIC EVALUATION OF RICE

Ahn S W, Seshu D V (1991) Blast reaction of durably resistant rice cultivars in multi-location trials. Phytopathology 8(1):1150. (abstr.)

INTERNATIONAL RICE GERMPLASM CENTER

Aragones D A, Senmandi S, Seshu D V, Yamauchi M (1991) *See* **Agronomy, Plant Physiology, and Agroecology**.

Chang T T (1991) Rice and plant variety: a practitioner's view. Forum Appl. Res. Public Policy 6(3):95-99.

Chang T T (1991) The role of improved seeds in agricultural development of the developing world. SABRAO J. 23:1-5.

Chang T T, Li C C (1991) Genetics and breeding. Pages 23-102 *in* Rice production. Vol. I. 2d ed. B.S. Luh, ed. Van Nostrand Reinhold Co., New York.

Chang T T, Luh B S (1991) Overview and prospects of rice production. Pages 1-12 *in* Rice production. Vol. I. 2d ed. B.S. Luh, ed. Van Nostrand Reinhold Co., New York.

Chang T T, Vaughan D A (1991) Conservation and potentials of rice genetic resources. Pages 531-552 *in* Biotechnology in agriculture and forestry. Vol. 14. Y.P.S. Bajaj, ed. Springer-Verlag, New York.

Juliano B O, Perez C M, Chang T T (1991) *See* **Plant Breeding, Genetics, and Biochemistry**.

Ng N Q, Chang T T, Vaughan D A, Zuno-Altoveros C (1991) African rice diversity: conservation and prospects for crop improvement. Pages 213-227 *in* Crop genetic resources of Africa. Vol. II. N.Q. Ng et al, eds. IITA-IBPGR-UNEP-CNR. Trinity Press, UK.

Vaughan D A (1991) Choosing rice germplasm for evaluation. Euphytica 54:147-154.

Vaughan D A, Sitch L A (1991) Gene flow from the jungle to farmers: wild-rice genetic resources and their uses. BioScience 41:22-28.

Information Center

A list of Japanese rice literature (quarterly).

IRRI Library manual.

Library list of recent accessions (January-December 1991) (12 issues).

Theses and dissertations on rice available in the Library of the International Rice Research Institute.

Asian Rice Farming Systems Network

Ahmed N U, Prime G M, Carangal V R (1991) Potential of pigeonpea after rainfed lowland rice. Rice Farming Syst. Tech. Exch. 1(3):6-8.

Carangal V R (1991). Sustainable intensification of smallholder animal production in rice-based farming systems. Proceedings: Sustainable Intensification of Smallholder Agricultural Production in Developing Countries: The Role of Animal. April 8-12, 1991.

Elahi Nur-E, Furoc R E, Carangal V R, Parder W D (1991) Intercropping sesbania green manure with mungbean at different row ratios under rainfed condition. Rice Farming Syst. Tech. Exch. 1(3):5-6.

310

Godilano E C, Carangal V R (1991) Geographic information systems: a tool in FSR/E technology extrapolation. Rice Farming Syst. Tech. Exch. 1(3):14-17.

Morales A C, Pargas A A, Carangal V R (1991) Phenotypic stability for grain yield in mungbean [*Vigna radiata* (L) Wilczek]. Food Legumes Coarse Grain Newsl. 16: 12-13.

SEMINARS

Special seminars

Rice research at CIAT: progress in hoja blanca virus, rice blast, and upland rice cropping systems. Dr. Z.R. Zeigler, rice program leader, International Center for Tropical Agriculture, Cali, Colombia.

The vegetable gene bank of Horticulture Research International. Dr. D. Astley, officer-in-charge, Institute of Horticultural Research, Wellesbourne, UK.

The importance of plant genetic resources and plant breeding research for crop improvement. Dr. M.T. Jackson, lecturer, School of Biological Sciences, University of Birmingham, Birmingham, UK.

Building research networks: experience of ICARDA and IDRC. Dr. G. Hawtin, director of agriculture, Food and Nutrition Sciences, International Development Research Centre (IDRC), Ottawa, Canada.

Origin and exploitation of cowpea and rice in African agriculture. Dr. Nyat-Quat Ng, head, Genetics Resource Unit, International Institute of Tropical Agriculture, Ibadan, Nigeria.

Growth, photosynthesis, and nutrition of rice during complete and partial submergence. Dr. T. Setter, senior lecturer, School of Agriculture, The University of Western Australia, Nedlands, Western Australia.

Relationship of biomass production and water use efficiency to gas exchange rates and efficiency. Dr. S. Peng, postdoctoral associate, Citrus Research and Education Center, Institute of Food and Agricultural Sciences (IFAS), University of Florida, USA.

Photosynthesis, aspects of regulation by nutrition, water and genotype and role in crop production. Dr. D.W. Lawlor, principal scientific officer, Rothamsted Experimental Station, Harpenden, Herts. England.

Climate change and rice: CO_2 and temperature. Dr. J.T. Baker, assistant research scientist, IFAS, University of Florida, USA.

IRRI: challenges for 1991. Dr. K.J. Lampe.

Indian experience in irrigation water management with special references to situational compatibility. Dr. B. Sahni, professor and head, Irrigation Engineering, Water and Land Management Institute, Aurangabad, India.

Research to sustain increases in productivity under variable environments. Dr. K. Fischer, deputy director general for research, International Institute of Tropical Agriculture, Ibadan, Nigeria.

Some water management aspects of sulfate soils in Mekong Delta, Vietnam. Dr. To Phuc Tuong, chairman, Department of Water Management, University of Agriculture and Forestry, Ho Chi Minh, SR Vietnam.

Implementing IRRI's personnel policy—guiding principles, status and outlook for 1991. Dr. K. Lampe.

Irrigation and production of rice in Abu Raya, Kafer El-Sheikh. Dr. R.L. Tinsley, professor of agronomy, Colorado State University, Fort Collins, Colorado, USA.

Tsukuba RFLP Project: past and future. Dr. A. Saito, National Institute of Agrobiological Resources, Tsukuba, Ibaraki, Japan.

Endophytic fungi, their properties and potential for increasing crop production. Dr. G. Latch, plant pathologist, New Zealand Department of Scientific and Industrial Research, New Zealand.

The production to consumption systems approach to agricultural commodities development; the vegetable oil/protein sub-sector in Kenya. C. Zulberti, consultant, The Vegetable Oil/Protein Sub-Sector in Kenya, IDRC, Canada.

Strengthening national agricultural research systems through training: the ICRAF approach. Ms. E. Zulberti, International Council for Research in Agroforestry, Nairobi, Kenya.

