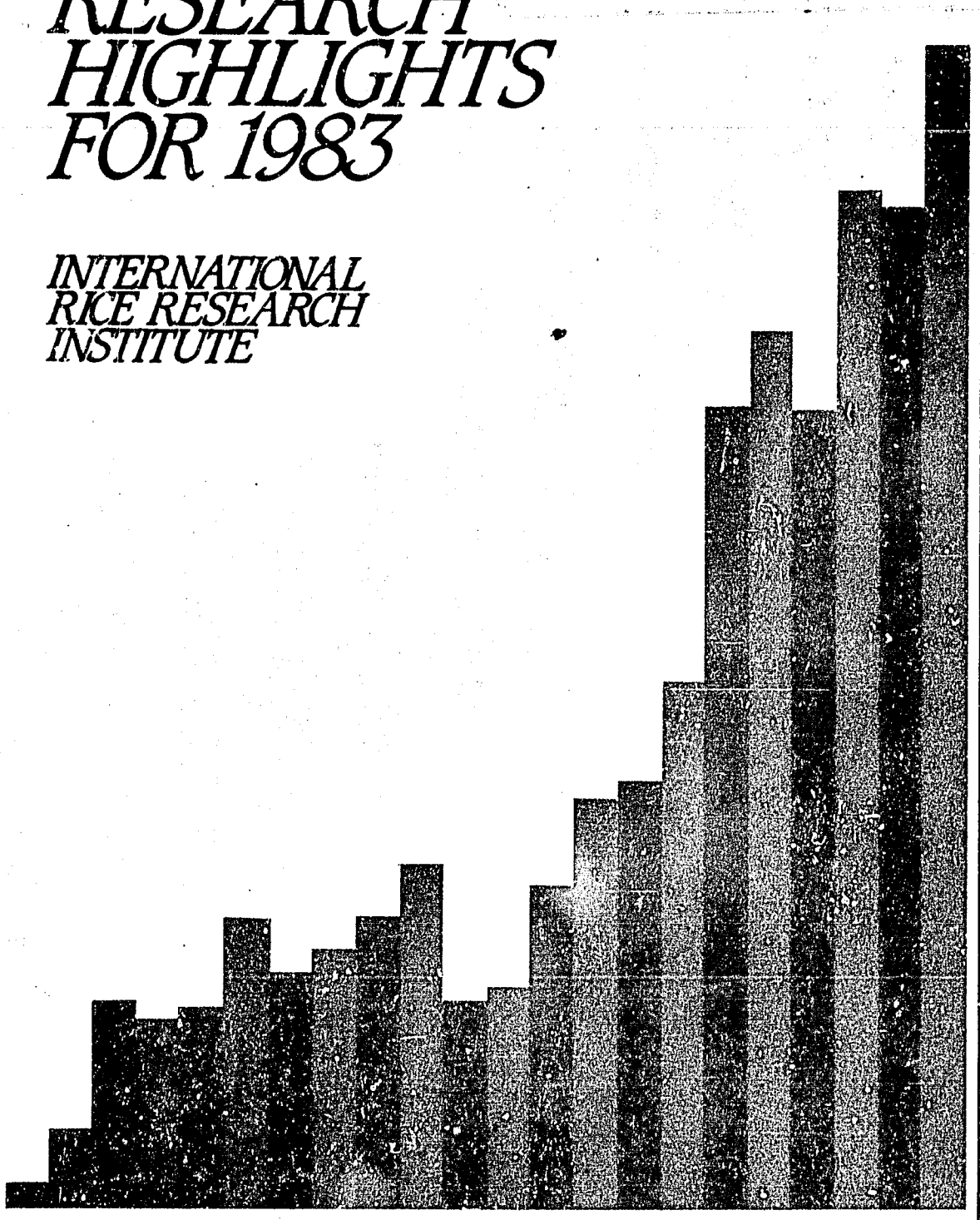
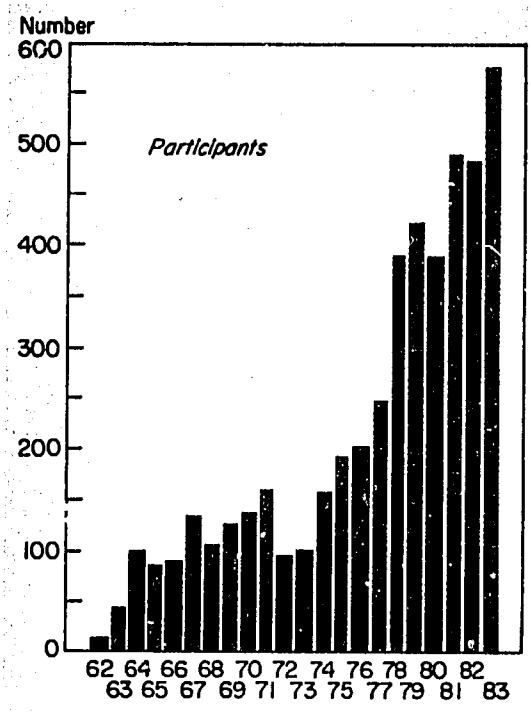
PN-AAQ-551
ISN 35683

RESEARCH HIGHLIGHTS FOR 1983

INTERNATIONAL RICE RESEARCH INSTITUTE





The number of IRRI trainees has increased from less than 25 in 1962 to 564 in 1983. We conduct regular and special long- and short-term training programs for rice scientists around the world.

RESEARCH HIGHLIGHTS FOR 1983

1984
THE INTERNATIONAL RICE RESEARCH INSTITUTE
LOS BAÑOS, LAGUNA, PHILIPPINES
P.O. BOX 933, MANILA, PHILIPPINES

2

The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today IRRI is one of 13 nonprofit international research and training centers supported by the Consultative Group for International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 50 donor countries, international and regional organizations, and private foundations.

IRRI receives support, through the CGIAR, from a number of donors including:

the Asian Development Bank
the European Economic Community
the Ford Foundation
the International Development Research Centre
the International Fund for Agricultural Development
the OPEC Special Fund
the Rockefeller Foundation
the United Nations Development Programme
the World Bank

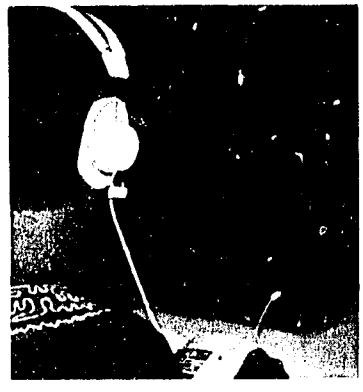
and the international aid agencies of the following governments:

Australia
Belgium
Brazil
Canada
Denmark
Fed. Rep. Germany
India
Japan
Mexico
Netherlands
New Zealand
Philippines
Saudi Arabia
Spain
Sweden
Switzerland
United Kingdom
United States

The responsibility for this publication rests with the International Rice Research Institute.

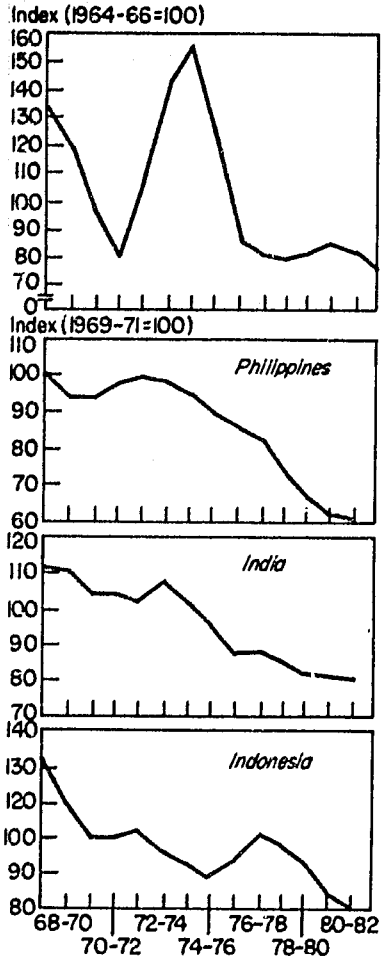
Contents

5 BUILDING NATIONAL PROGRAMS
11 GENETIC EVALUATION AND UTILIZATION
11 Conserving, distributing, and using rice germplasm
12 Agronomic and physiological characteristics
18 Grain quality
18 Disease resistance
22 Insect resistance
29 Nutritional value
30 Drought tolerance
36 Adverse soils tolerance
38 Deepwater and flood tolerance
39 Adverse temperature tolerance
40 Innovative breeding methods
44 Computerized data management
45 International Rice Testing Program
48 Integrated GEU program
53 CONTROL AND MANAGEMENT OF RICE PESTS
53 Disease control
55 Insect control
60 Weeds
64 IRRIGATION WATER MANAGEMENT
68 SOIL AND CROP MANAGEMENT
69 Fertilizer management
77 Rice crop culture
78 International Network on Soil Fertility and Fertilizer Evaluation for Rice
79 CLIMATIC ENVIRONMENT AND RICE
83 CONSTRAINTS ON RICE YIELDS
87 CONSEQUENCES OF NEW TECHNOLOGY
91 CROPPING SYSTEMS
91 Analysis of the physical and biological environment
92 Analysis of the social and economic environment
93 Pest control in rice-based cropping systems
95 On-site cropping systems research
98 Component technology
100 Agronomic management in rice-based cropping systems
103 Preproduction testing and technology transfer
104 Asian Rice Farming Systems Network
105 MACHINERY DEVELOPMENT AND TESTING
113 FINANCES
114 BOARD OF TRUSTEES
115 PERSONNEL
118 ACRONYMS AND ABBREVIATIONS



Training is an essential component of national program building. IRRI training programs emphasize group discussion, field work, presentation of experiment results, and individual instruction.

Building national programs



Trends in real world rice price and in rice price to consumers in selected, formerly rice importing, countries.

World rice production in 1983 was about 440 million t, 3% more than in 1982 and more than the FAO long-run trend. Production increased in most of Asia, especially in Bangladesh, Burma, China, India, Indonesia, Pakistan, Sri Lanka, and Thailand. Such increases continue the long-term trend of growth in rice production ahead of population. Yields have become the major source of growth, as the 1970s saw further improvements in the MVs first introduced in the mid-1960s. Many traditional rice importing countries have become self-sufficient in rice, and the real price of rice in those countries and the world market has declined. In Latin America production increased slightly, but it declined in Africa.

When Premier Zhao Ziyang of China presented the 1982 Third World Prize to IRRI in April 1983, he described IRRI's role in increasing rice production:

> IRRI has developed many good strains to help developing countries increase rice yield and improve quality. Those strains not only can increase the yield markedly, but also can resist plant diseases and insect pests, shorten the maturing period, and save water. IRRI has made important advances in rice genetics, physiology, and soil science. Its achievements have spread far and wide in the Third World.

Premier Zhao Ziyang of the People's Republic of China presents the 1982 Third World Prize scroll to Dr. M. S. Swaminathan, IRRI director general.

In 1983 IRRI worked to strengthen collaborative research with national research systems and other international agricultural research centers, and to magnify the impact of the International Rice Testing Program, the International Network on Soil Fertility and Fertilizer Evaluation for Rice, and the Asian Rice Farming Systems Network.

We also organized collaborative research planning meetings with scientists and institutions in Bangladesh, Burma, China, Egypt, India, Indonesia, Korea, Pakistan, and Thailand. With the Philippine Ministry of Agriculture, we sponsored two technology transfer workshops for extension workers from the 12 agricultural regions of that country.

Collaborative research with national scientists is the foundation for many major research projects. IRRI staff work with national scientists at selected agroclimatic sites where they conduct in depth research using similar methodology, and frequently exchange research results and materials. For example, by comparing the interactions of local BPH populations on 10 selected rice varieties, entomologists in China, India, Indonesia, Sri Lanka, Thailand, and IRRI established that there are at least 4 distinct BPH biotypes. Cultivation of BPH resistant varieties has become the principal method of controlling that insect.

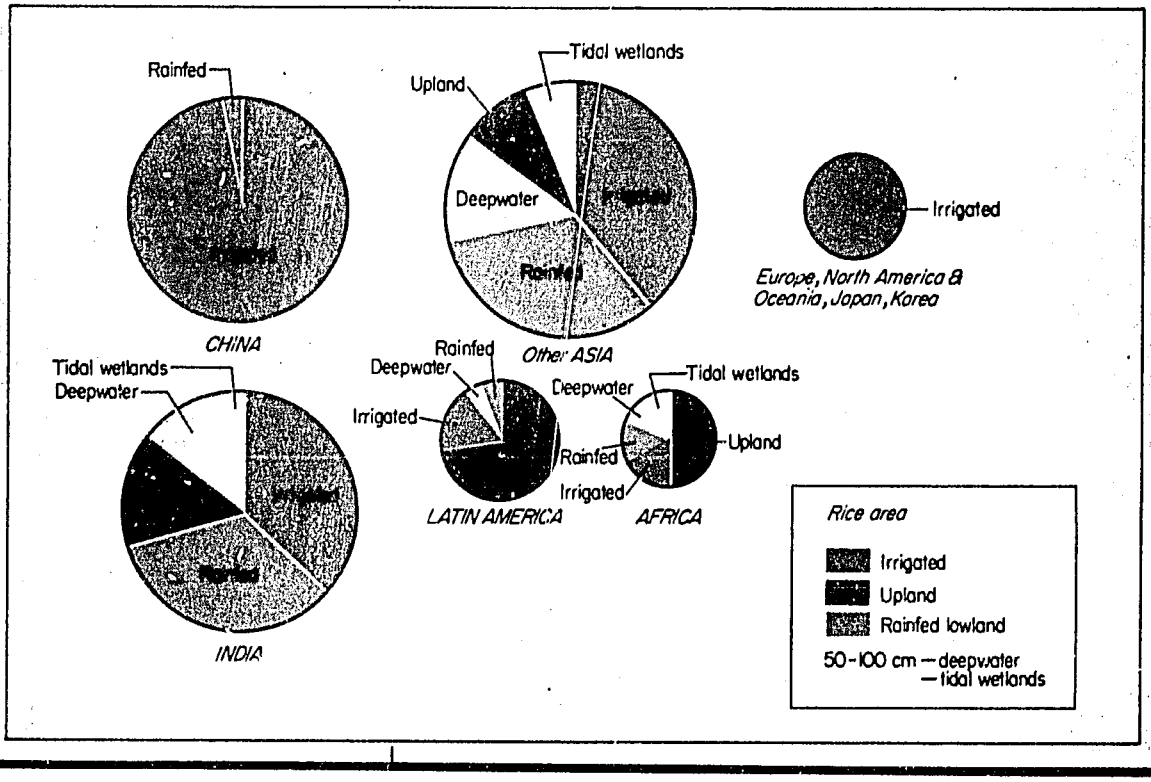
IRRI scientists joined rice scientists from IITA, Zambia, Zimbabwe, Tanzania, Kenya, and Madagascar to observe rice growing areas of southern and eastern Africa. Here, they are examining rice grown in hydromorphic areas near the Laupula Agricultural Research Institute, Mansa, Zambia.

In 1983, in addition to Los Baños staff, IRRI supported 22 scientists in 8 countries. We laid the foundations for a new cooperative program with the Malagasy Republic, brought our team in Egypt up to full strength, and developed closer ties with CIAT, IITA, and WARDA for rice research in Africa and Latin America. In October 1983 the IRRI Board of Trustees visited Malagasy and Tanzania and met in Egypt, where they visited the Rice Research and Training Project, which is a cooperative venture with the Universities of California and Arkansas.

A memorandum of agreement was signed by CIAT, IITA, IRAT, IRRI, and WARDA that established an intercenter coordinating committee for upland rice research. The committee, to be chaired by each center in turn, will promote communication among cooperators by publishing an upland rice newsletter in English with French and Spanish translations. EMBRAPA, a national agricultural research center in Brazil, is also participating.

At the 1983 International Rice Research Conference, we agreed to use an operational classification of rice growing environments that lists major environments as irrigated, rainfed lowland, deepwater, upland, and tidal wetland. Within those five categories are 20 subcategories. Our goal is to sharpen the precision of that system through continued environmental

Proportional area of rice grown in different cultural systems. IRRI is intensifying efforts to categorize environments and inventory rice growing areas around the world.



Deepwater rice workers take plant samples in Thailand. The Thai Department of Agriculture and IRRI have a long history of cooperation in deepwater and other rice projects.

In 1983 IRRI signed a memorandum of agreement with Bhutan to train Bhutanese scientists. Site visits and discussions with local farmers are important in all cooperative projects with national programs.

research and cooperation with rice scientists around the world.

At the request of the Chinese Ministry of Agriculture and the Chinese Academy of Agricultural Sciences, IRRI is assisting in the development of the Chinese National Rice Research Institute at Hangzhou. Our long-term cooperation with the Bangladesh Rice Research Institute, Thai Department of Agriculture, and the Indonesian Central Research Institute for Food Crops continued to yield substantial returns.

In 1983 we signed a memorandum of agreement with Bhutan for training of Bhutanese scientists at IRRI, exchange of genetic materials and research information, collaboration on research projects, and exchange of visits of Bhutanese and IRRI scientists.

As we develop collaborative relationships in more rice growing countries, we continually collaborate in the collection of rice varieties for conservation in the IRRI germplasm bank (renamed in 1983 as the International Rice Germplasm Center). In cooperation with the International Board for Plant Genetic Resources and major national research systems, we developed and immediately implemented a second 5-year plan for germplasm collection, conservation, and utilization (1983-87).

We also strengthened collaborative work with research organizations in developed countries. Joint research, particularly in biotechnology, was initiated with universities and institutions in the Federal Republic of Germany, France, United Kingdom, and the United States. Social science research was intensified in association with the Agricultural University of Wageningen, Netherlands.

Among several seminars, workshops, and conferences sponsored during 1983, two deserve special attention. The Conference on Women in Rice Farming Systems examined the impact of new technologies on women-specific operations and sought to identify where and how women can play a greater role in technology development and transfer. The Workshop on Copublication: Strategies for Multilanguage Publication in Agriculture brought together communication specialists from international, national, and commercial organizations to discuss publication and dissemination of agricultural information in the many languages of the developing world.