Shrub legumes for fodder on acid infertile soils of the humid tropics. Dr. B. Palmer, Division of Tropical Crops and Pastures, Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia.

Contribution of plant physiology to crop improvement: retrospect and propects. Dr. M.M. Ludlow, chief research scientist/program manager, Crop Improvement and Management, CSIRO, Australia.

The status of weed management in three types of rice culture. Dr. A.N. Rao, project officer, Andhra Pradesh State Council of Science and Technology, Hyderabad, India.

Matrix management for rice research design and implementation. Dr. H.G. Zandstra.

New technology of monoclonal antibody hybridomas. Dr. J.E. Liddell, training officer, Monoclonal Antibody Unit, University of Wales, College of Cardill, Wales, UK.

Research or extension?: on-farm experimentation in the Central Plateau of Burundi. Dr. M.M. Gaudreau, consultant, St. Paul, Minnesota, USA.

Starting from scratch: developing a researcher-extension-farmer interface for food crop research across diverse ecologies in Cameroon's rain forest. Dr. S.W. Almy, Food & Resource Economics Department, IFAS, University of Florida, USA.

Applications of near infrared technology in agriculture. P. Williams, laboratory consultant.

Divergent selection of maize population for adaptation to alternative cropping systems. Dr. T.C. Barker, Department of Plant Breeding, Cornell University, USA.

One out of the other three reflections from Cambodia. Dr. R.C. Chaudhary, plant breeder, Cambodia-IRRI Project.

Write it right—with your secret editor (an analysis of a computerized editorial program). Ms. C. Dedolph, University of Wisconsin-Madison.

Ecological approaches for engineering crops expressing *B. thuringiensis* genes. Dr. F. Gould, professor of entomology, North Carolina State University.

Pest population genetics and implications for resistance gene deployment. Dr. F. Gould, professor of entomology, North Carolina State University.

Welcome to IRRI. (Video presentation)

Aedes aegypti blood feeding behavior and the transmission of Dengue virus in a rice-growing area of southeastern Thailand. Dr. T.W. Scott, Department of Entomology, University of Maryland, College Park, Maryland, USA.

The importance of mentoring in professional development. Dr. J.R. Sedlacek, candidate, training and courseware specialist.

Rice in Eastern, Central, and Southern Africa: the need and opportunities for strengthening rice research in the region. Dr. K. Alluri, IRRI liaison scientist and INGER regional coordinator for Africa.

Indonesia and Cambodia: similarities and contrasts in plant nutrition, research, and extension. Dr. R. Chisholm, soil scientist.

Gender analysis: strengthening Winrock projects. Produced by the Development Studies Center of Winrock International Institute for Agricultural Development.

Private research and public benefit: a case study of pearl millet and sorghum hybrids in India. Dr. C. Pray, professor, Rutgers University, New Jersey, USA.

An anthropologist's view of rice. Dr. H.C. Conklin, professor of anthropology, Yale University, New Haven, USA.

Structure and expression of rice amylase multigene family. Dr. Ning Huang, Department of Genetics, University of California-Davis, USA.

Mode of action of lepidopteran-specific *Bacillus thuringiensis* delta-endotoxins endotoxins. Dr. M.G. Wolfersberger, senior research scientist, Department of Biology, Temple University, Pennsylvania, USA.

The molecular biology and manipulation of nitrogen metabolism in plants. Dr. T. Brears, postdoctoral associate, Laboratory of Plant Molecular Biology, The Rockefeller University, 1230 York Avenue, New York, USA.

Phosphorus in rainfed agriculture. Dr. K. Harmsen, director, Institute for Soil Fertility Research, Haren, The Netherlands.

Progress towards improving frost tolerance in plants with antifreeze protein gene. Dr. M. Saleem, plant molecular geneticist, Plant Biotechnology Institute, National Research Council of Canada, 110 Gymnasium Place, Saskatoon, Canada.

The CIAT Rice Program: research organization and progress in rice blast. Dr. R.S. Zeigler, rice program leader, Centro Internacional de Agricultura Tropical, Colombia.

Global warming: methane emission from wetland rice. IRRI-EPA Methane Project Team.

Soil microbial biomass in temperate arable cropping systems. Dr. K. Ritz, senior scientific officer, Soil-Plant Dynamics Group, Cellular and Environmental Physiology Department, Scottish Crop Research Institute, UK.

Enhancement of insect resistance in rice: gene mapping and transgenic approaches. Dr. J. Bennett, International Center for Genetic Engineering and Biotechnology, New Delhi, India.

A multidisciplinary approach to improving nitrogen use efficiency in maize. Dr. R.J. Eaglesham, adviser/consultant, Metapontum, Agrodios Metaponto, Italy.

Agroecosystem, sustainability, and participatory rapid appraisal. Dr. G. Conway, country representative, Ford Foundation, New Delhi, India.

Upland-lowland interactions and relationship between sustainability and poverty. Dr. P.L. Pingali.

Dynamics of microbiological processes in soil: from a micro-site to a soil-crop system. Dr. M. Saito, senior researcher, Department of Yamase Area Agro-Environment, Tohoku National Agricultural Experiment Station, Morioka, Japan.

Cultivation of direct-seeded flooded rice in the Krasnodar Region, USSR. Dr. A. Dobermann, Universitat Leipzig, Institut fur Tropische Landwirtschaft WB Bodenkunde & Dungung, F. R. Germany.

A new world for IRRI: new challenges, new partners. Ambassador R.O. Blake, chairman, Committee on Agricultural Sustainability for Developing Countries, 1709 New York Avenue, NW, Washington, D.C., USA.

The resource-poor producer: should our approach have a technological or socio-political focus? Dr. N.P. Magor, cropping systems agronomist, Bangladesh-IRRI Project.

Breeding and crop modeling. Prof. L.A. Hunt, Department of Crop Science, Ontario Agricultural College, Guelph, Ontario, Canada.

Thursday seminars

The International Rice Genealogical Data Base: how it evolved, and what it can do for you. Dr. T.R. Hargrove and Ms. V. L. Cabanilla.

RICECOM: operationalizing IRRI's support to the Philippine rice program. Dr. F.O. Cariño, IRRI communication liaison officer for the Philippines.

Growth, photosynthesis, and nutrition of rice during complete and partial submergence. Dr. T. Setter, The University of Western Australia, School of Agriculture, Nedlands, Western Australia.

Relationship of biomass production and water use efficiency to gas exchange rates and efficiency. Dr. Shaobing Peng, postdoctoral associate, Citrus Research and Education Center, Institute of Food and Agricultural Sciences, University of Florida.

Photosynthesis, aspects of regulation by nutrition, water and genotype and role in crop production. Dr. D.W. Lawlor, principal scientific officer, Rothamsted Experimental Station, Harpenden, Herts, England.

Climate change and rice: CO_2 and temperature. Dr. J.T. Baker, assistant research scientist, Institute of Food and Agricultural Sciences, University of Florida.

IRRI: the challenges for 1991. Dr. K.J. Lampe.

Seeds of hope. (video)

Use and misuse of mean comparison. Dr. V.A. Samaranayake, associate professor, Department of Mathematics and Statistics, University of Missouri, Rolla, USA.

Biofertilizer germplasm collections in Soil Microbiology Division. Dr. I. Watanabe, soil microbiologist and head; and Dr. P.A. Roger, visiting scientist, Soil Microbiology Division.

Determinants of rice price protection. Dr. C.C. David.

Travel. Ms. J.G. de Villa, author of *Luzon by car* and *Philippine vacations*.

Evaluation of the health effects of pesticide use among rice farmers. Dr. C.B. Marquez and Dr. P.L. Pingali.

Effects of pesticides on soil and water microflora and fauna in wetland ricefields. Dr. P.A. Roger, visiting scientist, Soil Microbiology Division.

Modeling in the analysis of pest management strategies. Dr. K.L. Heong.

Progress of research in Madagascar: toward identifying 75 low input technological improvements by 1995. Dr. J.R. Hoopper III, agronomist, Madagascar-IRRI Project.

Policy reforms and rice research priorities in Vietnam. Dr. P.L. Pingali.

Traditional rainfed lowland rice varieties and farmers' decision-making in varietal preference in Cambodia. Dr. R.P. Lando, technology transfer specialist, Cambodia-IRRI Project.

Word for word: perfect! Tricks with Word5. Mr. F. Hilario, free-lance word processing specialist.

Reducing N fertilizer losses: what are the potential economic benefits? Dr. R.J. Buresh, visiting scientist, Agronomy, Plant Physiology, and Agroecology Division; and Dr C.A. Banaante, economist, International Fertilizer Development Center, Alabama, USA.

Phosphorus chemistry and fertility in relation to phosphorus sources in acid soils in South and Southeast Asia. Dr. S.K. Sanyal, visiting scientist, Agronomy, Plant Physiology, and Agroecology Division.

Stem nodule-Rhizobium symbiosis: a system with several unusual features. Dr. J.K. Ladha.

Farmers' azolla management and determinants of its use in Philippine rice production. Mr. A. Mandac, Mr. V. Marciano, Mr. W. Ventura, Dr. J.C. Flinn, and Dr. I. Watanabe.

Strategic agronomic research for modern rice technology. Dr. S.K. De Datta.

Cereals on the slopes: the crop ecological implications of contour hedgerow technologies. Dr. D.P. Garrity.

Hilly land sustainable agriculture. Dr. F. Gorrez, Toledo Agricultural and Marketing Project, Belize.

Isolation, characterization, and assay of *Bacillus thuringiensis* for use against rice insect pests. Dr. W. Theunis, postdoctoral scientist, Entomology Division.

Techniques for evaluating insect resistance in crop plants. Dr. Z.R. Khan.

Highlights of the Rockefeller Rice Biotechnology Network. Dr. G.H. Toenniessen, associate director, The Rockefeller Foundation, New York, USA.

Insect population genetics: implications for plant resistance. Dr. G.G. Roderick, assistant professor, Department of Entomology, University of Maryland, College Park, USA.

Two ears of corn: a review of the economic consequences of agricultural research. Dr. R.E. Evenson, visiting scientist, Social Sciences Division.

Prospects of biological weed control in Southeast Asia. Dr. A. Watson, visiting scientist, Plant Pathology Division.

Assessment of training needs of crop management researchers in developing countries. Dr. R. Raab, ISNAR, The Hague, The Netherlands.

Soil solution in activities and zinc, iron, and manganese transformation in submerged soils. Dr. G. Amedee, visiting scientist, Soil and Water Sciences Division.

Weed management for rice in Latin America: herbicide resistance, competition, and approach to predicting yield losses from multispecies interference. Dr. A. Fischer, Centro Internacional de Agricultura Tropical, Cali, Colombia.

Intercropped green manuring for rainfed lowland rice. Dr. T.N. Chaudhary, research fellow, Agricultural Engineering Division.

Needs and constraints in the development and implication of Integrated Pest Management in Sub-Saharan Africa. Dr. A. van Huis, tropical entomologist, Wageningen Agricultural University, The Netherlands.

Diversity and developmental biology of riceland spiders. Mr. A.T. Barrion.

Durable resistance to rice blast: influence of environment. Dr. J.M. Bonman.

Rice ecosystem analysis for Cambodia. Dr. R.C. Bruce, consultant, Cambodia-IRRI Project.

Engineered pest control: rodents, snails, and safer pesticide application. Dr. N.K. Awadhwal and Dr. G.R. Quick.

Application of remote sensing and geographic information systems for ecosystems planning and management. Mr. E.C. Godilano.

The IPM Program in Indonesian rice. Dr. I.N. Oka, principal scientist, Bogor Research Institute for Food Crops, Bogor, Indonesia.

Insect pest monitoring and control practices of rice farmers from several areas in Luzon. Dr. L.R.I. Velasco, assistant professor, Department of Entomology, University of the Philippines at Los Baños.

Sustainability and soil quality: What do we know about the irrigated rice ecosystem? Dr. K. J. Cassman.

Micro and meso level applications of geographic information systems (GIS) among slash-and-burn (swidden) horticulturalists or, just what is an archaeologist doing at IRRI? Dr. E.D. Hunt, visiting GIS specialist, Agronomy, Plant Physiology, and Agroecology Division.

Upland-lowland interactions and the relationship between sustainability and poverty. Dr. P.L. Pingali.

Current rice situation in Japan: production, consumption, and policies. Dr. S. Ito, associate professor, Faculty of Agriculture, Tottori University, Japan.

Moving biotechnology from the laboratory to the field: issues and considerations. Dr. R.J. Cook, research leader, Root Disease and Biological Control Research Unit, USDA-Agricultural Research Service, USA.

Division seminars

Agronomy, Plant Physiology, and Agroecology

Intercropping of upland rice with forage legumes in a low input system. Mr. R.D. Magbanua.

Service and research activities of the Agroclimatic Unit. Ms. H.G. Centeno.