Our training programs are extremely important in our role of institution building. About 3,500 IRRI-trained scientists work as members of national rice research and development teams. Since IRRI was founded, we have collaborated with the graduate education program of the University of the Philippines at Los Baños. To strengthen training in national programs, we now have similar collaborative arrangements with Cairo University, Egypt; Institut Pertanian Bogor, Indonesia; Univer-

The Conference on Women in Rice Farming Systems examined the role of women in rice farming and stressed their importance in the technology development and transfer process.

IRRI trainees are instructed how to use a knapsack sprayer to apply herbicides

siti Pertanian Malaysia, Malaysia; Central Luzon State University, Philippines; Postgraduate Institute of Agriculture, Sri Lanka; Faizalabad Agricultural University, Pakistan; Kasetsart University, Thailand; Asian Institute of Technology, Thailand; and Cornell University, United States. We are discussing similar agreements with seven other universities.

In addition to graduate training, we conduct several annual short courses. In 1983 we added an Upland Rice Training Course. There are special courses in multilocation testing and varietal screening for upland crops. To maintain high standards of relevance and excellence in our educational programs, we formed, in 1983, an IRRI Academic Council composed of IRRI staff and outside experts.

Rice scientists and scholars around the world depend on the IRRI communications program and library for current information on rice science. In 1983 the Information Services Department was redesignated the Communication and Publications Department. This change reflects an increasing mandate not only in publishing and providing information support for IRRI scientists but also in institution-building and development of agricultural communication capabilities in national programs.

The IRRI Communication and Publications Department, in association with GTZ and CGIAR, organized the first book exhibit of the international agricultural research centers at the 1983 Frankfurt Book Fair, the world's largest publication rights market. CGIAR and other international agricultural research centers participated.

IRRI released 15 new books in 1983 and distributed about 70,000 copies of major books. Book publishing is self-sustaining; new titles are funded by sales.

IRRI and the German Agency for Technical Cooperation organized the first book exhibit of the international agricultural research centers at the 1983 Frankfurt Book Fair. Seventeen centers displayed about 1,000 titles. The fair attracted more than 500,000 visitors, mostly librarians and book buyers.

In 1983 the Library and Documentation Center published the 1982 supplement to the *International Bibliography of Rice Research*, a 5-year cumulative index to the *Bibliography*, *The International Directory of Rice Workers*, and the *1983 Supplement to Theses and Dissertations on Rice Available in the Library of the International Rice Research Institute.*

The number of books and journals borrowed from the library increased markedly and, as in previous years, requests for copies of Japanese literature on genetics and breeding exceeded those for literature on all other topics.

We acquired 4,106 new volumes, bringing the collection to 66,528 monographs, 196 serial titles, maps, translations, and microfilm. The library continued to purchase and distribute books to IRRI research scholars and other trainees.

Genetic evaluation and utilization

CONSERVING, DISTRIBUTING, AND USING RICE GERMPLASM

The IRRI Rice Genetic Resources Program has been reorganized as the International Rice Germplasm Center (IRGC), a global research service, to emphasize its international dimensions and long-term security. An advisory committee will guide the IRGC's worldwide activities.

Collection activities

Indigenous rice varieties are continually collected in rice-growing countries and sent to IRRI for safekeeping. In 1983 we received samples of 443 varieties previously not represented in the collection. Our collection now includes commonly available rices from most areas; we estimate, however, that 10,000 more rice varieties remain uncollected in remote areas.

Because the tempo of field collection has gradually waned since we drafted our first 5-yr plan for field exploration and collection in 1977, in 1983 we cosponsored with the International Board for Plant Genetic Resources (IBPGR) a second workshop on genetic conservation. Forty-four participants from 21 national and 6 regional and international centers developed the second 5-yr plan for germplasm collection. Proceedings of the workshop were presented at the XV International Congress of Genetics.

An IBPGR-funded advisor is working with IRRI to assist in national rice germplasm collection activities. In Bangladesh, the advisor helped collect 91 varieties from 5 districts. The high-altitude rice belt of Bhutan yielded 84 varieties, 23 of which are grown above 2,000-m elevation.

Germplasm holdings exceed 70,000

Cooperators donated 3,873 seed samples in 1983, bringing the total viable, distinct, registered accessions to 63,490. Still to be planted and registered are 5,038 samples. The collection also includes 4,700 African rices, wild species, and genetic testers.

Improved seed production

To increase seed production, we have moved about half of our seed increase and rejuvenation activities to 10 ha of farmers'

fields, where pest incidence is low. Production of clean seed has markedly improved.

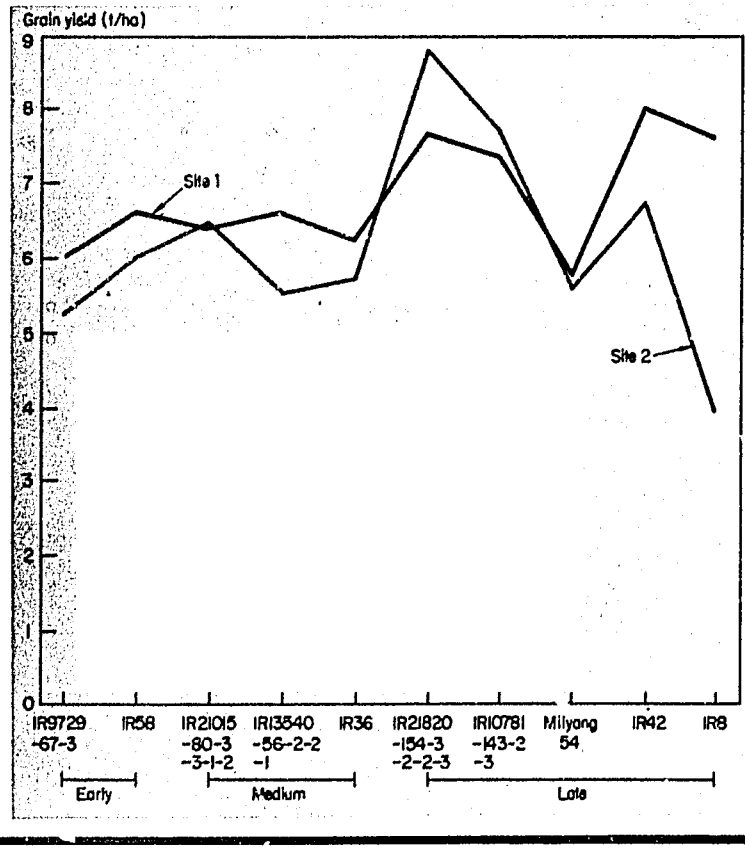
Expanding germplasm distribution

The IRGC annually receives nearly 300 requests for germplasm from IRRI staff and 150 from other scientists. In 1983 we supplied 27,290 Asian cultivars to IRRI GEU scientists and 3,756 samples to other scientists. We also sent 1,314 seed samples of African rices, wild species, and genetic testers. Because many requests are for highly specific purposes — popular objectives being varieties with early maturity, cold tolerance, BI resistance, adverse soils tolerance, and drought resistance — we frequently resort to a computerized system to retrieve accessions with two or more of the desired characteristics.

AGRONOMIC AND PHYSIOLOGICAL CHARACTERISTICS

Maximum yield experiment

Rice yields have gradually declined at IRRI, and have fallen more in DS than in WS.



1. Highest yields in 1983 DS (yield at lowest N level except for IR58, where yield at highest level was used), by variety at two IRRI sites.

We initiated multidepartment, maximum yield experiments using the best available rices and production technology to understand the yield decline and find ways to reverse it.

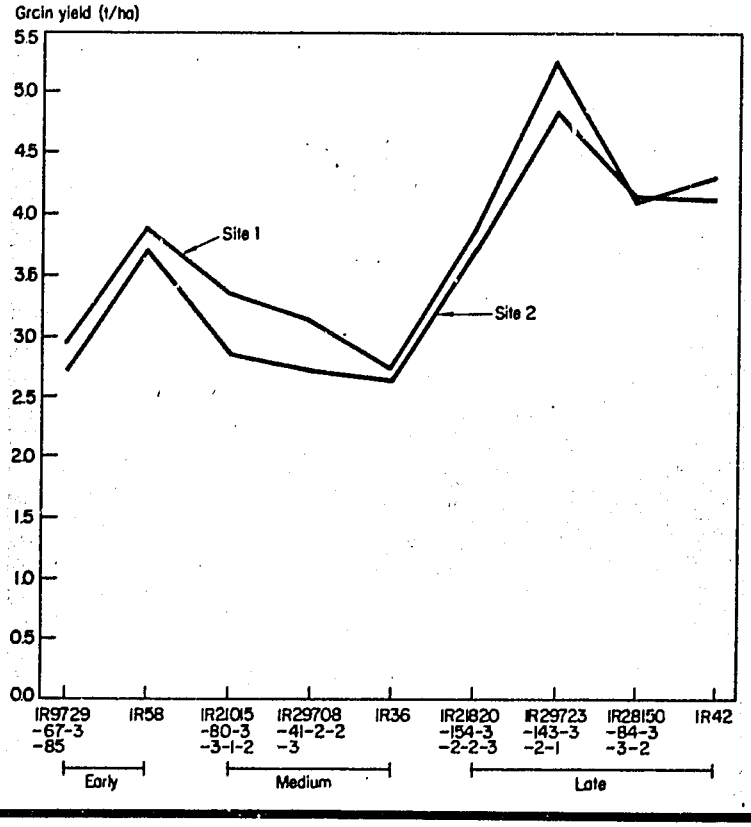
In 1983 DS, IR21820-154-3-2-2-3 yielded highest — 8.9 t/ha (Fig. 1), and late maturing rices gave the highest mean yields. SB and BPH seriously damaged susceptible rices.

In WS, late maturing IR29723-143-3-2-1 yielded highest — 5.3 t/ha (Fig. 2). RTV was severe in IR8 and moderately severe in IR42.

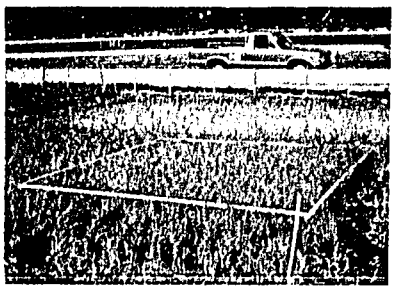
Lodging was heavy, particularly in the early-maturing rices that received high N rates. Heavy rains caused most rices to lodge in WS. High boron content in irrigation water in DS and low spikelets per unit area in WS may have also contributed to low yields.

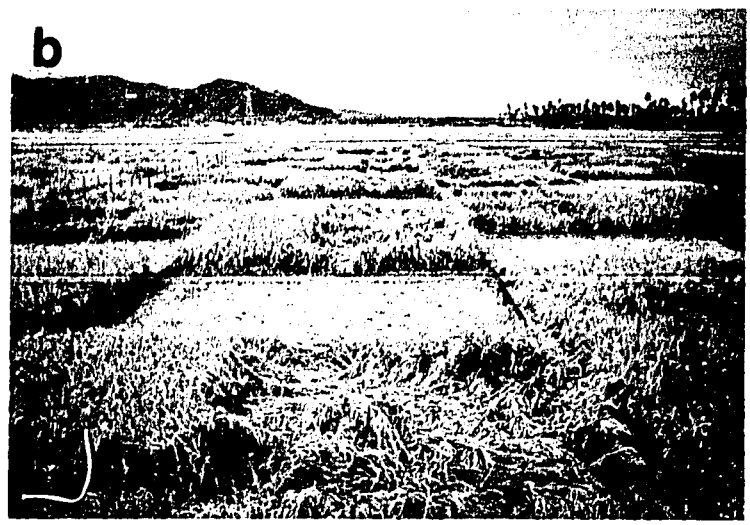
Lodging resistance

Modern rices produce high grain yields with large amounts of applied N. However, heavy N applications increase lodging, which reduces yields. Additionally, as higher levels of insect pest and disease resistance have been bred into modern semidwarf varieties, lodging resistance has tended to decline.



2. Highest yield in 1983 WS by variety at two IRRI sites.



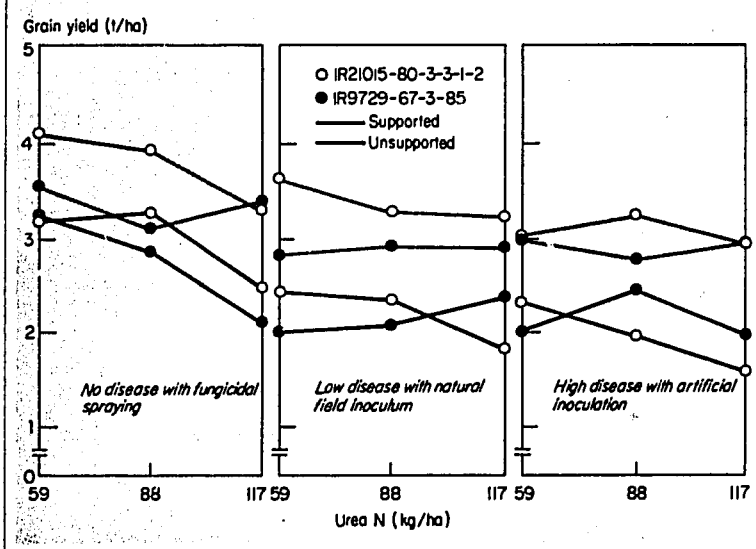


3. To evaluate lodging resistance, plants in some plots were supported by steel frames and nylon nets (a). At late growth stages unsupported plots of GEU lines IR21015-80-3-3-1-2 and IR9729-67-3-85 lodged (b)

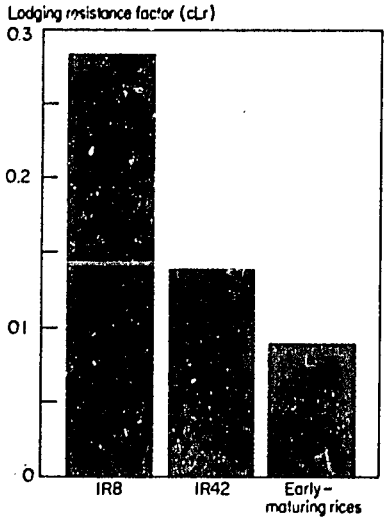
In 1983 WS we evaluated lodging resistance in modern semidwarfs from the GEU program, with emphasis on the effect of SR and fertilizer N levels. Plants in one-half of each test plot were supported with nylon mesh on a steel frame; those in the other half were unsupported (Fig. 3).

Without support, both GEU breeding lines lodged. Yield loss to lodging was 0.7 t/ha for IR9729-67-3-85 and 1.0 t/ha for IR21015-80-3-3-1-2. Results emphasize the need to breed varieties with better lodging resistance, and indicate that N levels interact to increase lodging (Fig. 4).

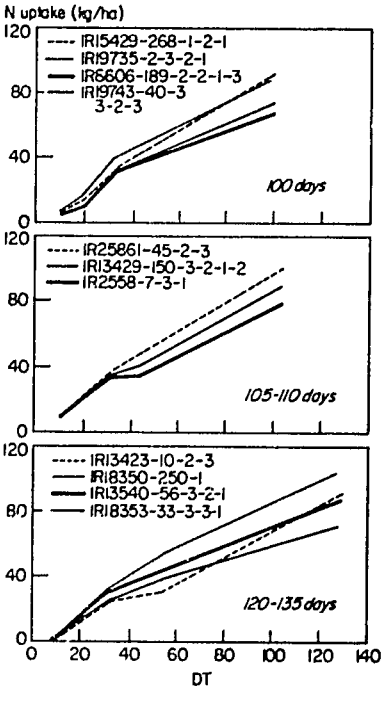
In another experiment, we tested IR8, IR36, IR42, IR50, and IR60 and nine promising early-maturing rices with various N



4. Grain yield in supported and unsupported plots at three disease and N application levels



5. Lodging resistance of IR8, based on cLr, was significantly higher than that of IR42 in 1983 DS. Both varieties had significantly higher cLr values than IR36, IR50, IR60, and 9 other early-maturing lines.



6. Total soil N uptake by rice of 3 maturity groups at different growth stages without fertilizer N

fertilizer rates and application methods. Early-maturing rices had significantly lower lodging resistance than medium-maturing IR8 and IR42 (Fig. 5), but IR42 had significantly less lodging resistance than IR8.

Further research is necessary to understand the contribution of disease, N levels, and duration to maturity to crop lodging as conditioned by environmental conditions.

Varietal use of soil nitrogen

Earlier studies showed that IR42 and IR9729-67-3 utilize soil N more efficiently than most GEU elite breeding lines. 1983 studies with ^{15}N-depleted ammonium sulfate suggest that for the early-maturing rices soil N utilization rate is highest between 20 and 35 DT. Medium and late-maturing rices exhibited slower soil N uptake. After 35 d, N uptake patterns for all rices were similar (Fig. 6).

Sources of semidwarfism

We evaluated recently received semidwarf accessions of the germplasm center to determine which semidwarfing gene they have and to identify promising new semidwarfing sources that could broaden the base of MVs. New sources are Chai-yeh-ching, Tung-ting-wan-hsien 1, and Kwang-er-ai 5 from China; M401, M302, and Calmochi 202 from USA; Pulut Unggul from Indonesia; and Dwarf B. Theega, Dwarf J. Sanna, China 1039 mutant, and Dwarf Jenegudu from India.

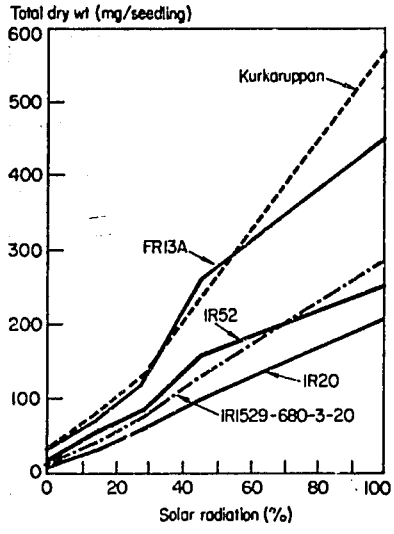
Screening for shade tolerance

Rice plants have low-light stress when grown in shade under coconut trees, in pockets of forest land, or as a mixed crop with taller plants. Yield is limited by insufficient solar radiation. Shade tolerance for varieties grown in those areas or during cloudy weather could improve grain yield. We sought to determine parameters necessary in screening for shade tolerance.

In the greenhouse, 10-d-old seedlings were grown in 45, 28, and 14% of normal light for 14 d. Two sets were grown in darkness for 7 or 14 d and another set was submerged in 30 cm water for 6 d with continuous light to compare varieties with shade tolerance with those with submergence tolerance.

Lower solar radiation gradually decreased total dry matter (Fig. 7). IR20, IR42, and IR1529-680-2-20 seedlings had least shade tolerance. At 55% shading, Kurkaruppan and FR13A had highest total dry weight. Varieties with highest dry matter at 100% light had high dry matter yields when shaded.

Shading significantly reduced leaf area. Varieties, except Thavalu (Acc. 15314), which had thicker leaves with high dry



7. Effect of different solar radiation levels on total dry matter of rice seedlings.

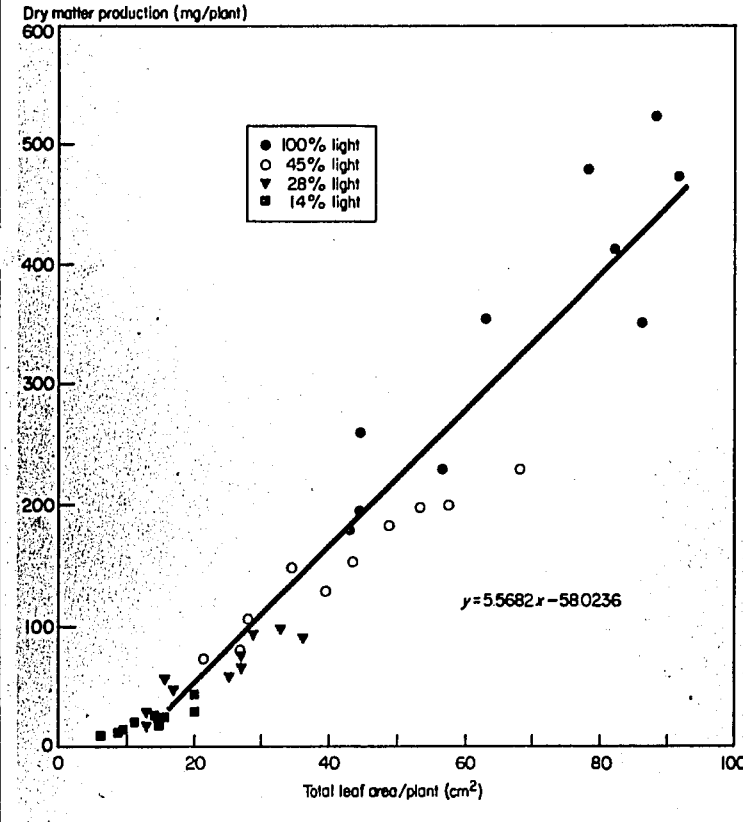
matter weight had high leaf area (Fig. 8), indicating the importance of leaf area to dry matter production in shaded areas. Leaf area and thickness at later growth stages need evaluation.

More seedlings of RD19, Kurkaruppan, Thavalu, and FR13A survived submergence or complete darkness. Survival percentage of plants at 7 d of darkness is positively correlated with survival at 6 d of submergence. Although it has been suggested that submergence tolerance can be determined by complete-darkness treatment, IR52 had high survival in darkness but not when submerged. Almost all seedlings died at 14 d dark treatment.

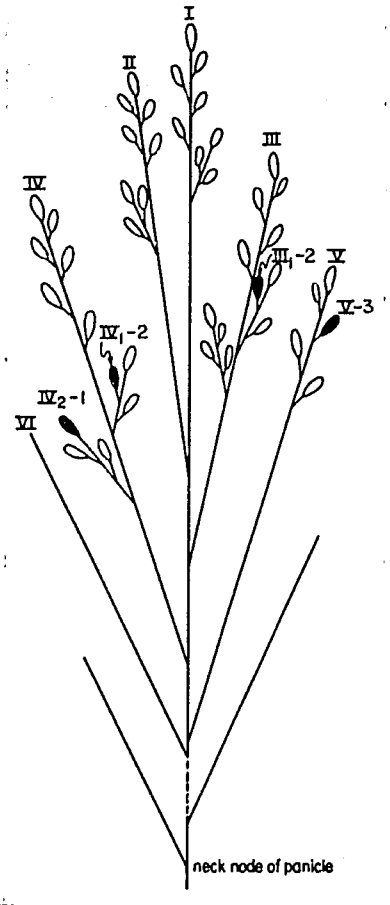
Rice microspore morphology

Microspore contraction has been used as an identifiable stage in pollen grain development. We studied IR36 to learn the true features of rice microspores during formation.

The first and second contractive stages (by the Kihara and



8. Relation between total leaf area/plant and dry matter production.



Order	Primary branches	Secondary branches			Spikelets
Top	I	I_1	II_1	IV_1	1
	II	I_2	II_2	IV_2	2
	III			IV_3	3
	.				.
	.				.
	.				.
	.				.
Bottom	.				.

Spikelets connected directly to primary branches		Spikelets connected directly to secondary branches		
I-1	II-1	I_1-1	I_2-1	II_1-1
I-2	II-2	I_1-2	I_2-2	II_1-2
I-3	II-3	I_1-3	I_2-3	II_1-3

9. Reductive division stage, by panicle observation, coincides with spikelet III_1-2.

Hirayoshi classification) in rice microspore formation were not evident, and there were very few contracted microspores when correct methods were used. From the tetrad stage to mature pollen grain, microspore shape changed from fan-like to global and size from small to big. Cell wall thickness increased gradually. As it became thicker the pore became more visible.

Various contracted microspores were seen when anthers were fixed by Carnoy's fluid or by glutaraldehyde. Sometimes the normal and contracted microspores appeared on the same slide, which indicates that microspore contraction cannot be used to identify the sequence of their growth stages.

Determining the reductive stage of rice plants

Because the reductive division stage is the most critical growth period of the rice plant, its correct identification is important for rice cultivation and in screening for resistance at critical growth stages. Although the anther squash method for determining reductive stage is precise, which and how many spikelets should be sampled is still difficult to determine.

We sampled IR36 and IR42 panicles with different flag leaf-penultimate leaf auricle distances and checked every spikelet using an anther squash slide to determine its growing stage and the morphological characteristics related to it.

For both IR36 and IR42, on the panicles checked, the most representative spikelet, viz. one whose stage of development coincides with that of the most spikelets of that panicle, is III_1-2 (Fig. 9).

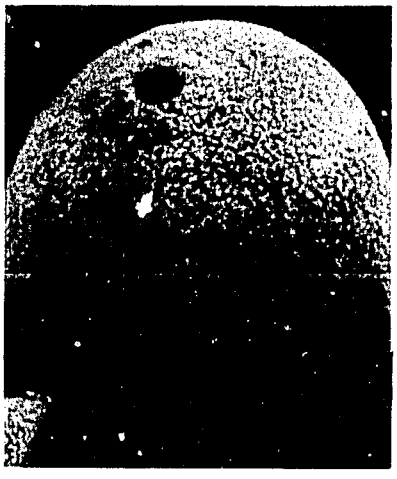
Preparation of *Oryza* pollen grains for scanning electron microscope study

We tested several methods of preparing pollen grain samples for viewing by scanning electron microscope to determine which would best show the pollen grain surface sculpture.

The following methods of pollen collection were successful:

- air-drying anthers and pollen grains;
- fixing anthers and pollen grains in Carnoy's fluid;
- fixing samples in 4% glutaraldehyde for 16 h (0-4°C), then washing with phosphate buffer 2 times and storage in the same solution; and
- keeping pollen grains in a vial in the refrigerator.

After the collection procedure, samples of pollen grains were either acetolyzed, or dehydrated and passed through a critical point dryer. 2000X to 4500X magnification can be used to observe the shape and surface ornamentation of different *Oryza* species (Fig. 10).



10. Acetolyzed pollen grain of *O. jeyporensis*, accession 101174 (3000X).

GRAIN QUALITY

Cooked rice hardness and alkali spreading value

Because our breeding program emphasizes development of intermediate-amylose rices, it is important to understand the relations of various quality factors to cooked rice Instron hardness. In our studies of elite IR lines with intermediate-amylose content, we observed a negative relationship with gel consistency, and found that cooked rice Instron hardness values are positively correlated with alkali spreading value in both WS and DS (Fig. 11). This trend probably reflects the earlier observation that cooked rice of BPI-121-407 (alkali spreading value 7) is about 1 kg harder than that of C4-63g (alkali spreading value 3-4). Both rices are important sources of intermediate-amylose content in IR lines. To ensure soft cooked rice, selection among intermediate-amylose lines should be for intermediate alkali spreading value (3-5) and soft gel consistency (>60 mm).

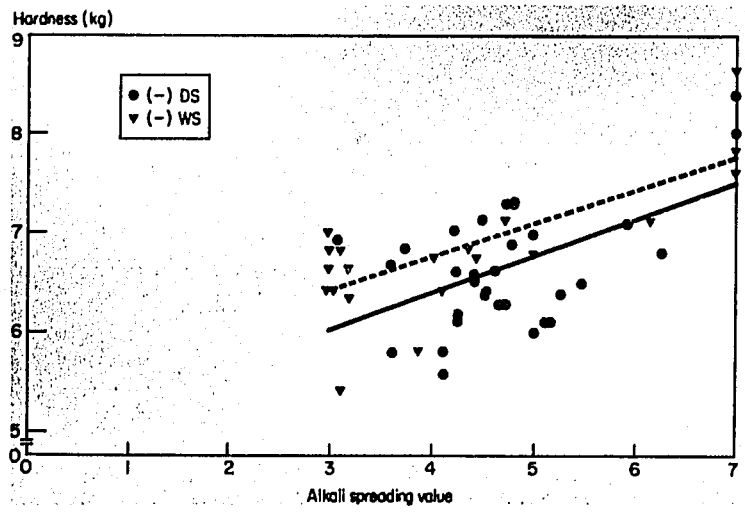
DISEASE RESISTANCE

Although rice varieties with multiple disease resistance are widely grown, resistance levels and pathogen races change and vary at different sites and times. We continue to screen rice varieties for disease resistance, and have developed collaborative projects with scientists in different nations to assess pathogen variability.

Screening for resistance

In 1983 we screened 17,094 rices for resistance: 8,044 for RTV, 2,980 for GSV, and 6,070 for RSV. Several entries, including

11. Relation between alkali spreading value and cooked rice Instron hardness among intermediate-amylose IR lines in DS and WS.



resistance sources and breeding lines, were resistant to all three virus diseases.

Rice tungro virus collaboration

In 1978 we initiated a collaborative project with pathologists in Bangladesh, India, Indonesia, Malaysia, and Thailand to test the reactions of rice varieties to the RTV vector *N. virescens* and to RTV infection at different locations in those countries.

In our evaluation of Ambemohar, Gam Pai, Habiganj, IR26, IR34, Kataribhog, Latisail, Pankhari 203, Ptb 18, and TN1, we observed remarkable differences in average insect lifespan in Pankhari 203, and in RTV infection in Kataribhog among locations. Those varieties may be used as differentials to determine the possible existence of vector biotypes and different RTV strains.

Variability of *Pyricularia oryzae*

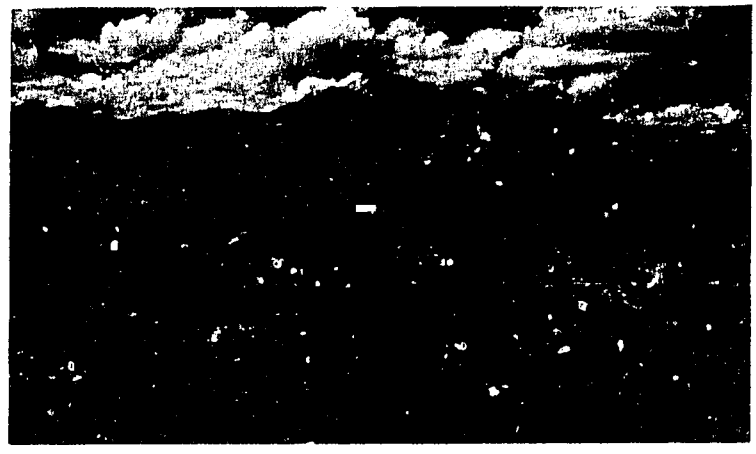
There is controversy over the degree of pathogenic variability exhibited by *P. oryzae*, the rice Bl fungus. Some data indicate the fungus is highly variable and that single-spore isolates from a single lesion or pure culture can produce many physiological races. Some pathologists believe there are stable *P. oryzae* isolates that do not produce multiple races when subcultured. In 1983 we undertook, with scientists from the Korean Office of Rural Development, a joint study of *P. oryzae* variability. We tested single-spore isolates from single lesions for virulence patterns on the Philippine Bl differential set.

We evaluated 25 single-spore cultures each from 3 lesions from IR442-2-58 and 2 lesions from Milyang 23. Isolates from two IR442-2-58 lesions and one Milyang 23 lesion produced single-spore cultures of the same race. For the remaining IR442-2-58 lesions we found 22 isolates of one race and 3 identical variant isolates. For the Milyang 23 lesion we found 23 isolates of the same race, and 2 different variants.

In all cases, the virulence pattern of the variant isolates was similar to that of the majority for that lesion. The data indicate that single-spore isolates from single lesions do not necessarily produce a multiplicity of races, which supports the hypothesis that pathogenically stable *P. oryzae* isolates exist.

New blast screening facility

In 1983 we built a new facility for Bl resistance screening. It has 140, 16- × 1.5-m concrete seedling beds and sprinkler irrigation (Fig. 12). The new facility will help us screen collected germplasm and new breeding lines more efficiently, and will facilitate testing of new seedling screening techniques.

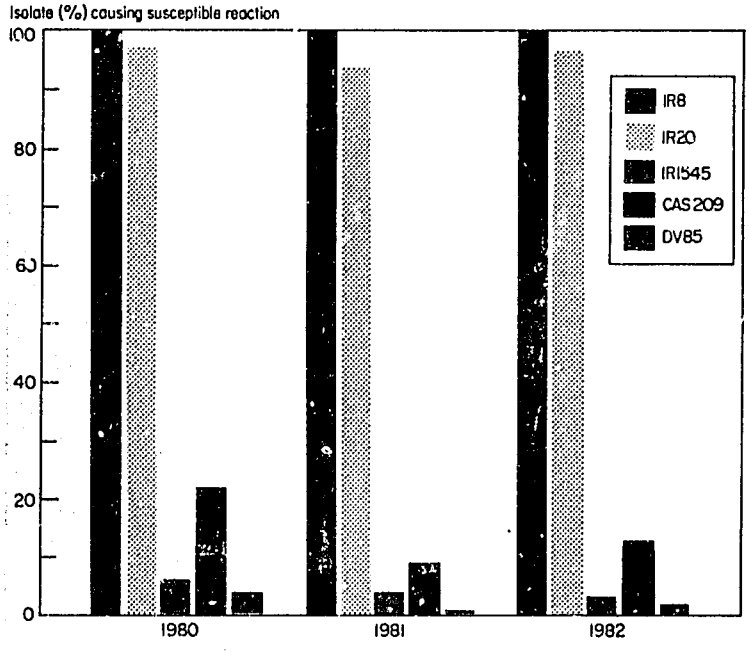


12. Our new BI facility will help us screen collected germplasm and new breeding lines more efficiently.

Bacterial blight in the Philippines

IR varieties with resistance to BB, caused by *Xanthomonas campestris* pv. *oryzae*, have been grown in the Philippines since the mid-1970s. We annually survey BB incidence to determine the predominance of races and the ability of different races to attack rice varieties with different genes for BB resistance.

Earlier data from the Philippines show that race 1, which attacks IR8 with no gene for resistance, was predominant. Data from 1980 forward indicate that most BB isolates now belong to race 2, which attacks IR20 (Fig. 13). IR20 has the *Xa 4* gene for resistance.



13. Frequency distribution of isolates of *X. campestris* pv. *oryzae* in the Philippines, 1980-82, that are virulent to IR8, which has no known gene for BB resistance. IR20 has *Xa 4* gene for resistance; IR1545, *xa 5*; CAS209, *Xa 10*; and DV85, *xa 5* and *Xa 7*.

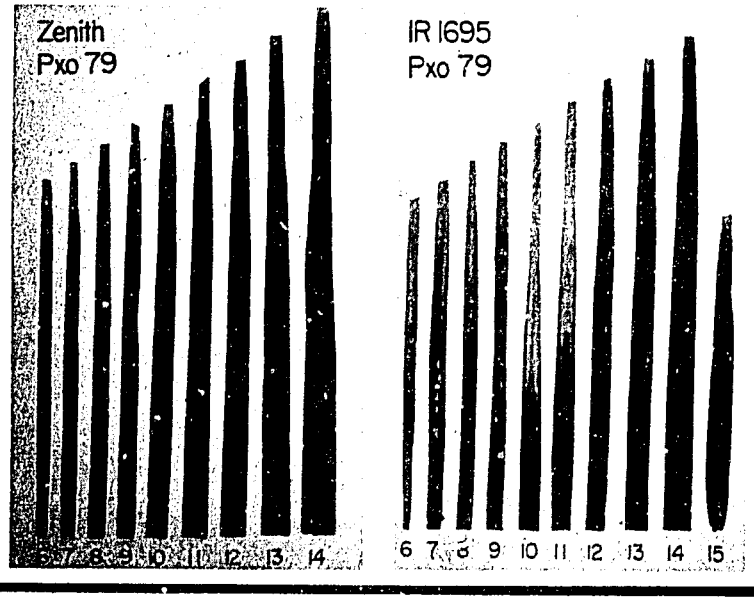
Races 1, 3, and 4 are seldom found in the Philippines, although race 3 is also virulent to *Xa 4* and to *Xa 10*. Race 3 is more common than races 1 and 4. We also found previously undescribed races of *X. campestris*. Our data on changing BB races in the Philippines emphasize the importance of continuing to breed varieties with a broad genetic base.