Crop intensification and its effects and weeds and crop yields in Claveria, Misamis Oriental. Mr. E.M. Castin, Mr. P.C. Elliot, Mr. H. Franje, and Dr. K. Moody.

Performance of three soybean cultivars grown under furrow irrigation. Ms. J. Alagos.

Root dynamics of wet-seeded and transplanted rice as characterized by the mini-rhizotron technique. Ms. F.D. Bueno, Dr. K.T. Ingram, and Dr. C.A. Beyrouty.

Lock-lodging technology for a successful ratoon rice cropping. Mr. A.N. Calendacion, Dr. D.P. Garrity, and Dr. K.T. Ingram.

Applications of GIS in agroecology research. Mr. A. Blanco and Dr. D.P. Garrity.

Weed problems in rice and research needs in the IRRI-Bhutan rice farming systems research. Mr. D.C. Navarez and Dr. K. Moody.

Agronomic and physiological responses of upland rice to different levels of soil water deficit. Ms. O.S. Namuco, Mr. J.A. Malabuyoc, Dr. K.T. Ingram, and Dr. S.K. De Datta.

Evapotranspiration and yield of wetland rice under non-submerged condition. Mr. C.A. Redulla and Dr. S.K. De Datta.

Grain yield as a function of rainfall, soil moisture, and solar radiation in upland rice. Mr. J.A. Malabuyoc and Dr. S.K. De Datta.

Quantification of crop-weed interactions and weed management. Dr. M.J. Kropff.

Simulation of upland rice yields in response to soil moisture. Ms. E.B. Yambao, Dr. K.T. Ingram, Mr. J.A. Malabuyoc, and Dr. S.K. De Datta.

High temperature effects on crop and grain growth of four rice cultivars. Dr. A.E. Egeh, consultant; and Dr. K.T. Ingram, agronomist and deputy division head.

Collaborative Vietnam/IRRI/IFDC research on integrated nutrient management. Dr. T.T. Son, nondegree research scholar; Mr. N.N. Hung, nondegree research scholar; and Dr. R.J. Buresh, visiting scientist.

Entomology

Screening for BPH resistance and the Division centralized insect rearing and collection. Mr. F. Medrano.

Integration of farming system to IPM development. Mr. J. Bandong.

Sources of information in entomology. Ms. M. Austria.

Genetic variation in populations of the yellow stem borers *Scirpophaga incertulas* (Walker) on hybrids of *Oryza sativa* and *Oryza brachyantha* cross. N. van Huynh, Ph D scholar.

Application of Geographic Information Systems (GIS) on pest surveillance—a case study in Korea. Dr. Y. Song, research fellow I.

Effect of single and multiple pests and stresses on yield loss of transplanted rice. Mr. B. Canapi.

Plant Breeding, Genetics, and Biochemistry

Anther and isolate microscope culture studies in rice—a progress report. Dr. A.L. Carpena, postdoctoral fellow.

Cytoplasmic and nuclear genome differentiation in rice species. Dr. T. Ishii, research fellow.

Overview of rice research and production in Egypt. Dr. M.S. Balal, director, Rice Research and Development Program, Agricultural Research Center, Giza, Egypt.

Analysis of international nurseries and implications to breeding programs — a study of wheat nurseries. Prof. D. Byth, chairman, Sugar Research and Development Corporation, Australia.

Plant Pathology

On IPM and sustainable agriculture. Dr. P.S. Teng.

Interest of categorized information on crop loss studies. Dr. S. Savary.

New technology of monoclonal antibody hybridomas. Dr. J. Eryl Liddel, training officer, Monoclonal Antibody Unit, University of Wales, College of Cardiff, Wales.

Epidemiology of bacterial blight of rice using monoclonal antibodies. Ms. P. Roberts, scholar.

Nematode problems in rice ecosystems prospective. Dr. J. C. Prot.

Rice virus disease problem in Madagascar. Mr. P.Q. Cabauatan.

Partial resistance to rice blast. Dr. E. Roumen, collaborative research fellow.

Genetics of the rice blast fungus: from laboratory to the field. Dr. H. Leung.

Rice diseases in DPR Korea and Iran. Dr. T.W. Mew.

On-farm pest survey. Mr. F.A. Elazegui.

Moving biotechnology from lab to the field: issues and considerations. Dr. R.J. Cook, research leader, USDA/ARS, Department of Plant Pathology, Washington State University.

Soil Microbiology

Prediction of mechanism of soil N supply to irrigated and rainfed lowland rice. Ms. G.B. Mascariña.

Exploration and evaluation of aquatic legumes as green manure for lowland rice. Ms. D. de Castro.

Standardization of NO_3 analysis method. Ms. C. Ramirez.

Taxonomic characterization of *Sesbania* and *Aeschynomene* Rhizobia. Mr. R. So.

Azolla collections—shoot tip culture. Ms. T. Ventura and Mr. B.C. Padre.

IRRI-NifTAL collaborative project: conservation and use of soil and atmospheric N in lowland rice-based cropping systems. Ms. G. Punzalan.

Occurrence and activity of carbonic anhydrase in ricefield floodwater. Ms. Ma. L. Daroy.

Microbial biomass analysis/CHN analyzer. Ms. R. Jimenez.

Varietal screening for N uptake and N utilization efficiency. Ms. A. Padre and Mr. B. Pacia.

Performance of aquatic legumes on different soils. Dr. B. Kranz, affiliate research scholar, University of Hohenheim, Germany.

IRRI-NifTAL-IFDC collaborative research: a progress report. Dr. T. George, collaborative research fellow, NifTAL, University of Hawaii, USA.

Availability of nitrogen in some wetland rice soils: a progress report. Dr. I.J. Manguiat, research fellow III.

Soil and Water Sciences

Field variations of soil and the growth of direct-seeded flooded rice. Dr. A. Dobermann, collaborative research scientist.

Staff changes

January

Dr. Vethaiya Balasubramanian, former maize agronomist and coordinator, IITA/Cameroon, was appointed as soil scientist, Madagascar-IRRI Rice Research Project.

Dr. Serge Savary, senior scientist, ORSTOM, France, joined the Plant Pathology Division as visiting scientist.

Dr. Moo Sang Lim, scientist, Rural Development Administration, Korea, joined the Plant Breeding, Genetics, and Biochemistry Division as visiting scientist.

Dr. David R. Bouldin, professor of Soil Science, Cornell University, USA, joined the Soil and Water Sciences Division as visiting scientist.

Mr. D. Subramaniam, chief engineer, ICRISAT, India, joined the Director General's Office as visiting scientist.

Mr. John M. Dowling, rejoined IRRI as consultant, Office of the Deputy Director General for Finance and Administration.

February

Dr. Walter Roder, former research agronomist, Swiss Association for Development and Cooperation, Bhutan, was appointed as agronomist, LAO-IRRI Project.

Atty. Zosimo Q. Pizarro, manager, Legal Office, retired.

Dr. Evangelyn C. Alocilja, visiting assistant professor, Michigan State University, USA, joined the Plant Pathology Division as consultant.

Dr. Romeo Bruce, rejoined IRRI as consultant, Agronomy, Plant Physiology, and Agroecology (APPA) Division.

March

Dr. Kenneth G. Cassman, former assistant professor, Department of Agronomy and Range Science, University of California at Davis, USA, was appointed as head, APPA Division.

Dr. Stephen J. Banta, editor, Communication and Publications Services, resigned.

Dr. Iwao Watanabe, soil microbiologist and head, Soil Microbiology Division, resigned.

Dr. Mubarik Ali, agricultural economist, ACSCA Project, Islamabad, Pakistan, joined the Social Sciences Division as visiting scientist.

Dr. Keijiro Otsuka, rejoined IRRI as consultant, Social Sciences Division.

April

Dr. Tomas Masajo, former plant breeder, Rice Research Program, IITA, Ibadan, Nigeria, was appointed as plant breeder, Madagascar-IRRI Rice Research Project.

Dr. Hubert G. Zandstra, deputy director general for research programs, resigned.

Dr. Philip Williams, Canadian Grain Commission, Grains Research Laboratories, Winnipeg, Manitoba, Canada, rejoined IRRI as consultant, Office of the Deputy Director General for Research Programs.

May

Dr. Richard L. Tinsley, former professor of agronomy, Colorado State University, USA, was appointed as agronomist and team leader, Egypt-IRRI Rice Research Project.

Mr. William H. Smith, editor, Communication and Publications Services, resigned.

Dr. James R. Hoopper III, agronomist, Madagascar-IRRI Rice Research Project, left after completing his assignment.

Dr. H. David Catling, rejoined IRRI as consultant, IRRI-Thailand Office.

Dr. David R. Bouldin, visiting scientist, Soil and Water Sciences Division, left after completing his assignment.

Dr. Philip Williams, consultant, Office of the Deputy Director General for Research, left after completing his assignment.

Dr. Laurian Unnevehr, rejoined IRRI as consultant, Social Sciences Division.

June

Dr. To Phuc Tuong, former chairman, Department of Water Management, University of Agriculture and Forestry, Ho Chi Minh City, Vietnam, was appointed as water management engineer, Soil and Water Sciences Division.

Dr. David J. Mackill, plant breeder, Plant Breeding, Genetics, and Biochemistry Division, resigned.

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Dr. Zeyaur R. Khan, associate entomologist, Entomology Division, left after completing his assignment.

Dr. A. P. K. Reddy, plant pathologist, Egypt-IRRI Rice Research Project, left after completing his assignment.

Dr. H. David Catling, consultant, IRRI-Thailand Office, left after completing his assignment.

Dr. Laurian Unnevehr, consultant, Social Sciences Division, left after completing her assignment.

Dr. Derk HilleRisLambers, plant breeder, transferred from Plant Breeding, Genetics, and Biochemistry Division to Egypt-IRRI Rice Research Project.

July

Dr. Michael T. Jackson, former lecturer, School of Biological Sciences, University of Birmingham, UK, was appointed as head of the Genetic Resources Center.

Dr. Adusumilli Narayana Rao, former associate professor, Andhra Pradesh Agricultural University, India, was appointed as agronomist (weed scientist) in the Egypt-IRRI Rice Research Project.

Dr. Ramesh C. Saxena, entomologist, Entomology Division, left after completing his assignment.

Dr. Richard P. Lando, technology transfer specialist, Egypt-IRRI Rice Research Project, left after completing his assignment.

Mr. Timothy L. Bertotti, director for administration, left after completing his assignment.

Mr. James J. Mullaney, international human resource consultant, joined as consultant and acting director for administration, Director General's Office.

Dr. Alan K. Watson, professor, Department of Plant Science, McGill University, Canada, joined the Plant Pathology Division as visiting scientist.

Ms. DeeAnna Adkins, from Extension and Agricultural Information, University of Missouri-Columbia, USA, joined the Communication and Publications Services as editorial associate.

Dr. Robert Evenson, from Yale University, joined as visiting scientist, IRGC and INGER Program.

Dr. Douglas Gollin, from University of Minnesota, joined as assistant visiting scientist, IRGC and INGER Program.

Dr. Evangelyn C. Alocilja, consultant, transferred from Plant Pathology Division to APPA Division.

August

Dr. Ellis L. Matheny Jr., former visiting scientist, Training Center, was appointed as head of the Training Center.

Dr. Kenneth S. Fischer, former deputy director general for research, IITA, Nigeria, was appointed as deputy director general for research programs, Director General's Office.

Dr. Surapong Sarkarung, former plant breeder, CIAT, Cali, Colombia, was appointed as plant breeder, Plant Breeding, Genetics, and Biochemistry Division.

Dr. Susan W. Almy, from the Food and Resource Economics Department, IFAS, University of Florida, USA, was appointed as agro-economist, Madagascar-IRRI Project.

Dr. Martha M. Gaudreau, former consultant, INADES-Burundi for UNIFEM, New York, was appointed as cropping systems agronomist, Madagascar-IRRI Project.

Dr. Timothy L. Setter, former senior lecturer, Tropical Crops Research Group, The University of Western Australia, was appointed as plant physiologist, APPA Division.

Ms. Carolyn C. Dedolph, freelance editor/writer from Stratford, Wisconsin, USA, was appointed as science editor/writer, CPS.

Mr. Jeffrey J. Hastings, former research scientist, University of Queensland, Gatton College, Australia, was appointed as project leader, Engineering Component, ADB Project TA5349.

Dr. Dan R. Minnick, training specialist and head, Training Center, resigned.

Dr. Robert Evenson, visiting scientist, IRGC and INGER, left after completing his assignment.

Dr. Douglas Gollin, assistant visiting scientist, IRGC and INGER Program, left after completing his assignment.

Mr. D. Subramaniam, visiting scientist, Director General's Office, left after completing his assignment.

Dr. Romeo Bruce, consultant, APPA Division, left after completing his assignment.

Dr. Pierce H. Jones, associate professor, Agricultural Engineering Division, University of Florida, USA, joined the APPA Division as consultant and left the same month after completing his assignment.

September

Dr. John M. Bonman, plant pathologist, Plant Pathology Division, resigned.