Bacterial blight resistance

Adult plant resistance, which is absent in young seedlings, develops as plants mature. Although few rice varieties are resistant to BB as seedlings, many are resistant at flowering stage.

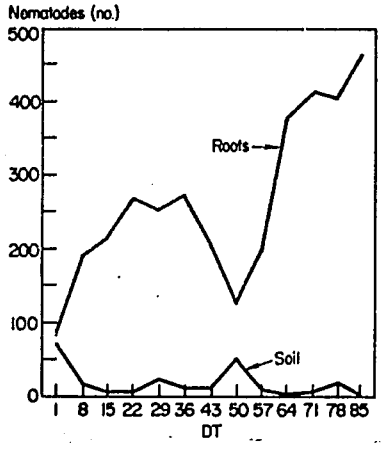
Zenith and Malagkit Sungsong have the BB resistance gene *Xa 6*, which makes mature plants resistant to all four known races of BB. We characterized the adult plant resistance of Zenith, Malagkit Sungsong, and lines IR1695 and IR944, derived from them. Both varieties and lines were susceptible to the four races as seedlings, but were resistant when inoculated at 11- and 12-leaf stage (Fig. 14).

BB resistance may be influenced by temperature, with infection being more severe at 25-35°C than at 20-25°C. In the phytotron, we tested the two varieties and lines for levels of resistance at different temperatures. Temperature did not affect lesion development on Zenith and Malagkit Sungsong, and although IR1695 and IR944 were somewhat less resistant than their parents, their resistance response was consistent across all four races. Based on these findings, adult plant resistance appears to be stable for those varieties and lines.



14. Adult plant resistance of BB. Distinctive disease response of Zenith (*Xa 6* gene) and progeny line IR1695 at 11th- and 12th-leaf position.

15. Microscope view of rice root nematodes found in IRRI fields.



16. Population density of rice root nematodes in the IRRI rice garden.

17. In our new YSB rearing method, a YSB larva is placed on a panicle within the boot of a rice plant. The larva will develop and pupate within the stem.

Rice root nematodes

We know little of the effect of nematodes on rice production. We are cooperating with scientists from the Commonwealth Institute of Parasitology, UK, to characterize the occurrence and activity of rice parasitic nematodes. Preliminary surveys indicate the presence of the rice root nematode *Hirschmaniella* sp (Fig. 15) in IRRI fields. Nematode population density was highest in fields planted to three crops each year, followed by those planted to two crops and one crop. No difference in nematode density was noted among the four rice varieties — IR46, IR9729, IR54, and Binato — observed. In the rice garden, we observed two rice root nematode population peaks, and found that the nematodes migrated from soil to rice roots and from roots to soil (Fig. 16).

INSECT RESISTANCE

Rearing yellow stem borer

We need large numbers of first-instar YSB larvae in screening rice varieties and lines for YSB resistance. To obtain larvae for screening we collect moths from the field and allow them to oviposit on plants in cages. However, for much of the year moths are not abundant, which disrupts the continuity of the screening program. Until now, artificial rearing techniques have been unsuccessful.

To provide larvae on a regular basis, we have developed a new rearing method that has increased survival to adult stage to 80% and promotes uniform larval development. A slit is opened in the bulging leaf sheath of the boot and with a camel hair brush, one larva is placed on the exposed, developing panicle within the boot (Fig. 17). The slit is closed and the larva remains inside where it feeds and develops to adulthood. With this method, 6 m^2 of potted plants can produce 150 moths and about 5,000 larvae/wk.

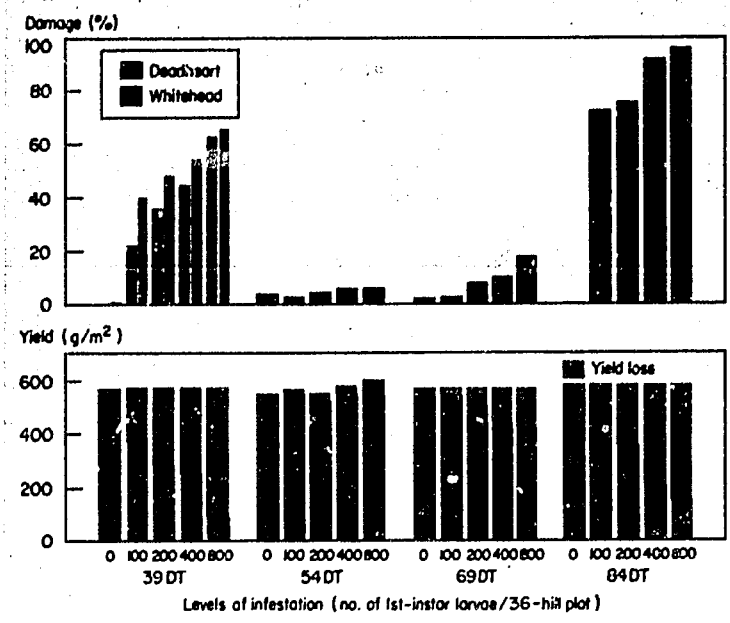
Rice age and susceptibility to yellow stem borer

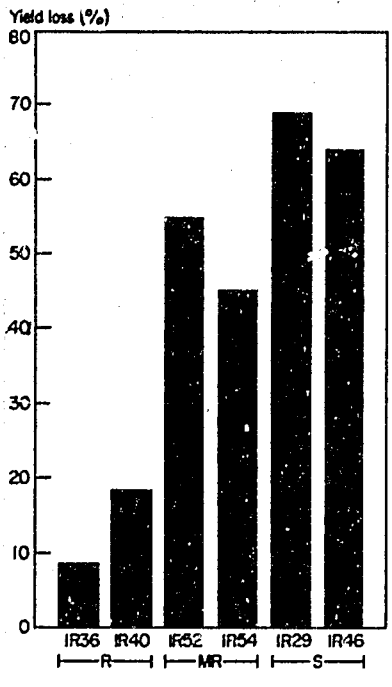
To evaluate rice varieties for YSB resistance, IR46 plants were infested 30 DT, when that variety is susceptible. We found that resistance to YSB increases during early reproductive stage. Plant damage and yield loss were high at the vegetative phase (39 DT), but the plant was resistant during panicle initiation to booting (54 to 69 DT). Susceptibility increased just before flowering (84 DT) (Fig. 18).

Effect of striped stem borer on yield

The measure of SSB resistance in screenhouse and field tests is percent deadhearts or whiteheads as described on a 0-9 scale.

18. Reaction of IR46 to YSB at different growth stages.





19. Percent grain yield loss of resistant (R), moderately resistant (MR), and susceptible (S) rice varieties when infested with 5 SSB/hill.

To correlate resistance level with yield loss we evaluated two resistant (IR36, IR40), two moderately resistant (IR52, IR54), and two susceptible (IR29, IR46) varieties.

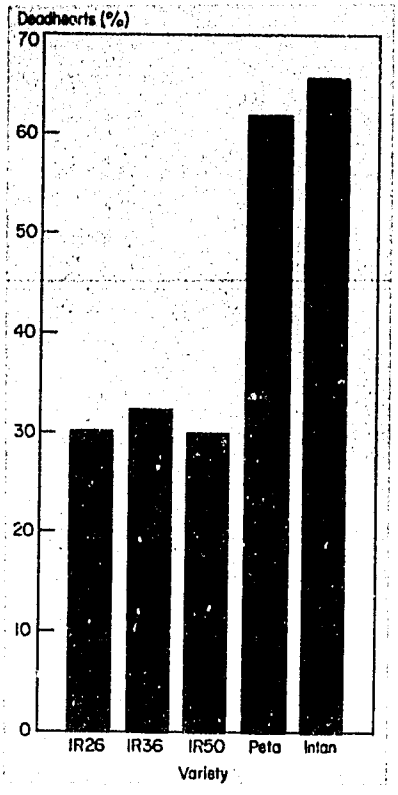
The value of varietal resistance in preventing yield loss was evident (Fig. 19). Yield loss was 8 and 18% for resistant IR36 and IR40, 46-55% for moderately resistant IR52 and IR54, and 64-69% for susceptible IR29 and IR46. Results indicate that the rating scale based on deadhearts is practical, and that SSB-resistant IR varieties effectively prevent yield loss.

Resistance to striped stem borer

We found that the MVs IR26, IR36, and IR50 were more resistant to SSB than the traditional varieties Peta and Intan. The MVs had half as many deadhearts as the traditional varieties (Fig. 20), fewer eggs and pupa, and lower weight. We also found that growing SSB-resistant varieties has an accumulative effect in decreasing SSB populations because more males than females survive on MVs.

Chemical basis of striped stem borer resistance

We confirmed that the level of oviposition deterrent to SSB, designated compound A, is affected by rice variety, plant age, and environment, particularly in resistant varieties. Compound A tended to decrease progressively with plant age, except for a minor peak at maximum tillering. At 50 to 60 DT, resistant TKM6 and, to a limited extent, IR20, had greater compound A level at



20. Level of resistance of modern (IR26, IR36, IR50) and traditional (Peta, Intan) varieties to SSB, by deadheart damage.

12 h daylength and 50 klx light intensity than at 10 and 14 h daylength and 25 klx light intensity. Level of compound A was higher at 26-18°C than at 29-21°C and 35-27°C.

Collaborative projects

We collaborate with scientists in South and Southeast Asia in evaluating varieties with different genes for resistance to GLH and WBPH to determine differences in insect biotype virulence. Reactions of differential varieties to GLH were similar, except in Pankhari 203, which has the *Glh 1* gene for resistance. Pankhari 203 is resistant at IRRI and in Indonesia but susceptible in India and Malaysia. Moddai Karuppan is slightly resistant at IRRI but is highly resistant at other locations. The response of differential varieties to WBPH populations in Asia was similar except in Vietnam where the insect is more virulent on all varieties. These data seem to indicate that two or more GLH and WBPH biotypes exist.

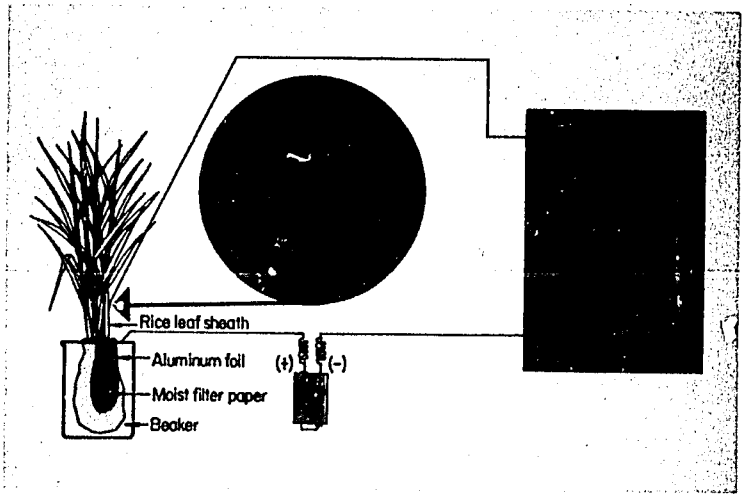
A new gene for whitebacked planthopper resistance

In our studies of the inheritance of WBPH resistance, we evaluated the genetics of resistance in 15 additional resistant varieties. We crossed F_1 and F_2 populations and F_3 progenies from crosses of those varieties with WBPH-susceptible TN1, and found that single dominant genes confer resistance in Boegi Boera, DD4, PI 184675-6, Siam Garden, Rening, N'Diang Marie, Manggar, Oha, Gokhue Saier, Tjempo Tolo, and Nemai. Two independent dominant genes govern resistance in ARC5752, Chaia Anaser, Katuyhar Dhan, and Dhera Dun Basmati.

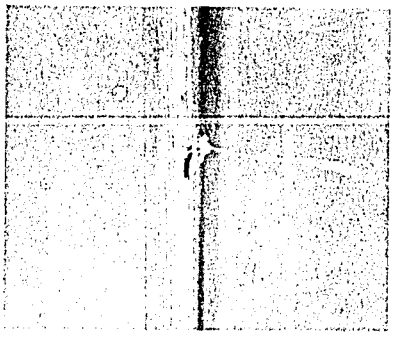
Tests for allelism with known genes for WBPH resistance showed that the single dominant genes in Boegi Boera, DD4, PI 184675-6, Siam Garden, Rening, Oha, Gokhue Saier, Tjempo Tolo, and Nemai, and one of the two independent dominant genes in ARC5752, Chaia Anaser, Katuyhar Dhan, and Dhera Dun Basmati are allelic to *Wbph 1*, and that the second gene in ARC5752 is allelic to *Wbph 2*. The second gene of Chaia Anaser, Katuyhar Dhan, and Dhera Dun Basmati is allelic to *Wbph 3*. The dominant genes of N'Diang Marie and Manggar segregated independently of *Wbph 1*, *Wbph 2*, and *Wbph 3*. The dominant resistance gene of N'Diang Marie was designated *Wbph 5*, but the allelic relationships to *Wbph 5* of the dominant gene of Manggar are unknown.

Feeding behavior of whitebacked planthopper

Reliable, rapid techniques for evaluating insect resistance in rice germplasm are needed. We used an electronic device to monitor WBPH feeding behavior on susceptible and resistant



21. Diagram of the circuit and equipment for recording WBPH feeding on rice plants.

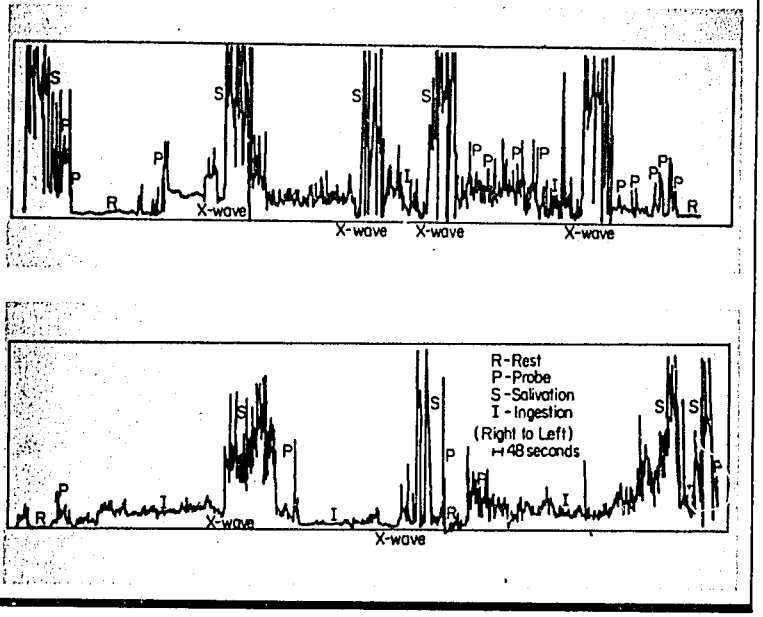


22. Copper wire attached to WBPH female to record feeding activity on susceptible and resistant rice plants.

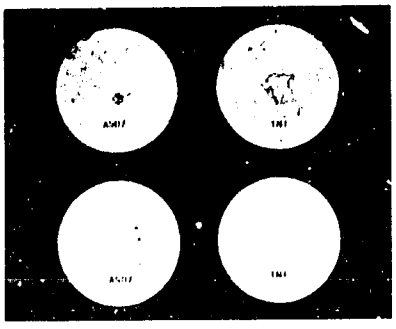
rice varieties. The feeding insect completed an electrical circuit and the resulting voltage changes, caused by the flow of salivary and substrate liquids through the insect stylets, were registered by a chart recorder.

A 10-cm-long, fine copper wire was attached to the dorsum of a brachypterous female and the insect was starved for 2 h and then placed on the leaf sheath of a 45-d-old rice plant (Fig. 21, 22). The insect was wired to the chart recorder, and WBPH feeding activity was monitored for 60 min.

Distinct differences in waveform patterns associated with WBPH feeding on susceptible and resistant rice varieties were observed (Fig. 23).



23. Electronic waveforms recorded by an electronic monitoring device during WBPH feeding on susceptible TN1 (top) and resistant IR2035-117-3 (bottom).



24. Filter paper discs on which GLH honeydew was collected when it fed on resistant ASD7 and susceptible TN1. Bluish amino acid spots on ninhydrin-treated filter paper (top) indicate phloem feeding. Red spots (bottom) indicate xylem feeding on safranine-treated plants.

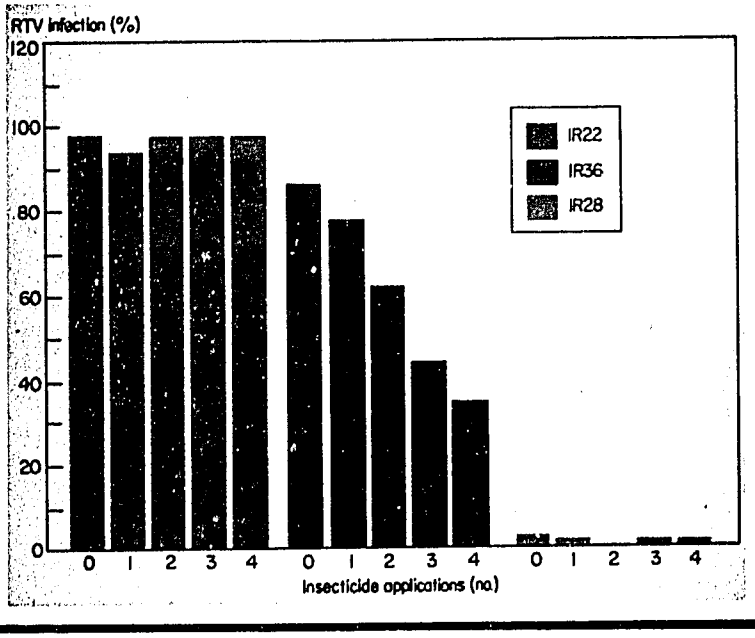
Feeding sites of leafhoppers and planthoppers

Knowing where on rice plants leafhoppers and planthoppers feed is helpful in evaluating germplasm for resistance to those insect pests and the diseases they transmit. We tested a simple technique by which we could identify phloem or xylem feeding on susceptible and resistant seedlings treated with safranine by the color of the insect's excreta. Safranine is a dye that is selectively translocated through roots into xylem vessels. On safranine-treated seedlings of resistant ASD7, GLH honeydew was red, indicating that the insect fed from xylem vessels. Clear honeydew excreted on susceptible TN1 seedlings indicated phloem feeding (Fig. 24). We found that BPH and WBPH were primarily phloem feeders.