Dr. John C. Flinn, principal scientist, Social Sciences Division, died.

Ms. Leslie Rose, joined the Communication and Publications Services as consultant.

Dr. Eleazer D. Hunt, acting assistant professor, Department of Anthropology, University of Washington, USA, joined the APPA Division as visiting scientist.

Dr. V. Samaranayake, visiting scientist, Project Management Services and Biometrics, left after completing his assignment.

Dr. Gaston Amedee, visiting scientist, Soil and Water Sciences Division, left after completing his assignment.

Dr. Keijiro Otsuka, consultant, Social Sciences Division, left after completing his assignment.

October

Dr. Robert T. Raab, former research associate, Training Materials Development, ISNAR, The Hague, The Netherlands, was appointed as training and courseware specialist, Training Center.

Dr. Shaobing Peng, postdoctoral associate, University of Florida, USA, joined the APPA Division as visiting scientist.

November

Mr. John Dowling, consultant, Office of the Deputy Director General for Finance and Administration, left after completing his assignment.

December

Mr. Noel P. Magor, agronomist cropping systems, Bangladesh-IRRI Project, left after completing his assignment.

Dr. Thomas R. Hargrove, editor and head, Communication and Publications Services, resigned.

Dr. Muhammad Akbar, plant breeder, Network Coordination, left after completing his assignment.

Dr. Te-Tzu Chang, principal geneticist and head, International Rice Germplasm Center, retired.

Ms. Leslie Rose, consultant, Communication and Publications Services, was appointed associate video producer (visiting scientist), Communication and Publications Services.

Dr. Wesley Buchele, professor emeritus, Iowa State University, USA, joined the Agricultural Engineering Division as visiting scientist.

Dr. Robert and Mrs. Eleanor Huke, rejoined the Social Sciences Division as visiting scientists.

Dr. Abdullahi O. Egeh, postdoctoral fellow, APPA Division, was appointed as consultant, APPA Division.

Dr. H. H. van Laar, from the Wageningen Agricultural University, joined the APPA Division as consultant.

Dr. Robert Bos, scientist, Community Water Supply and Sanitation Unit, and secretary, WHO, Geneva, Switzerland, joined the Entomology Division as consultant.

Dr. Jit Bhuktan, consultant, IPMO, left after completing his assignment.

Dr. Evangelyn C. Alocilja, consultant, APPA Division, left after completing her assignment.

Ms. Gina Ordoñez, consultant, Training Center, left after completing her assignment.

Dr. Pierce H. Jones, consultant, APPA Division, rejoined IRRI and left the same month after completing his assignment.

Dr. Benito S. Vergara, plant physiologist and acting division head, APPA Division, became Director for Administration.

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Finances

Summary of financial support to IRRI core and complementary (special) projects committed for 1991.

Source	Amount (US$)			
	Core		Complementary (special) projects	Total
	Unrestricted	Restricted[a]		
Japan		7,281,882	78,400	7,360,282
United States Agency for International Development	5,400,000	26,737	2,615,443	8,042,180
United States Environmental Protection Agency			933,642	933,642
International Bank for Reconstruction and Development	2,887,000			2,887,000
European Economic Community	2,313,265			2,313,265
Canadian International Development Agency	1,576,942		173,882	1,750,824
Australia	665,890	41,861	904,529	1,612,280
United Nations Development Programme		1,910,634		1,910,634
Overseas Development Administration — United Kingdom	1,555,016		152,723	1,707,739
The Swiss Development Cooperation		22,417	582,690	605,107
Federal Republic of Germany	710,430		6,793,015	7,503,445
The Rockefeller Foundation		340,483	402,023	742,506
The Netherlands		339,775	193,299	533,074
France[b]		255,931		255,931
Swedish Agency for Research Cooperation	805,143			805,143
Asian Development Bank		258,059	1,500,840	1,758,899
Danish International Development Agency	573,466		58,200	631,666
Finland	555,546			555,546
Belgium	150,376	166,242	120,315	436,933
The Ford Foundation	150,000	262,000	163,000	575,000
International Development Research Centre — Canada			613,422	613,422
Italy	80,199	200,000		280,199
Philippines	103,339		32,356	135,695
Norway	121,960			121,960
India	100,000			100,000
China	50,000			50,000
Food and Agriculture Organization — UN			59,399	59,399
Spain	30,000			30,000
Republic of Korea	200,000	30,000	117,839	347,839
Others			32,490	32,490
Total	18,028,572	11,136,021	15,527,507	44,692,100

[a]Includes essential special projects. [b]The Government of France (through the research organizations ORSTOM and IRAT) also provided IRRI the services of four resident scientists; the value of their services cannot be quantified.

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Weather summary

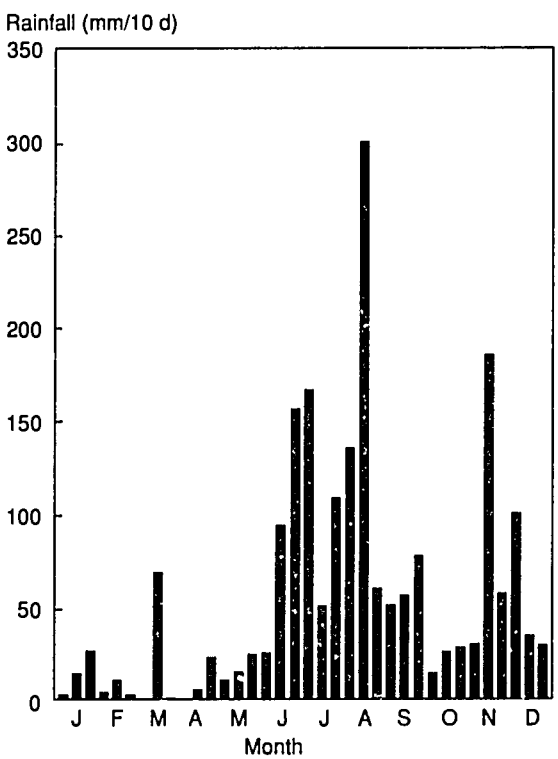
Table 1 summarizes monthly weather data on the dryland site, the wetland site, and seven outreach and cooperating stations in the Philippines during 1991.

Annual total rainfall was 1,963 mm for the dryland (upland) site and 1,980 mm for the wetland (lowland) site. This was 162 mm lower than the long-term average rainfall at the upland site and 68 mm lower than that at the lowland site. The wet season (WS) lasted from mid-June until December (Fig. 1). The longest wet spell lasted 14 d on the upland farm (8-21 August) and 12 d (10-21 August) on the lowland farm. An unusual 9-d dry spell occurred in October. During the January to May dry period, 7 isolated days had more than 10 mm of rain. The longest dry spell (28 d) lasted from 22 March to 18 April.