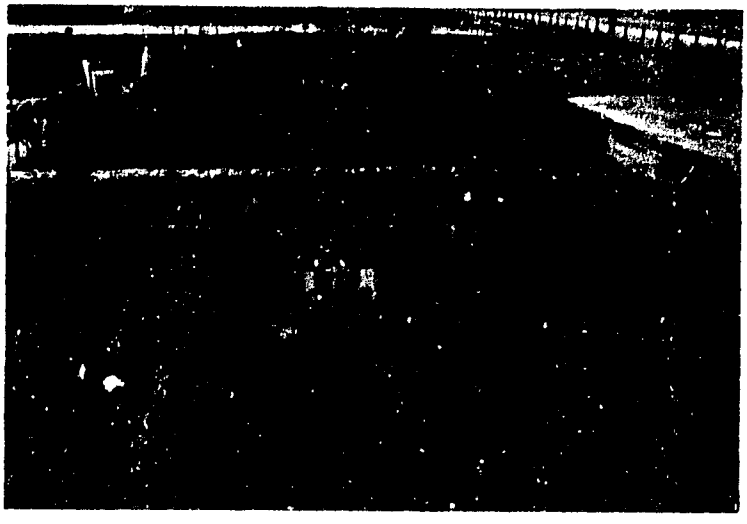
Effect of resistance and chemical control for tungro virus control

We evaluated GLH-susceptible IR22, moderately resistant IR36, and resistant IR28 for RTV infection at different insecticide applications. When treated with one, two, three, or four diazinon applications, IR28 had less than 5% RTV infection for all insecticide treatments while IR22 had 100% (Fig. 25). However, IR36 had 86% RTV in the untreated check and 36% at 4 applications.

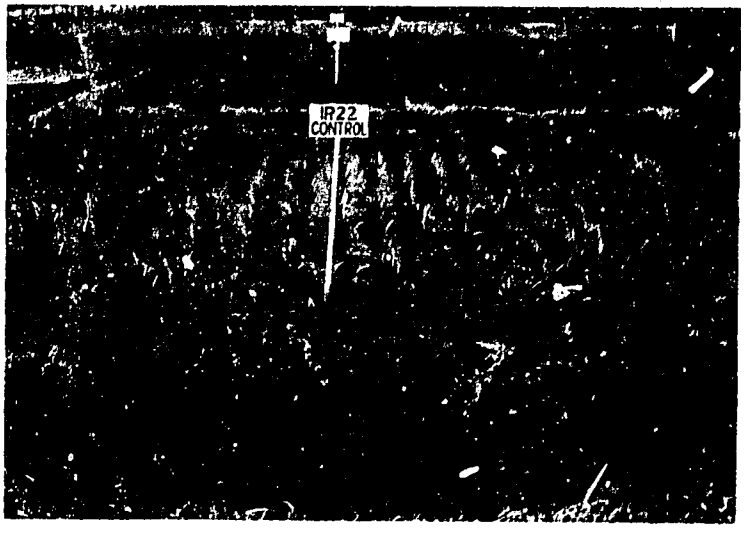
The results indicate that IR28 (Fig. 26) has sufficient resistance not to require any insecticide for RTV control while IR22 (Fig. 27) is so susceptible that even four applications provided no control. Although IR36 had a high RTV infection in the



25. Percentage RTV infection in GLH-resistant IR28, moderately resistant IR36, and susceptible IR22 60 DT with 0-4 applications of 1 kg diazinon ai/ha.



26. IR28 without insecticide is RTV-free.

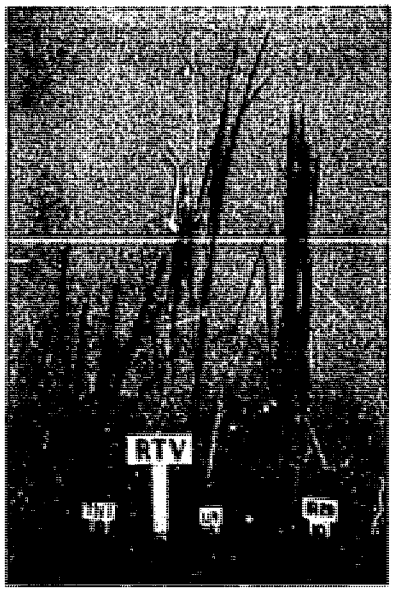


27. IR22 without insecticide is severely infected with RTV.

untreated check, the combined effect of moderate resistance and chemical GLH control reduced RTV and increased yield as insecticide application frequency increased.

Utri Rajapan planthopper tolerance and virus resistance

We are interested in identifying tolerant varieties for use as donors in our breeding program because new insect biotypes do not overcome them. However, tolerant varieties may be more prone to virus infection because vector insects feed freely on them. In 1982 we reported that the Indonesian variety Utri Rajapan can be infested with high BPH populations without suffering severe yield loss, which is a characteristic of a tolerant variety.



28. Although both TN1 and Utri Rajapan are susceptible to GLH, Utri Rajapan is free of RTV while TN1 is infested with 10 viruliferous GLH/plant.

29. YSB screening is being done in this simple screenhouse built cooperatively by the Thai Rice Research Institute and IRRI.

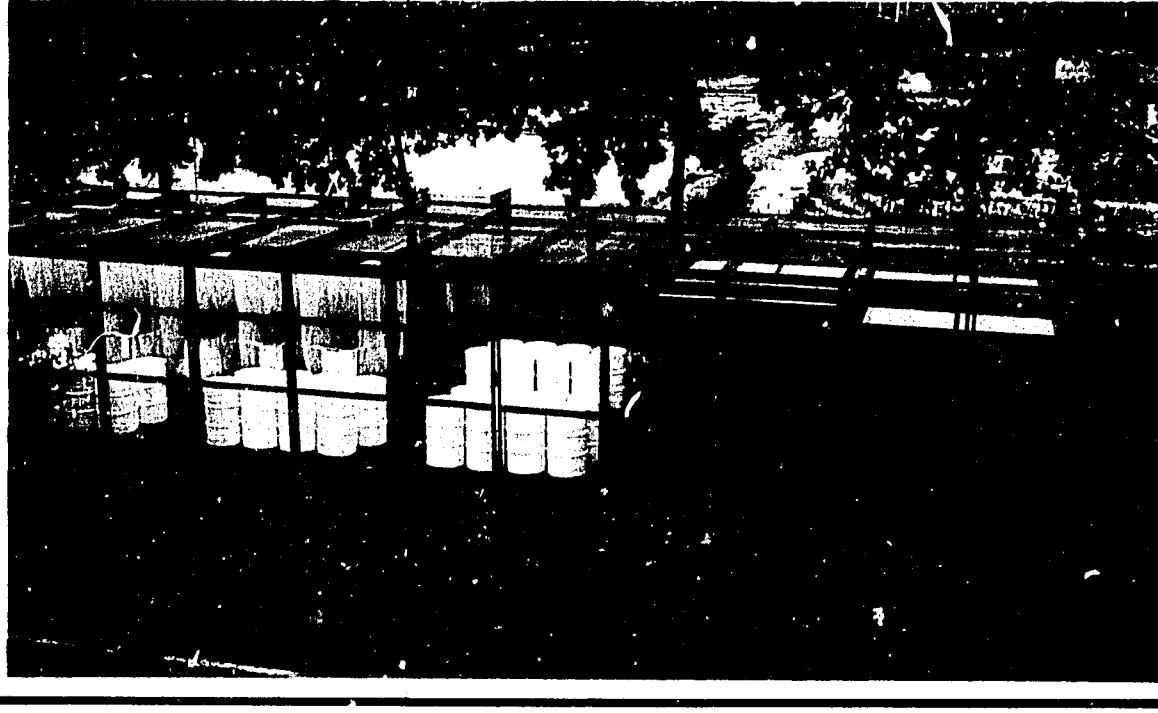
In 1983 we found that it has resistance to RSV transmitted by BPH. It also is resistant to RTV, although it is susceptible to GLH, the RTV vector (Fig. 28). We have crossed Utri Rajapan with BPH-susceptible varieties to determine the inheritance of its tolerance characteristic.

IRRI-Thailand deepwater rice pest management project

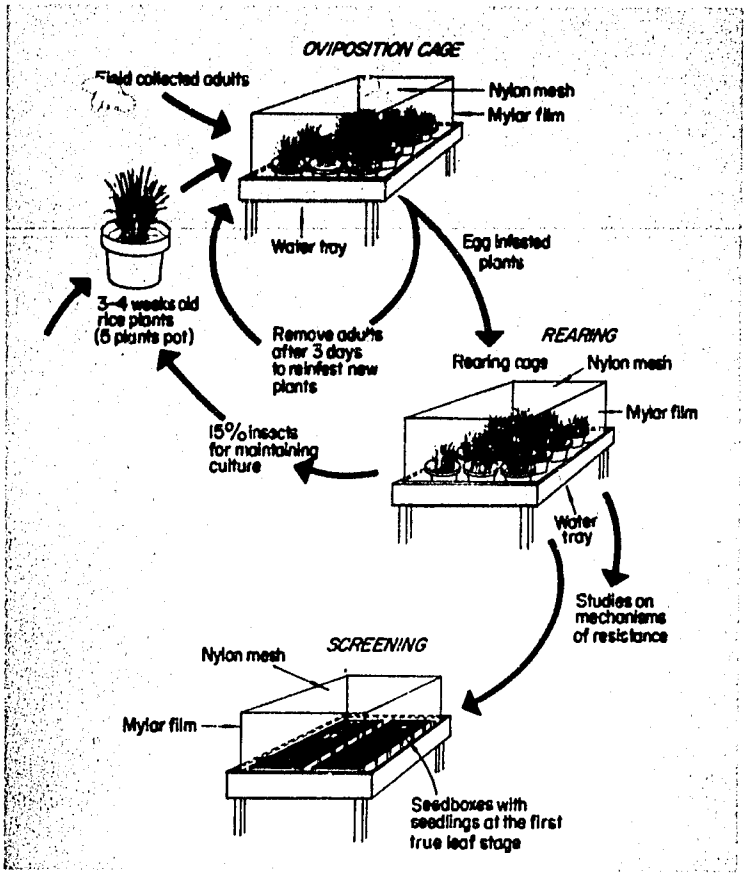
Most deepwater rices are susceptible to YSB, RSV, and the RSV vector, BPH. In 1983 we began a collaborative program with the Thai Rice Research Institute to screen deepwater rice, advanced breeding lines, and leading traditional varieties for resistance to those pests. We are evaluating genotypes from Thailand, India, and IRTP nurseries (Fig. 29). To date, almost all genotypes screened have been susceptible to YSB, but several entries have some BPH resistance.

Screening for thrips resistance

Field screening of rice varieties for thrips resistance is difficult because thrips population levels are unpredictable. In 1983 we developed a rearing technique that allows thrips screening in the greenhouse (Fig. 30). We screened 164 entries and identified 11 traditional and 12 wild rices with resistance. Our evaluation of resistance mechanisms indicated that resistance limited thrips feeding and that oviposition and larval survival on resistant varieties are low.



30. Procedure for rearing and greenhouse screening for thrips resistance.

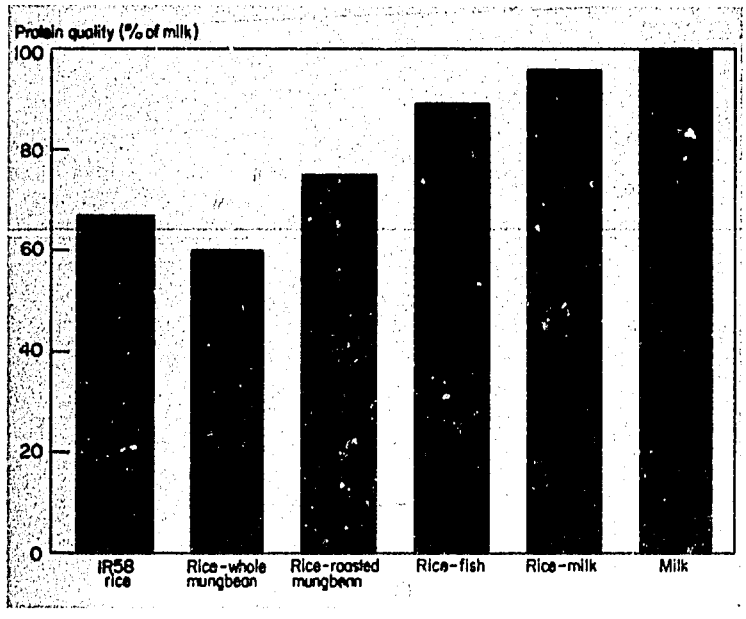


NUTRITIONAL VALUE

Protein quality of rice and rice diets

We completed a 4-yr collaboration with nutritionists from the Food and Nutrition Research Institute of the Philippine National Science and Technology Authority during which we established a Nutritional Evaluation Laboratory (NEL). At NEL we estimated the safe level protein requirements of rice and typical rice-based weaning foods using 4 dietary protein levels for Filipino preschool children at a daily energy intake of 418 kJ/kg body weight.

Rice-milk and rice-fish diets (1/3 of nitrogen from milk or fish) had protein similar to milk in quality (0.89 g protein/kg body wt daily). The rice-whole mungbean diet had poorer protein than other weaning diets (Fig. 31), but good amino acid balance. Roasting and dehulling mungbean somewhat improved the protein quality, but the diet was still of lower quality than rice-milk or rice-fish diets. We found that children eating high-protein (11%) IR58 milled rice retained 67% of the protein.



31. Relative protein quality in diets of preschool Filipino children eating rice and rice-based diets based on the safe protein requirement of 0.89 g protein/kg body weight daily for cow's milk. Values in parentheses are the number of children.

retained in a milk diet. An estimated short-term nitrogen balance index showed an IR58 diet had relative protein quality of 69% of rice-milk or 66% of milk. Those values correlate with amino acid score of 65% based on dietary lysine and with the 68% net protein utilization of milled IR58 in rats. Our research indicates that adding lysine-rich animal protein to lysine-deficient milled rice improves the protein quality of rice-based weaning diets to a level near that of milk.

DROUGHT TOLERANCE

Periodic drought is a major constraint to rainfed lowland and upland rice in many parts of South and Southeast Asia, Latin America, and Africa. Our drought resistance screening program, root studies, and water stress physiology studies help us understand drought resistance mechanisms so that we may more effectively breed new varieties for drought-prone areas.

Screening for drought resistance

We use two methods of screening for drought resistance. In 1983 we screened 5,600 traditional varieties, breeding lines, and checks for field resistance to drought under upland conditions using a gravity irrigation system to regulate water supply. Of the germplasm accessions screened, 64.3% had drought resistance at vegetative stage. They were traditional upland varieties from Asia, Latin America, and Africa. Of the other entries, 12.5% were moderately drought susceptible.

During 1983 DS we continued to screen rice germplasm for drought resistance at reproductive (flowering) stage. GEU scientists visited the fields at peak water stress to get firsthand information on screening procedures and varietal differences

32. After 5 wk without applied water, accession KDML 65-GIU-45, from Thailand, had normal panicle exsertion at 15 bars SMT

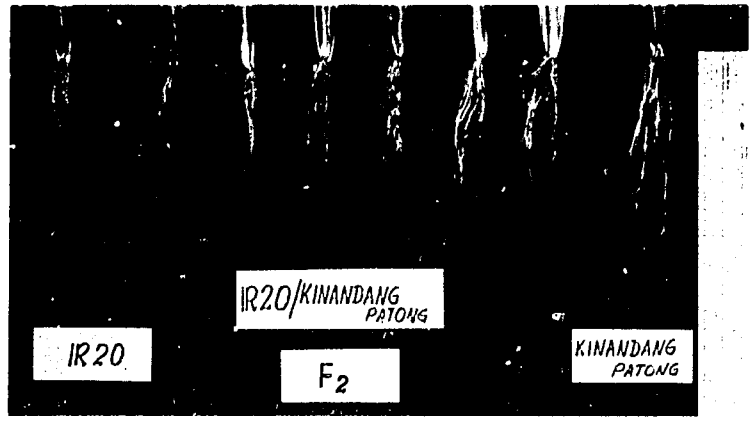
Among the breeding lines from upland nurseries, F_4 lines which had been selected for deep and thick root systems had a high level of drought resistance, and 77% of the advanced lines scored between 1 and 4 on the decimal scale. Lines from IITA, IRAT, and Brazil also had high levels of resistance at vegetative stage.

We screened 3,842 improved varieties, breeding lines, and accessions for field drought tolerance based on soil moisture tension (SMT). After 3 wk of imposed drought, when SMT was 3 bars, plants began to show different reactions to desiccation. Of varieties screened, 37 rices (24 accessions, 12 IRRI breeding lines, and IR52) had more drought resistance at 15 bars SMT than the tolerant check Salumpikit (Fig. 32).

The 1983 IURON included 11 rices selected from earlier field drought screening.

Genetic studies on root systems

We studied the genetics of rice root systems in the field to improve the selection method for deep-and-thick root characters. We grew seeds of IR20, Kinandang Patong, and the F_2 population from a cross of those varieties in a dry seedbed for 23 to 30 d. Root length of the F_2 population varied from 5.0 to 21.5 cm (Fig. 33), and root thickness was 0.2 to 1.2 mm. Mean root length of IR20 was 10.2 cm and that of Kinandang Patong was 13.0 cm. There was a strong correlation between long roots and tall plants and long roots and thick roots.



33. Variation in root length of 25-d-old seedlings of an F_2 population of IR20/Kinandang Patong and parents grown in the field.

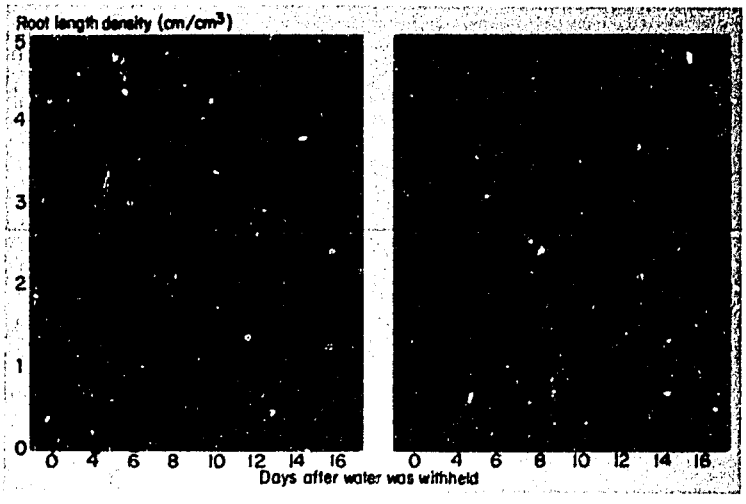
Comparing the roots of that F_2 field population with the same cross grown in the aeroponic system for 45 d shows a similar continuous segregation pattern, but data from plants grown in aeroponics were skewed toward longer roots. Similar observations were obtained from the cross IR20/Moroberekan.

Response of the rice root system to water stress

In 1983 we expanded our root system studies to puddled soil to investigate the changes in growth and activity caused by water stress. Information on root system response to water stress in puddled soil will help us breed new varieties and develop suitable management technologies for efficient water and nutrient use.

In a greenhouse experiment using a root length scanner (Fig. 34), we estimated IR36 root length density (RLD) from 0 to 25-cm depth at 5-cm intervals during a drying cycle 16 d before

34. The Comair Root Length Scanner is a bench-top unit capable of accurately measuring the length of roots from soil cores. M. Thangaraj, postdoctoral fellow from India, is preparing root samples for measurement.



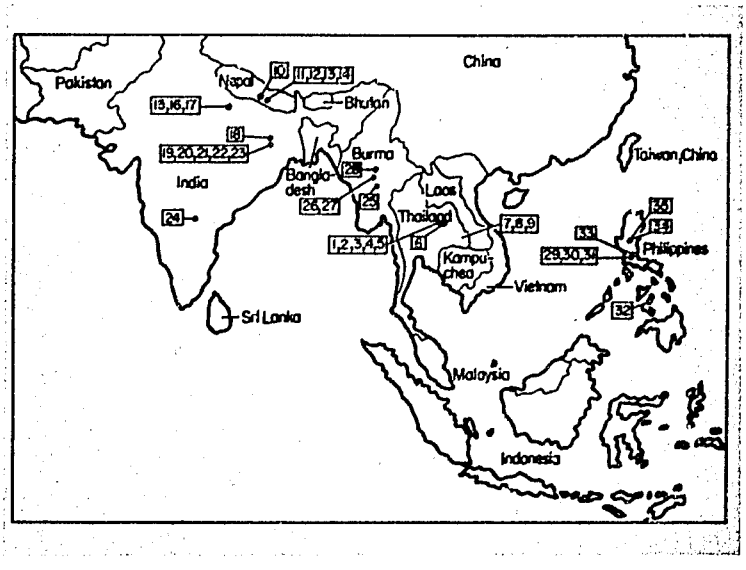
35. Effect of water management on root length density in a puddled lowland soil (Maahas clay).

and 17 d after transplanting. Figure 35 illustrates changes in RLD of stressed plants with time and depth. RLD decreased progressively as plant and soil water stress increased, with significant differences at all soil depths from 12 d after stress. The trend in root and shoot weight was similar.

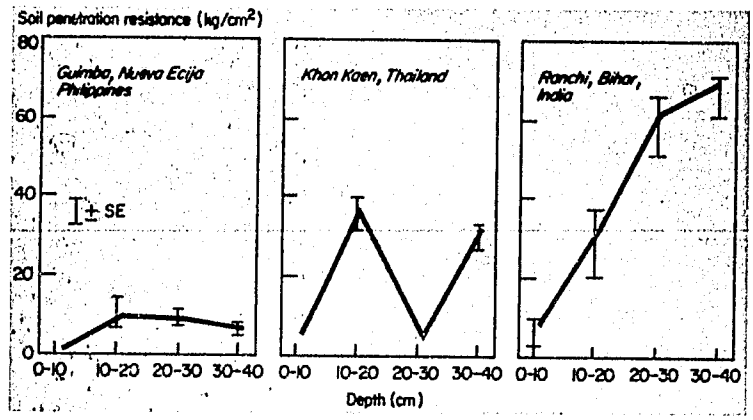
Soil penetration resistance in rainfed rice fields

Root growth and root zone depth are important to production of drought-prone rainfed lowland rice, but we know little about the penetration resistance of lowland rice soils and how it affects root growth.

In 1983 we surveyed the penetration resistance of rice soils at 35 locations in South and Southeast Asia (Fig. 36). Penetration

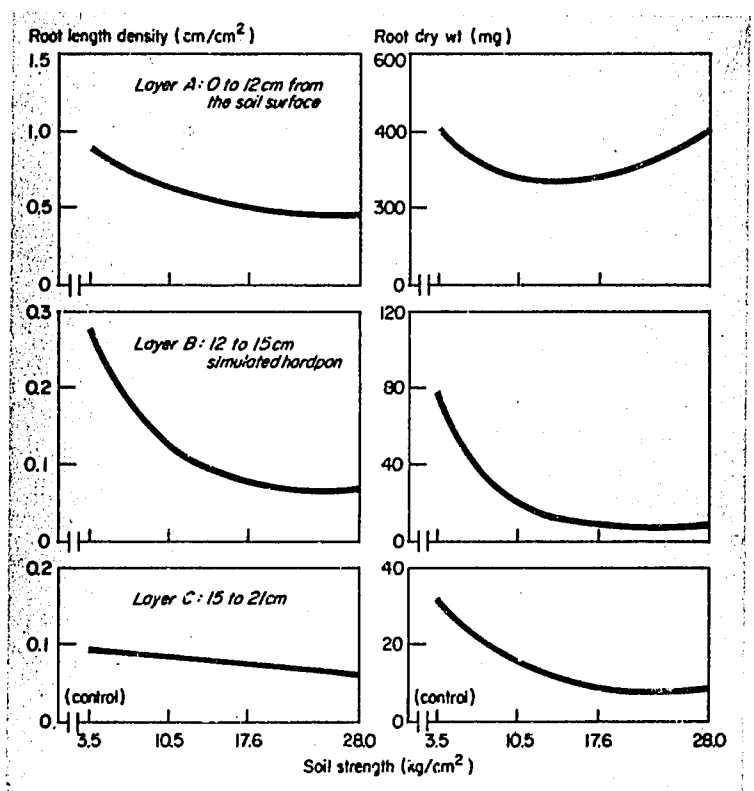


36. We measured soil penetration resistance at 35 locations in South and Southeast Asia in September-October 1983.

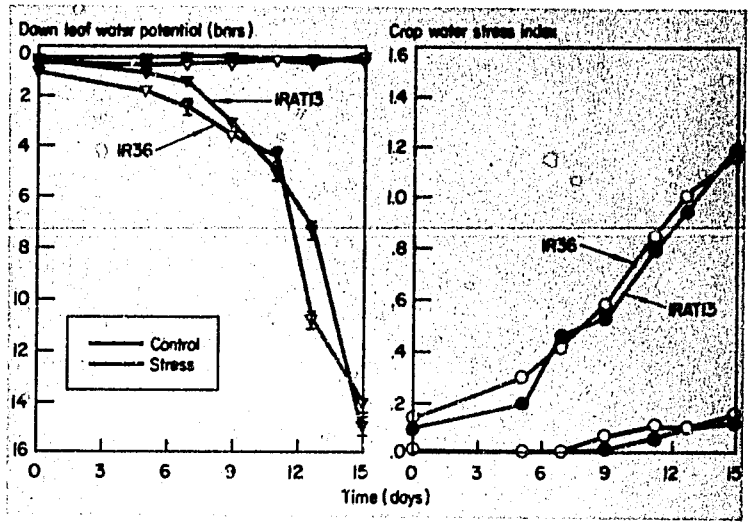


37. Data from a farmer field in the Philippines and two experiment stations in Thailand and India illustrate the variation in degree of soil penetration resistance found in our survey of rainfed lowland rice fields in South and Southeast Asia.

resistance in experiment station and farmer fields varied substantially (Fig. 37). At IRRI we conducted greenhouse experiments to learn the level of penetration resistance that would inhibit root system growth (Fig. 38). As we suspected, most rainfed lowland fields surveyed have a very shallow (0-10 cm) cultivated zone in which root growth is not physically impeded. Below 0-10 cm soil penetration resistance was



38. Mean root length density and dry weight of 4 cultivars. Hardpans were compacted to the three levels of soil strength on the X axis. Soil moisture was maintained at field capacity ≃ 0.03 MPa.



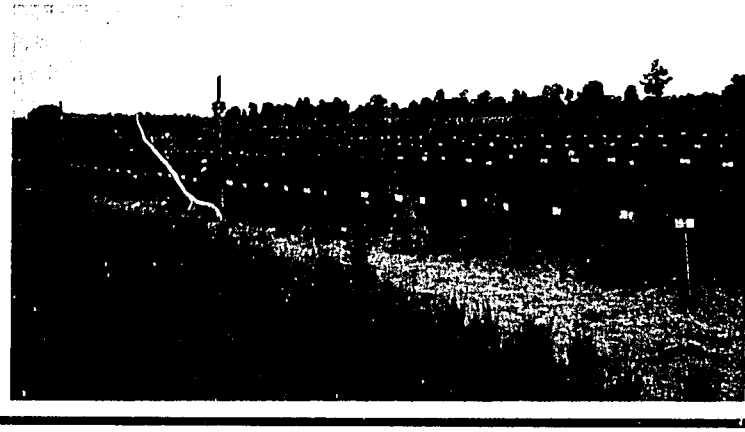
39. Relationship between CWSI and dawn leaf water potential of IR36 and IRAT13 during the 15-d water stress period after anthesis.

generally above levels that inhibit root growth. If drought occurs, shallow or inhibited root development substantially affects rice growth and yield.

Effect of water stress during postanthesis

To identify drought resistance characters, we evaluated in 1983 the effect of induced water stress at postanthesis on upland cultivar IRAT13 and lowland IR36. We successfully used crop water stress index (CWSI) as a tool to control the frequency and amount of irrigation applied to cultivars, and to evaluate the degree of water stress and the kinetics of stress development during 15 d immediately after flowering.

The dawn leaf water potential of both cultivars decreased linearly as CWSI increased (Fig. 39). Throughout the stress period, IRAT13 tended to have higher midday leaf water potential and panicle water potential than IR36. Water stress



Field screening of upland cultivars for drought resistance at the Northeast Regional Agricultural Research Center, Khonkaen, Thailand.

reduced IR36 grain yield by 29.0% and that of IRAT13 by 17.4%. Grains per panicle, percent unfilled spikelets, and 100-grain weight followed a similar trend. IRAT13 had high stem weight loss and increased apparent translocation, which indicated better contribution of stem carbohydrates to grain filling.

ADVERSE SOILS TOLERANCE

In 1983 we continued screening to identify rice varieties tolerant of soil problems such as salinity, alkalinity, strong acidity, excess organic matter, B toxicity, Al and Mn toxicities, and deficiencies in Zn, P, and Fe. Screening was expanded to include materials from the IRTP and we began collaborative experiments with the tissue culture section. We screened 17,000 rices and found 4,000 tolerant of 1 or more of 8 adverse soil conditions (Table 1). IR54 is tolerant of salinity, alkalinity, Zn deficiency, P deficiency, and B toxicity.

Table 1. Screening for adverse soils tolerance in 1983 covered 8 soil conditions and more than 17,000 entries.

Soil stress	Varieties (no.)	
	Screened	Tolerant
Salinity	9,692	2,780
Alkalinity	4,065	925
Peat	551	266
Acid sulfate	428	19
Iron toxicity	452	35
Zinc deficiency	1,799	191
Phosphorus deficiency	619	141
Boron toxicity	95	14
Total	17,701	4,371

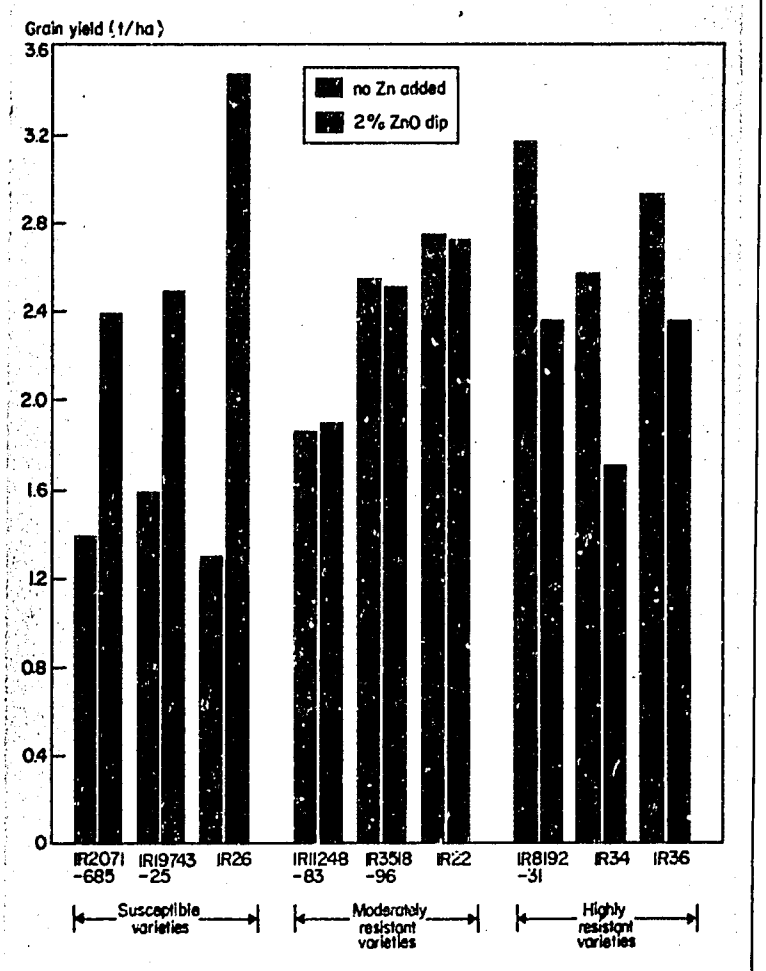
H. U. Neue and R. Lantin, Soil Chemistry Department, recording varietal reaction to Zn deficiency.

Tolerance for zinc deficiency

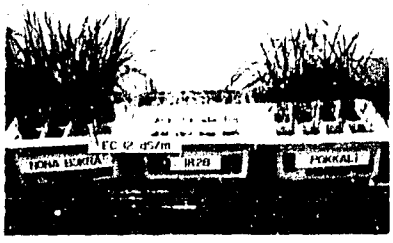
On marginally Zn-deficient soils, tolerant varieties have negative or no response to Zn application, but susceptible varieties respond well (Fig. 40).

In soil and culture solution studies, we could not explain varietal tolerance for Zn deficiency by Zn content alone. Because of its lower Zn requirement, more efficient Zn translocation, and the ability to maintain lower Fe/Zn, Cu/Zn, Mg/Zn, and P/Zn ratios in the shoots, IR34 was more tolerant of Zn deficiency than the susceptible variety IR26. Adding Zn further reduced those nutrient ratios, which caused deficiencies and Fe, Mg, and P mineral inbalance in IR34. Zn seems to affect the uptake and translocation mechanisms of Fe, Mg, P, and Cu.

Our studies indicate that Zn application on marginally Zn-deficient soils low in Fe, Cu, or Mg is not advisable if deficiency-tolerant varieties are used.



40. Effect of Zn addition on grain yield of rices in field experiments in marginally Zn-deficient soils.



41. Of three varieties tested, Nona Bokra had the highest degree of salt tolerance.

Screening for salinity tolerance

We screened for salinity tolerance 522 rice varieties and mutant lines regenerated by tissue culture. Of the entries screened 6% were tolerant, 14% were moderately tolerant, and 80% were susceptible to salinity.

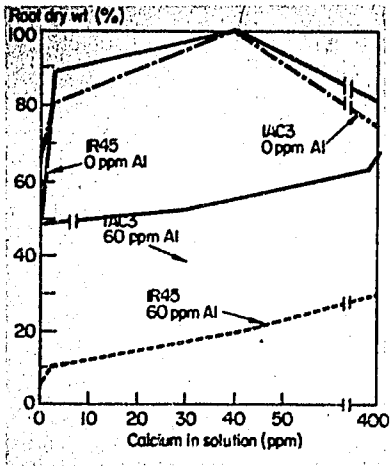
Selecting and multiplying salt-tolerant Nona Bokra variants

Salt-tolerant varieties like Nona Bokra can expand rice cultivation into marginal saline areas. However, Nona Bokra is tall and droopy, has open tillers, is highly susceptible to BI, and yields low. We grew tissue culture-regenerated Nona Bokra variants in the field, and found that many of the lines had better plant type, higher fertility, and were more BI resistant (Fig. 41). Line selection continues in 1984.

Aluminum toxicity

Al toxicity can be expected in soils where the soil solution contains more than 2 ppm Al. Using soil solution analysis, 10 of 39 acid soils we studied were expected to have Al toxicity. Their Al concentration varied from 5 to 152 ppm, and pH was below 4.5. Exchangeable Al was 5 meq or more/100 g soil and Al saturation ranged from 29 to 82%.

Ca concentration varied from 0.5 to 653 ppm. Generally, 40 ppm Ca is adequate for normal rice growth. When excess Ca is present, it competes with Al for exchange sites in the rice roots and reduces Al toxicity. Growth of Al-sensitive IR45, and Al-tolerant IAC3 improved slightly with increasing Ca concentration (Fig. 42). IAC3 grew consistently better than IR45, but at the highest Ca level both varieties grew poorly compared to growth in Al-free and low-Ca soils.