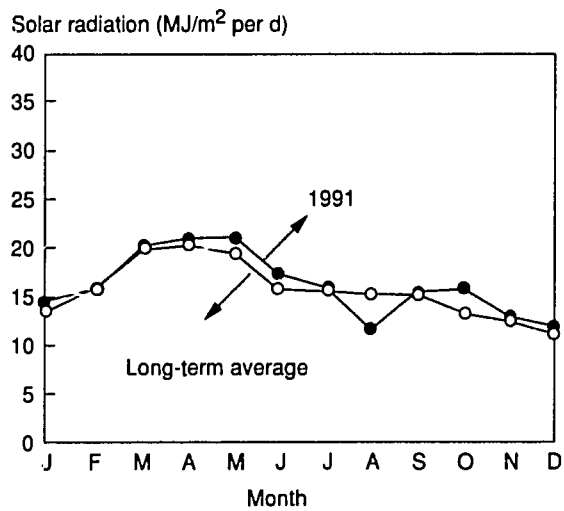
Solar radiation peaked at 21 MJ/m^2 per d in May, then declined below 15 MJ/m^2 per d in December. The radiation trend conformed to the past 12-yr pattern (Fig. 2). Radiation was extremely low in August, corresponding with the high rainfall in that month.

Sunshine averaged 8 h/d from January to June, then declined to 4 h/d in December. The sky was overcast on 13-21 August.

The monthly mean temperature peaked at 34.4 °C in May at the upland farm and at 33.6 °C at the lowland site, then gradually decreased to a mean monthly low value of 28.6 °C on the upland



1. Rainfall by 10-d period, IRRI, 1991.



2. Long-term average and 1991 solar radiation at IRRI.

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Table 1. Monthly weather data for IRRI outreach and cooperating stations in the Philippines, 1991.

Site		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total or daily average
							Rainfall (mm/mo)							
Banaue, Ifugao	(16°56'N, 121°00'E)	134	214	28	153	166	67	289	483	349	278	146	130	2428
Cavinti, Laguna	(14°17'N, 121°30'E)	176	173	177	216	201	500	302	503	256	202	410	610	3726
Claveria, Misamis Oriental	(08°38'N, 124°55'E)	115	32	88	109	46	97	249	157	105	332	56	16	1402
Guimba, Nueva Ecija	(15°39'N, 120°47'E)	2	0	2	35	62	233	203	355	390	167	51	0	1499
IRRI, dryland site	(14°13'N, 121°15'E)	40	25	73	32	43	198	290	519	193	82	301	165	1963
IRRI, wetland site	(14°11'N, 121°15'E)	47	19	70	28	50	275	324	493	181	65	268	160	1980
PhilRice, Muñoz, Nueva Ecija	(15°45'N, 120°56'E)	1	0	4	24	23	54	238	424	438	98	30	0	1334
Solana, Cagayan	(17°39'N, 121°41'E)	21	16	4	77	18	38	209	416	81	336	138	19	1373
Visayas Experiment Station, Iloilo	(10°45'N, 122°35'E)	7	25	39	76	34	319	273	511	75	136	198	40	1734
							Solar radiation (MJ/m² per d)							
Banaue, Ifugao		14.6	12.5	20.7	18.4	18.9	19.3	15.2	16.9	16.2	16.2	13.3	14.5	16.4
Cavinti, Laguna		14.9	16.6	20.0	20.8	21.2	18.0	17.2	12.8	15.7	19.4	14.6	13.8	17.1
Claveria, Misamis Oriental		16.7	19.8	20.3	21.3	19.9	18.9	18.6	19.8	18.7	19.2	18.3	17.8	19.1
Guimba, Nueva Ecija		17.2	18.3	21.1	21.5	21.8	18.9	18.0	13.9	16.8	19.6	19.4	18.9	18.8
IRRI, dryland site		14.8	15.2	20.1	20.2	20.8	16.3	15.4	11.2	15.6	16.0	13.4	13.0	16.0
IRRI, wetland site		14.6	15.7	20.3	21.1	21.2	17.4	16.1	11.8	15.7	16.1	13.2	12.2	16.3
PhilRice, Muñoz, Nueva Ecija		18.3	19.6	21.5	21.6	21.3	17.9	18.3	16.6	17.4	17.4	16.1	18.0	18.7
Solana, Cagayan		15.9	16.6	21.0	21.0	21.5	21.0	19.5	20.2	19.2	18.0	15.8	16.0	18.8
Visayas Experiment Station, Iloilo		16.7	18.6	19.3	20.8	19.3	15.6	16.1	13.9	17.5	17.5	17.0	16.1	17.4
							Temperature (°C)							
Banaue, Ifugao	Max	22.6	22.1	25.6	26.0	25.8	27.5	26.5	26.7	26.3	25.1	23.2	22.2	25.0
	Min	15.1	16.0	16.1	17.7	17.0	18.1	18.2	19.3	17.8	16.6	15.8	14.2	16.8
Cavinti, Laguna	Max	25.4	26.1	27.2	29.4	30.2	29.7	29.3	27.5	28.8	28.8	26.2	24.8	27.8
	Min	19.4	19.1	19.4	20.7	21.4	21.6	20.8	21.0	21.0	20.0	20.0	19.5	20.3
Claveria, Misamis Oriental	Max	27.5	27.4	28.5	29.5	29.6	29.7	28.5	29.7	29.8	28.9	28.5	28.3	28.8
	Min	20.2	20.5	20.2	21.4	22.4	22.7	21.7	22.2	22.0	21.4	21.2	20.9	21.4
Guimba, Nueva Ecija	Max	31.8	32.3	32.9	34.4	35.8	34.6	31.8	30.7	31.3	32.1	32.0	32.2	32.7
	Min	20.5	21.3	20.3	22.9	24.9	24.5	24.1	24.0	20.5	21.4	20.3	20.4	22.1

Table 1. Continued.