42. Effect of calcium on root growth of IR45 and IAC3 with and without aluminum.

DEEPWATER AND FLOOD TOLERANCE

In 1968 Thailand began testing IRRI crosses of semidwarf and floating rices in 30- to 100-cm deep water. In 1974 we formalized deepwater collaboration with Thailand, posted an IRRI scientist there, and assigned three scientists at IRRI to work part-time with the project. In 1981 we added an entomologist and an agronomist to the program in Thailand, and stationed a deepwater rice breeder at IRRI.

Since 1974 we have cosponsored four deepwater rice workshops, and in 1976 we began distributing the International Rice Deepwater Observational Nursery. Many countries now participate in the nursery. In 1983 promising entries were field tested in Thailand, Vietnam, Bangladesh, and India.

Our international deepwater activities have encouraged interest in this neglected rice culture, which cannot use

currently available MVs. Exchange and cooperative screening of breeding materials are the strengths of the collaborative project, and annual planning sessions in Thailand have highlighted research results and facilitated planning of future experimental efforts.

Cooperation with national programs in India, Bangladesh, Indonesia, Burma, and Vietnam and with WARDA and CIAT have increased exchange of materials, cooperation of deepwater rice breeders, exchange of research findings, and training programs.

Improved lines developed in India, Thailand, Bangladesh, and at IRRI have been tested and found promising in other countries. Varieties Yenet 1 and Yenet 2, now grown in Burma, originated in Thailand. BR224-2B-2-5 from Bangladesh and HTAFR77043-2 from Thailand were outstanding in Indonesia. Thai varieties RD17 and BKN6986-38-1 performed well in Vietnam and Mali, respectively. Several IRRI-developed lines have also proven outstanding.

ADVERSE TEMPERATURE TOLERANCE

One of our most successful national collaborations is the Korea-IRRI Rice Cold Tolerance Project, which began in December 1977. Varieties and breeding lines with cold tolerance at one or more growth stages are screened and selected in Chuncheon, Korea. We also conduct basic experiments to determine reactions of rice plants to low temperature. As part of the Project, we collaborate with the Philippine Ministry of Agriculture at a field experiment station in Banaue, Philippines, where cold temperatures limit rice production. Much of the initial cold tolerance screening for high-altitude tropical areas is conducted there.

Annual planning meetings at IRRI and the exchange of scientists, breeding materials, and data have made the project not only successful, but relevant to many countries with low-temperature problems during the rice growing season.

IRRI's rapid generation advance (RGA) facilities, which can save breeders 2 or 3 yr in the development of an improved variety, are particularly important to the cold tolerance collaboration because in most environments with low-temperature problems only one crop can be screened each year.

Many national program breeders have used the RGA, which has helped increase the diversity of cold tolerance materials, and makes available more fixed materials. This is particularly important to nations with limited breeding and screening resources.

The progress of the cross Watari-Iku 212/Dokita 34 illustrates

the effectiveness of RGA. F_1 seeds of the cross were sent to IRRI in January 1981 for RGA. In 1982 F_4 seeds were planted in Korea. Selected plants were then grown at 6 stations in 1983. One line which yielded an average 6.6 t/ha at 5 stations was named Suweon 329. The seeds of Suweon 329 were sent to IRRI during winter for seed increase, and have been returned to Korea for 1984 regional trials.

The IRCTN is another facet of international collaboration in breeding for cold tolerance. The IRCTN, begun in 1975, provides for the exchange and introduction of breeding materials in low-temperature rice growing areas. Thirty-five countries have participated in the nursery. Through the IRCTN new cold-tolerant varieties have been introduced in India, the Philippines, Nepal, and several African and Latin American countries. Donor parents were provided to national breeding programs in countries such as India, Japan, Indonesia, Nepal, Korea, Burma, and Bangladesh.

In 1984 our cold tolerance work will emphasize improved environmental characterization for more effective breeding and screening programs.

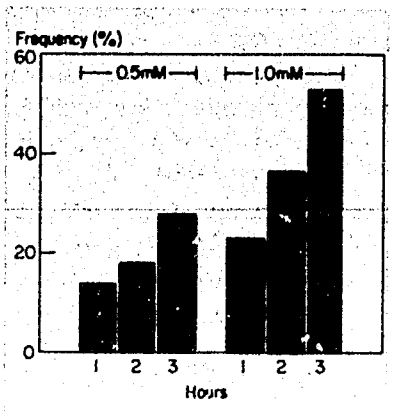
INNOVATIVE BREEDING METHODS

We continued to explore ways of improving the compatibility of hybridization and speeding the development of improved rice varieties. In tissue culture we emphasized research from test tube to field. Our hybrid rice breeding program seeks to determine the potential of improving yields of tropical rices by exploiting heterosis. The male sterile characteristic has been bred into lines adapted to warm tropical conditions, and hybrids from this material continued to show better yield performance in trials in India, Indonesia, and Egypt, as well as IRRI.

Using zygotes to induce mutation

Seed is commonly used to induce mutation in rice. Because seed contains a multicellular embryo, mutagen treatment causes chimera formation and reduces mutation rate. Mutation losses can be avoided by inducing mutation at a unicellular level using a zygote. We evaluated N-methyl-N-nitrosourea (MNU) at different concentrations for inducing mature mutants.

Taichung 65 zygotes were treated with 0.5, 1.0, or 1.5 MNU for 1, 2, or 3 h, beginning 12 h after anthesis. Treated cells were grown to maturity. We found that seed setting, sterility, and germination percentage decreased as MNU concentration increased. Evaluation of the M_2 population showed that in-



43. Effect of treatments on frequency of chlorophyll mutations in M_2 populations.

Gametoclonal variation in grain size among anther culture-derived plants from Taipei 309.

creasing MNU concentration and treatment time increased the number of chlorophyll mutations (Fig. 43).

Induced variability for aluminum and salt tolerance. Al and salt toxicity are major constraints to rice production in large areas of the rice-growing world. We have successfully introduced variability for Al and salt tolerance by using MNU to induce mutation at rice zygote stage.

The M_2 population varied substantially in Al tolerance. Of 5,459 M_2 seedlings screened, 2.6% had high Al tolerance. Level of salt tolerance also varied. Of 244 M_1 plant progenies, 71 were tolerant. Of 15,000 M_2 seedlings, 1.29% were tolerant. We are evaluating the M_3 population of both groups.

Anther culture

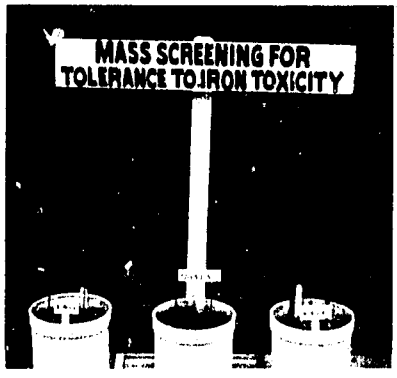
Anther culture is important in rice breeding programs because it increases selection efficiency, accelerates the breeding cycle, and permits faster production and selection of useful mutants.

In 1983, we grew anther culture-derived plants in the field. Gametoclonal variations in anther culture-derived plants from Giza 170 and Taipei 309 were observed in agronomic characteristics such as plant height, panicle length, culm length, flag leaf length, panicle number, percent fertility, days to flowering, and grain size and shape.

We observed similar variability in plants regenerated from anther culture of F_1 sexual crosses; however, no variability was noted among the progenies of regenerated plants, which suggests that the regenerated plants were derived from pollen.

Several selected lines derived from anther culture of F_1 crosses were tested together with their parents in a replicated yield trial at Masapang, Victoria, Laguna, during the 1983 DS. The lines showed mixed characteristics from both parents, but we found no significant difference in yield when lines were compared with one or both parents (Fig. 44). One line from

44. Sister lines from anther culture-derived plants of an F_1 sexual cross of BG90-2 (indica)/Taipei 309 (japonica).



45. Growing anther culture-derived plants from variety Taipei 309 in a strong acid sulfate soil with pH 3.9 showed gametoclonal variability in tolerance for Fe toxicity due to anther culture-induced mutation.

46. Homozygous diploid lines from anther culture (center pots) of an F_1 cross of susceptible parents (end pots) were tolerant of Fe toxicity, possibly because of gene complementation or anther culture-induced mutation.

Suweon 290 (japonica)/BG90-2 (indica) yielded 8.31 t/ha. Suweon 290 yielded 8.26 and BG90-2, 7.99 t/ha.

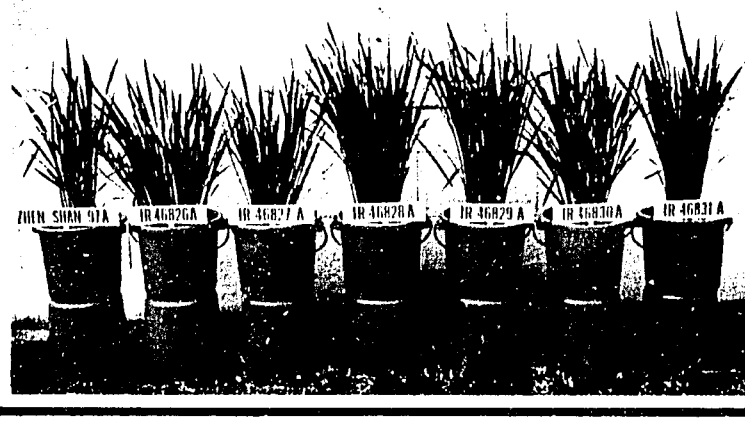
These results show that anther culture could be important to a breeding program, because conventional methods of making crosses between indicas and japonicas usually show high sterility. We also screened anther culture-derived plants for variable tolerance for cold and Fe toxicity and found gametoclonal variation (Fig. 45). For anther culture-derived plants from F_1 sexual crosses, regenerated plants with two Fe toxicity-susceptible parents were in some instances tolerant of Fe toxicity, which suggests that gene complementation or mutation occurred (Fig. 46).

Hybrid rice

Our hybrid rice breeding program seeks to improve yield potential of tropical rice varieties. In 1983 we identified new cytoplasmic-genetic male sterile (cms) lines and worked to develop hybrids with good levels of pest resistance. We also evaluated yield parameters of hybrid rices and collaborated with the Chinese Academy of Agricultural Sciences in evaluating production data collected from Chinese hybrid rice farmers.

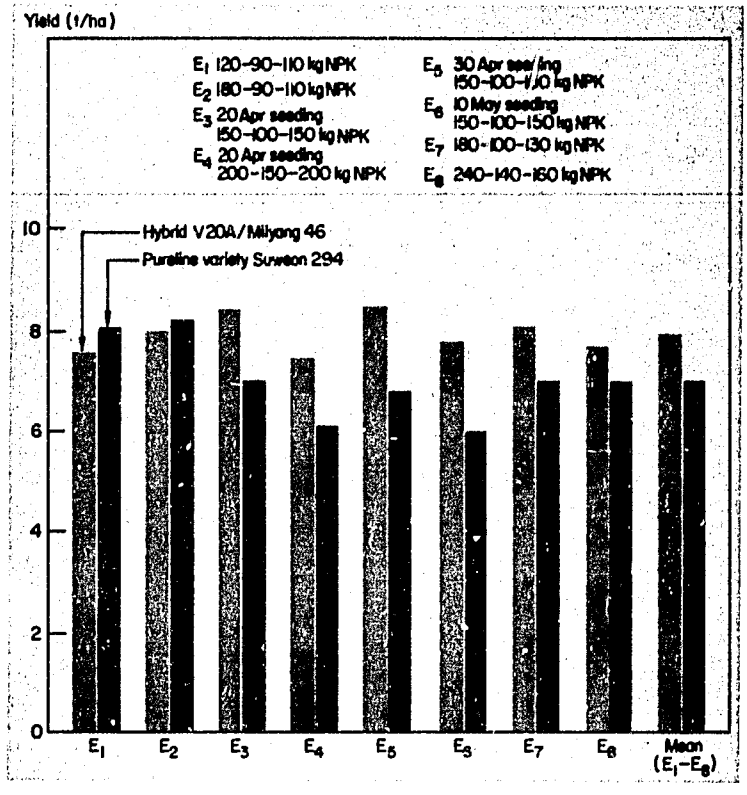
New cytoplasmic-genetic male sterile lines. We have developed six cms lines with better adaptability in the tropics than the Chinese lines V20A and Zhen Shan 97A (Fig. 47). The new lines are being evaluated by IRRI collaborators in India, Indonesia, and Korea. They do not have adequate disease and insect resistance for tropical areas where pest incidence is high. In 1984, however, we expect to have high yielding cms lines with good levels of pest resistance.

In 1983, experimental hybrids developed from Zhen Shan 97A and V20A and Korean restorer lines were evaluated at 3 locations in Korea. V20A/Milyang 46 yielded 7.9 t/ha, 0.9 t more



47. Six cms lines developed at IRRI (IR46826A to IR46831A) compared with the Chinese cms line Zhen Shan 97A.

48. Performance of the highest yielding rice hybrid (V20A/Milyang 46) and the highest yielding check variety (Suweon 294) in South Korea.



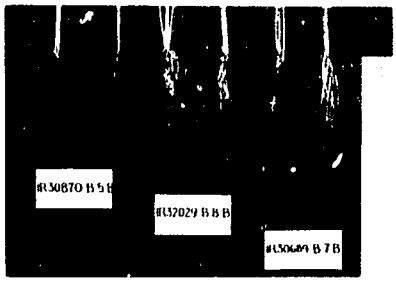
than the best check variety Suweon 294 (Fig. 48). Seed of that hybrid is being produced at IRRI for further evaluation in Korea.

Hybrid yield parameters. Our evaluation of hybrid rice yield parameters shows that hybrids produce more dry matter and have higher harvest index than their parents and check varieties.

Analysis of dry matter accumulation in 35 experimental F_1 hybrids and their parents showed that increased leaf area, not photosynthetic rate, resulted in increased dry matter. Each hybrid plant had more leaves and more tillers at vegetative stage. Leaves tended to emerge from the main culm more rapidly on hybrids than on their parents. Increased harvest index was due to higher spikelet number per square meter and 1,000-grain weight. Hybrids had more spikelets per panicle than other varieties.

In 1983, IRRI and the Chinese Academy of Agricultural Sciences collaborated to examine the economics of hybrid rice and seed production in China. Economists from the 2 institutions spent about 5 wk in China collecting production data for the 1982 crop year. After interviewing farmers in Fujian and Hunan Provinces, the economists reported these findings:

- Hybrids yielded 16% more at the farm level than the best



49. Root system of a 25-d-old seedling of F_5 lines grown in a dry seedbed.

pureline high yielding variety (6-7 t/ha).

- There was an economic advantage to hybrid rice cultivation only when paddy price was more than $200/t.
- Hybrid seed production was much more profitable than hybrid rice cultivation with the present seed yield of 1.3-2 t/ha and the present hybrid seed:paddy exchange rate of 1:10. It may be possible to lower the hybrid seed price in China to 1:7, which will allow seed producers to make 30% higher profits than hybrid rice growers.

Breeding for upland varieties

Using a genetic male-sterile (ms) line, we began in 1983 WS a program to combine drought and Bl resistance in varieties for upland culture. We crossed ms donors and 24 F_2 bulk populations with drought and Bl resistance, and harvested about 1 kg seeds from the ms plants after the first cycle of random mating. After 2 more cycles we will begin plant selection and testing.

Selection for deep and thick roots. Deep and thick roots are important for rice plants to withstand drought. In 1983 we implemented a modified bulk method to select for upland conditions plants with deep and thick roots.

Plants were selected for Bl and ShB resistance prior to bulking. Progenies were planted as a bulk population from F_2 to F_5. Because early selection for deep and thick roots yields tall-statured, low-tillering, lax-panicled phenotypes, we delayed selection until 25 DAS in the F_5 (Fig. 49), when we could recover a higher percentage of progenies with desired root and yield characteristics and intermediate stature. Selected plants were transplanted in a partially irrigated field and are being evaluated for desirable agronomic traits.

COMPUTERIZED DATA MANAGEMENT

In 1983 we installed the GEU computerized system into the newly installed IBM 4331, completed a standardized system for inventorying breeding lines tested at IRRI, and updated the GEU data base.

When the IBM 4331 system, IRRI's first large in-house computer, was installed, we immediately initiated the transfer to the system of the GEU computerized system developed for the IBM 370-135. The Interactive Germplasm Bank Information Retrieval System, which substantially improves the speed of information retrieval, was completed and used in the fourth quarter.

The inventory of all selected lines tested in various IRRI nurseries (F_1 hybrids, F_2 nursery, pedigree nurseries, observational yield trial, hybridization block, replicated yield trial, and

elite lines) was completed and systematized. To facilitate information retrieval from all data files involving advanced generation lines, we developed a program that can retrieve desired information based on specification either of a given set of varieties or lines, or of all lines of a given set of crosses.

We continued to update the GEU data files with data generated in 1983. We added 5,922 registered accessions of *O. sativa* to the IRRI germplasm computer data bank (bringing to 59,342 the total bank accessions as of 31 December) and 4,146 new IR crosses to the history-of-crosses master file (bringing the total to 46,831). Data on 18 GEU traits, used as the basis for the selection of 19,232 early generation lines from 138,148 tested during the year, were updated in the nursery inventory data files.

INTERNATIONAL RICE TESTING PROGRAM

The IRTP is an effective force for global rice improvement. Its main objective as an international cooperative network is to give each rice scientist in any country access to the world's elite rice germplasm for the diverse agroecological situations to which rice must be adapted. In 1983 we continued to emphasize development of rainfed rice nurseries for adverse environments.

The situation of Tulsi Das, a rice scientist with the Barisal Regional Rice Research Station in Bangladesh, shows how the IRTP works. Das is breeding rice for tidal wetlands, which are large areas where the rice crop is submerged twice daily for several hours because of tidal inundation by fresh water.

Each year his station receives the International Tide-Prone Rice Observational Nursery, which provides an annual source of potentially valuable material that would be difficult, if not impossible, for a single plant breeder to otherwise obtain. He tests materials from IRRI and tide-prone rice improvement programs in countries such as Indonesia and Thailand and crosses them with the best locally grown varieties. The result will be varietal releases for farmers in Bangladesh's tidal wetlands.