Site		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total or daily average
							Temperature (°C)							
IRRI, dryland site	Max	29.9	29.9	31.4	33.5	34.4	33.1	31.9	29.9	31.6	31.6	29.4	28.6	31.3
	Min	22.3	22.2	22.1	23.5	24.5	24.9	24.0	24.0	24.0	23.0	22.5	22.4	23.3
IRRI, wetland site	Max	28.9	29.2	30.0	32.1	33.6	32.7	31.3	29.8	31.3	30.9	29.1	28.1	30.6
	Min	21.9	22.1	22.0	23.7	24.7	25.0	24.3	24.4	24.5	23.4	22.6	22.5	23.4
PhilRice, Muñoz, Nueva Ecija	Max	29.5	29.7	30.3	32.4	33.8	33.1	31.3	29.7	30.4	30.5	30.6	30.9	31.0
	Min	21.4	21.8	20.9	22.8	23.7	24.2	23.0	23.8	23.7	22.1	21.3	21.0	22.5
Solana, Cagayan	Max	28.7	29.0	33.0	33.7	35.9	36.8	34.8	32.8	32.4	31.5	28.4	27.8	32.1
	Min	20.2	20.6	20.5	23.2	23.9	24.7	24.4	24.3	24.4	22.8	21.9	19.2	22.5
Visayas Experiment Station, Iloilo	Max	29.9	31.1	31.5	33.0	33.0	31.9	30.3	29.5	30.1	30.5	30.2	29.7	30.9
	Min	22.9	23.1	22.7	24.1	24.8	24.9	24.3	24.1	24.2	23.5	23.1	22.8	23.7
							Windspeed (m/s)							
Banaue, Ifugao		0.3	0.3	0.5	0.4	0.4	0.5	0.4	0.3	0.4	0.5	0.5	0.5	0.4
Cavinti, Laguna		2.3	2.3	2.4	1.9	1.9	1.6	1.7	1.9	1.8	1.3	2.2	3.0	2.0
Claveria, Misamis Oriental		0.8	0.9	1.2	1.3	1.2	1.1	0.9	0.9	1.0	0.8	0.7	1.0	1.0
Guimba, Nueva Ecija		2.3	2.2	2.0	2.1	1.6	1.5	m	m	m	m	1.7	3.0	2.0
IRRI, dryland site		1.7	1.5	1.8	1.5	1.6	1.9	1.6	1.4	1.9	1.4	1.6	1.9	1.6
IRRI, wetland site		1.8	1.7	1.8	1.7	1.7	1.7	1.6	1.3	1.7	1.5	1.6	2.0	1.7
PhilRice, Muñoz, Nueva Ecija		3.2	2.8	2.3	1.9	2.0	2.1	1.7	1.3	1.0	1.2	1.8	3.7	2.1
Solana, Cagayan		0.5	0.8	0.8	0.9	0.9	1.1	1.2	0.8	0.7	1.1	1.0	0.7	0.9
							Evaporation (mm/mo)							
Banaue, Ifugao		81	74	135	126	141	136	133	120	107	99	62	74	1288
Cavinti, Laguna		84	98	156	155	174	141	133	103	119	118	85	88	1453
Claveria, Misamis Oriental		129	138	163	171	169	156	154	165	154	154	138	138	1829
Guimba, Nueva Ecija		170	136	229	245	250	212	135	128	128	152	165	184	2134
IRRI, dryland site		146	122	205	201	227	175	147	101	146	145	104	111	1830
IRRI, wetland site		123	114	176	183	211	168	146	102	132	135	99	104	1693
PhilRice, Muñoz, Nueva Ecija		189	178	193	205	217	176	160	120	103	123	148	67	1879
Solana, Cagayan		101	113	184	182	224	229	186	156	134	136	89	83	1817
Visayas Experiment Station, Iloilo		161	181	191	210	181	162	129	120	129	131	119	133	1847

farm and 28.1 °C at the lowland site in December. The highest temperature, 36.3 °C, was measured on the upland farm on 15 May.

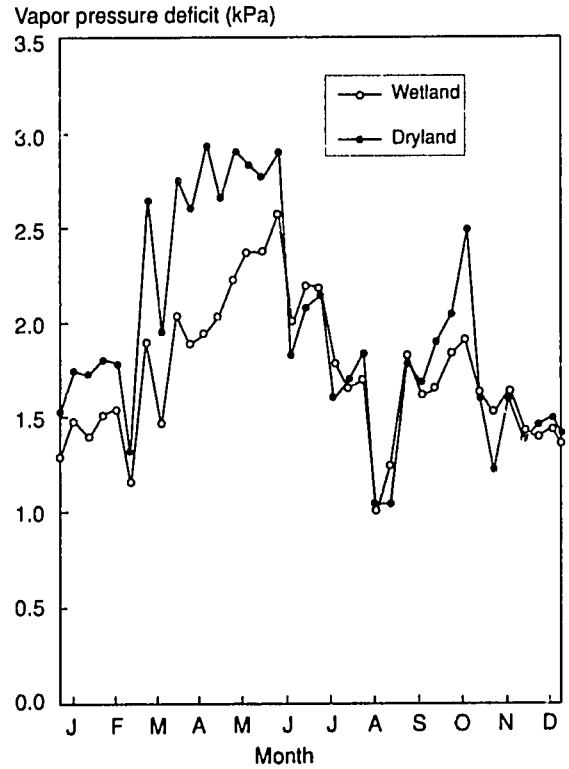
The monthly mean minimum temperature for both upland and lowland sites was 22-25 °C. The lowest minimum temperatures, 18.2 °C at the upland site and 19.1 °C at the lowland site, occurred on 11 November.

Mean relative humidity was lowest in May (76% on the upland farm and 74% on the lowland farm) and was more than 82% during WS at both sites. During the dry season (DS), vapor pressure deficits were generally higher at the upland station than at the lowland station (Fig. 3). Vapor pressure deficit at midday increased to 2.8 kPa in May on the upland farm and 2.3 on the lowland farm, and declined to approximately 1.4 kPa in WS at both sites.

Daily mean windspeed (measured at 2 m aboveground) was 1.6 m/s. Maximum 24-h average windspeed was 6.8 m/s at the upland site and 6.2 m/s at the lowland site (28 October).

Air temperatures and vapor pressure deficit were slightly higher on the upland farm than on the lowland farm, particularly during DS, causing slightly higher evaporation on the upland farm from January to June. The monthly total peaked in May (227 mm on the upland and 211 mm on the lowland farm), and was lowest during WS (approximately 100 mm at each site).

Sixteen tropical disturbances entered the Philippine area of responsibility in 1991. None caused damage in Los Baños. But *Uring* (early November) caused a flash flood that seriously damaged infrastructure, buildings, and livelihood in Leyte.



3. Midday vapor pressure deficit at wetland and dryland stations. IRRI, 1991.

Mt. Pinatubo erupted in June. The strong winds of typhoon *Diding* scattered the ashes over the country. About 2 cm of ash was deposited in the Los Baños area. Turbidity lowered the measured incoming solar radiation and partly (but temporarily) offset the global warming trend.

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