International nurseries

In 1983 23 different nurseries were composed for the various target environments and stresses. Rice scientists in 59 countries requested 1,228 sets. Analysis of 1982 data from hundreds of trials highlighted several entries which were outstanding for grain yield, acceptability, and stress resistance across many environments (Table 2).

The proportion of entries in the IRTP nurseries originating from national programs continues to grow, and more varieties

Table 2. More than 200 rices performed well at many sites in 1982 IRTP tests. Data from the tests were submitted by scientists at test sites and analyzed and summarized at IRRI. (Individual nursery reports published by IRRI provide detailed information.)

Nursery	Promising entries
	Nurseries for cultural types
Irrigated-Yield	
IRYN-VE (very early)	• IR50, IR9729-67-3, UPR103-80-1-2, BG367-7, IR19743-25-2-2-3-1, BG276-5, IR15429-268-1-2-1
IRYN-E (early)	• IR21015-80-3-3-1-2, IR13240-82-2-3-2-3-1, IR9828-91-2-3, IR13429-196-1, IR36
IRYN-M (medium)	• IR13540-56-3-2-1, BG400-1, B2489B-PN-1-76-8, IR19670-263-3-2-2-1, IR54, IR22082-41-2
Irrigated-Observational	
IRON	• AD9246, IR9852-22-3, Si-Pi 692033, Si-Pi 662106, IR8608-82-1-3-1-3, UPR79-85, IR17525-278-1-1-2, IR18349-94-2-1-1-3, IR19349-135-2-3-2-1, IR24632-60-3-3-2, M12C-34-3, UPR231-28-1-2-TCA2, Tainung sen 12
Arid Region	• IR19725-1-2-2, CR548-4-2-1, GZ839-S-2-1, IRAT118, IR19743-46-2-3, IR19746-28-2-2, Giza 172, DRN 9
Rainfed-Yield	
IRLRYN (lowland)	• IR8192-166-2-2-3, BR4, IR46, IR13146-45-2-3, IR14632-2-3, IR14753-49-2
Rainfed-Observational	
IURON (upland)	• M18, UPL Ri-7, B2997C-TB-60-3-3, B3016B-TB-260-3-2-1-1-3, IRAT140, IRAT101, BG35-2, B2992B-TB-73-4-2-3-3-3-2, ITA139, TOX502-2-SLR2-LS3-B1
IRLRON	• IR46, IR13146-45-2, IR19083-22-2-2, IR19256-88-1, IR21141-24-2, IR15583-89-7E-P3, IR10781-75-3-2-2, IR13564-95-1, IR4829-89-2, Pelita I-1, RP1045-25-2-1
IRDWON I-IV	
Flood tolerant rice	• B981D-SI-35-1, FR 13A, BKNFR76109-7-2, Tilak-kachari, CN540, CNM539, CR149-5010-228, IR20880-25-3, Jalaj
Deepwater rice	• BKNFR76014-1-9-2, BKNFR76014-1-9-3, HTA7406-110-1-1, RD19, SPR7282-151-2-1, SPR7282-2-0-24-1, TCA180-4
Floating rice	• IR11141-6-1-4, IR11288-B-B-118-1, SPR7411-7-2-1, BR222-B-191-3-2, HTAFR77043-1, HTA7205-11, HTA7421-8-1, Leb Mue Nahng III
Tidal swamp rice	• B2791B-MR-196-2-3-1-3, B2791B-MR-196-2-3-3-5, B3063B-CK-8-MD-14-2-1, B3063C-PN-151-2, Cisadane, IR13146-45-2, IR4819-77-3-2, IR5657-33-2-2-3, IR8192-166-2-2-3, IR9830-26-3-3, Kajalsail, Mahsuri
	Nurseries for individual stresses
Temperature	
IRCTN (cold)	• Deog Jeog Jodo, IR18476-86-3-3, IR19126-42-1, RP1848-109-2-1-1, Shoa-Nan-Tsan (check), Khudwani (check), Suweon 235 (check), IR9202-5-2-2-2

Nursery	Promising entries
Problems Soils	
IRSATON (salinity)	• A69-1, IR4422-6-2-3-1, IR4630-22-2-17, Pokkali, IR9884-3-3, Mahsuri, M152, Nonasail, PNL36-184-3-2, PNL5-30
(alkalinity)	• IR8608-139-1-1-3, IR13149-3-2-2, IR2071-105-9-1, IR2307-247-2-2-3, Pokkali, Suakoko 8
Acid upland	• Azucena, IR3646-8-1-2, IR6023-10-1-1, ITA116, Salumpikit, BPI Ri-6, B733C-167-3-2, IR9410-80, IR9671-1-4-6-8
Acid sulfate	• IR2153-26-3-5-6, IR4422-428-2-3-3, IR46, IR50, RPCB-2B-849, IR36, IR43
Peat soils	• IR3397-44-1-4-3, IR4422-51-1-1-2, IR34
Iron toxicity	• IR4422-480-2-3-3, IR4683-54-2-2-3, IR52, IR36
Diseases	
IRBN (blast)	• CIAT-ICA5, IRAT104, IR1905-81-3-1, IR2793-80-1, IR3259-8-172-5, IR5533-PP856-1, Tetep, Ta-poo-cho-z, Tres Marias, BG367-7, Cheol-weon 32, IR15314-43-2-3-3, IR2793-80-1, ITA231, P1377-1-15M-4-1M-1, Suweon 300, 16877, 16879
IRBBN (bacterial leaf blight)	• Cisadane, IR13525-43-2-3-1-3-2
IRTN (tungro)	• ARC11554, Utri Merah, Utri Rajapan, Naria Bachi
Leaf scald	• BR189-103-2-1-4-1, BR189-103-2-1-5-1-1, IR5677-22-5-2, IR5726-31-2, CR1002, IR13146-41-3, BR236-2-1-6-1-1, BR51-282-8
Ragged stunt	• IR13525-43-2-3-1-3-1, IR19661-131-1-3-1-3, IR19661-364-1-2-3, IR19660-131-3-3-3-3
Insects	
IRBPHN (brown planthopper)	• PTB33, Mudgo, Babawee, Rathu Heenati, IR15324-117-2-2-3, IR15324-12-2-3-3-2, IR19661-23-3-2-2
IRGMN (gall midge)	• RPW6-17, W1263, CR94-CRRP51-6288, IR9828-41-2-1, IR13429-287-3, IR14632-181-1, IR8608-189-2-2-1, IR9828-94-3
Yellow stem borer	• CO 18, IR15723-45-3-2-2-2, IR19373-44-3-2-2, IR36, IR8608-75-3-1-3, W1263, W1253
Leaffolder	• TKM6, W1263, PTB33, T2005
Rice thrips	• Dahanala 2220, Dahanala, Kalubalawee, CO 28, CO 32, IR4829-89-2-1, IR8, IAC47

developed in national programs are being released to farmers in other countries. Two-thirds of all IRTP entries now come from the national programs and one-third come from IRRI.

Hot spots for environmental stresses

A critical step in developing rices for adverse soils is the selection of sites with appropriate characteristics for screening. During the 1983 IRTP Monitoring Tour on Rice Improvement for Adverse Soils, participants from six South and Southeast Asian countries studied coastal saline and acid sulfate environments in Thailand, Bangladesh, and eastern India (Fig. 50).

50. An IRTP monitoring team studied current research to breed rice varieties and improve fertilizer efficiency in the acid sulfate and coastal saline environments in three Asian countries.

They evaluated the present screening sites for those soil stress environments and recommended one acid sulfate site in Thailand (Ongkharak) and a coastal saline site in West Bengal (Central Soils Salinity Research Institute, Canning) as particularly suitable for expanded varietal screening for adverse soils.

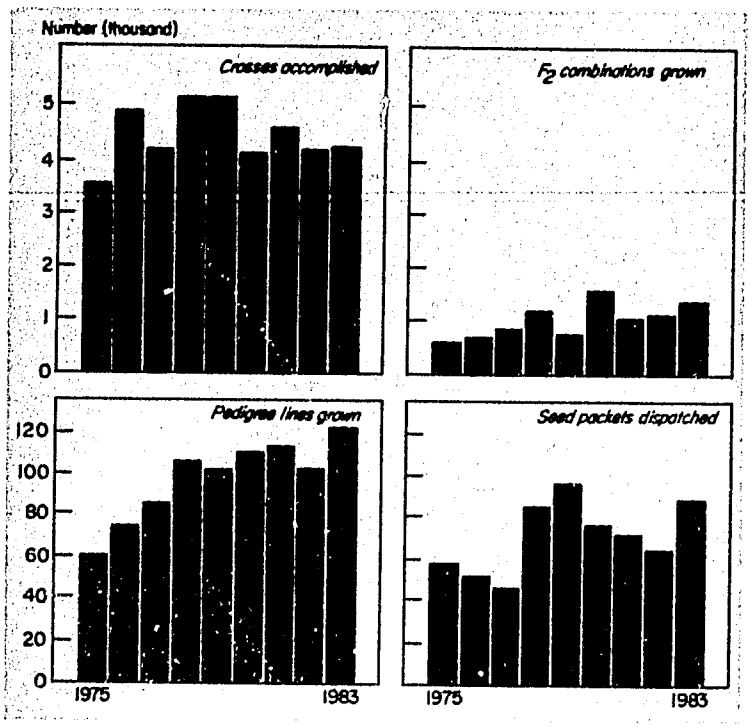
INTEGRATED GEU PROGRAM

The GEU program seeks to develop improved rices for the world's diverse rice growing environments through interdisciplinary and international cooperation. Our varietal improvement activities are carried out in close cooperation with national rice improvement programs. Thus many parents suggested by national program scientists are included in the hybridization blocks every year.

Numerous crosses are made at the request of collaborating scientists. Seeds of F_1, F_2, and other early generation materials are freely exchanged. Seed samples of fixed-generation IRRI breeding lines are sent to rice scientists around the world either as formalized IRTP nurseries or on request. Many are utilized in the local crossing programs and most outstanding ones are evaluated in yield trials as varietal possibilities.

To date, 127 varieties from IRRI breeding materials have been released in Asia, Africa, Latin America, and Oceania. They

51. Volume of the IRRI breeding program.



are now planted in more than 30 million ha of riceland. To meet the worldwide demand for improved germplasm we made 4,147 crosses in 1983, grew F_2 populations from 1,388 crosses, evaluated 122,614 pedigree nursery rows, and sent abroad 88,204 seed packets of IRRI breeding lines (Fig. 51).

IRRI rices named in nine countries

In 1983, 9 national programs named 12 IRRI breeding lines as varieties.

- IR2071-586-5-6-3, with multiple disease and insect resistance and adverse soils tolerance, was named Pyi Lone Chan Tha in Burma, which means wealth for the whole country. A reselection of this line was also released as AU42/1 in Tamil Nadu, India. It was first recommended as IR42 by the Philippine Seed Board in 1977 and has been released in Indonesia, Malaysia, Vietnam, Kampuchea, and Nigeria. IR42 is now the second most widely grown rice variety.
- IR790-35-5-3, a sturdy-stemmed selection with good grain quality, was released as Faro 7 in Nigeria.
- IR661-1-170-1-3 is grown as IR661 in the Kununura region of Western Australia.
- IR2058-78-1-3-2-3 was released in Brazil as Pesagro 102. It was released as IR46 in the Philippines in 1977, and also

has been recommended in Cameroons.

- IR8208-146-1 was recommended as Pesagro 101 in Brazil.
- IR2071-199-3-6, a sister line of IR36 and IR42, was released as BR15 (Mohini) in Bangladesh. It is suitable for boro and aus seasons, and resists RTV, BB, BLS, ShB, SR, and BI.
- IR2793-80-1 was recommended as BR16 (Shahi Balam) in Bangladesh for boro and aus. It is resistant to RTV, BB, SR, and BI.
- IR758-15-2 was named BAU63 (Varasha) in Bangladesh and approved for cultivation in boro. It is a sturdy-stemmed, lodging-resistant variety with moderate resistance to BB, BI, SR, and RTV.
- IR2071-625-1-252 was recommended in Anhui Province of China. It was first recommended as IR36 by the Philippine Seed Board in 1976, and has become the most widely grown rice variety in the world.
- IR13429-209-2-2-1, a line with resistance to many diseases and all the known BPH biotypes, was recommended in Indonesia. It was released as IR56 by the Philippine Seed Board in 1982.
- IR9752-71-3-2, a very early-maturing selection with multiple disease and insect resistance and excellent grain quality, was released as IR58 by the Philippine Seed Board. It matures in 100 d and is the earliest maturing of the IR varieties.
- IR13429-299-2-1-3 was released as IR60 by the Philippine Seed Board. This early-maturing selection, 105 d, has multiple resistance to various diseases and insects, and is resistant to all known BPH biotypes. It was recommended for cultivation primarily in Mindanao, Philippines, where the new BPH biotype is prevalent. IR60 has long slender grains with high milling recovery and strong dormancy.

Developing improved germplasm

In 1983 we continued to develop improved germplasm for diverse growing conditions.

Irrigated rice. For irrigated rice, we made 789 crosses, grew F_2 populations from 461 crosses, tested 66,802 pedigree nursery rows, and evaluated 966 breeding lines in replicated yield trials. Based on our tests, Philippine Seed Board trials at 12 sites, and international yield nurseries, we identified several promising lines for irrigated areas.

- IR13540-56-3-2-1 is an early-maturing line with resistance to major insects and diseases and all known BPH biotypes. It has medium-long, translucent grains and high yield potential, and was the highest yielding IRYN-M entry for the last 3 yr.

- IR13525-43-2-3-1-3-2 matures in 115-120 d and has multiple resistance to major diseases and insects, including all known BPH biotypes. It has long, slender, translucent grains.
- IR29723-143-3-2-1 is high yielding and matures in 135 d. It has sturdy stems and is lodging resistant. It has long, slender, translucent grains with high milling recovery and multiple resistance to major diseases and insects.

Cold-tolerant rice. We evaluated cold-tolerant materials at Banaue, Philippines, and in collaboration with Korean scientists at Chuncheon, Korea. Replicated yield trials at Banaue confirmed the superior performance of four lines. IR8866-30-3-1-4-2, IR9202-5-2-2-2, IR13155-60-3-1-3, and IR5716-18-1 are early-maturing, BB-resistant, have low-temperature tolerance, and yielded significantly higher than the local check Pinidua.

Rainfed lowland rice. Our major emphasis in developing varieties for rainfed lowlands is to incorporate tolerance for drought, submergence, and stagnant flooding. Because it has a vast area of rainfed lowland rice, we have developed a collaborative program with Thailand to evaluate early generation materials in that country. In 1983, we sent 70 F_2 populations from crosses between adapted Thai varieties and best IRRI parents which were grown at 5 research stations in northern Thailand during 1983 WS. From those populations, 2,781 plant selections were made and brought back to IRRI for RGA and screening. The F_4 will be sent to Thailand for further evaluation and selection in 1984 WS.

Several advanced breeding lines performed well both at drought-prone areas in the Philippines and in the drought screening nursery. IR26894-37-2-1-3, IR28441-164-1-5, IR29385-2-30-3, and IR33356-14-3-1-3 were drought resistant at vegetative stage in at least two different tests.

We evaluated several breeding lines in a yield trial under medium-deep, stagnant water. Water depth was maintained at 30-40 cm for most of the season. IR13149-71-3-2-3, IR33238-25-2-3-2, and IR26702-204-2-2-1-1-3 yielded better than the check variety IR42.

Deepwater rice. Varieties for deepwater areas must be adapted to local flooding regimes such as flash flooding or prolonged flooding. They also must flower within 2 wk of the optimal flowering date, which is determined by receding floodwater. These requirements emphasize the importance of rigorous selection under actual deepwater conditions. Therefore, we have developed arrangements with scientists in India, Bangladesh, Burma, Thailand, Vietnam, and Indonesia to collaboratively evaluate and exchange deepwater breeding materials at various developmental stages. Promising materials

Table 3. Promising improved breeding materials for deep water conditions in different countries.

Designation	Origin	Country where found promising	Comments
RD17	Thailand	Vietnam	Too early in Thailand but suitable in Vietnam
BKN6986-38-1	Thailand	Mali	Too early in Thailand but suitable in Mali
IR11288-B-B-118-1	IRRI, Thailand	Bangladesh	Developed at IRRI using RGA and selected in Thailand
IR11288-B-B-69-1	IRRI, Thailand	Several	Developed at IRRI using RGA and selected in Thailand
IR11141-6-1-4	IRRI, Thailand	Several	Developed at IRRI using RGA and selected in Thailand
CN540	Thailand, India	India	Selected in West Bengal from an F_2 received from Thailand
Yenet 1	Thailand	Burma	Developed in Thailand, reselected and released in Burma
Yenet 2	Thailand	Burma	Developed in Thailand, reselected and released in Burma
BR224-2B-2-5	Bangladesh	Indonesia	Floating rice developed in Bangladesh and found promising in Kalimantan, Indonesia

have been identified in several countries (Table 3).

Upland rice. Upland rice breeders from 11 institutions in Africa, Latin America, and Asia discussed breeding strategies with IRRI staff at the 1983 International Rice Research Conference, and agreed to send IRRI locally adapted materials to be used in a crossing program. IRRI will make the crosses and grow the F_1s to obtain F_2 seeds. The F_2 bulk populations will be sent to collaborators. In 1983, IRRI supplied 213 F_2 populations to 10 institutions and made 28 single and 128 multiple crosses at the request of collaborating scientists.

Forty advanced upland breeding lines were tested at three Philippine locations. IR3839-1 continued to show high yield potential under favorable environmental conditions, yielding 4.1 t/ha in a farmer's field at Santo Tomas, Batangas. However, its average yield at 3 locations was rather low (2.0 t/ha) because of moisture stress at flowering and prevalence of glume Bl and ShB. The average yield of check variety IR43 was 1.9 t/ha. IR3839-1 has intermediate reaction to Bl and moderate susceptibility to ShB. It is 96 cm tall and matures in 115 d, earlier than the local IR43.

Among the non-IRRI varieties tested, IRAT113, a 105-d line from Ivory Coast, yielded an average 2.7 t/ha across 3 environments. Earliness helps it escape moisture stress at reproductive stage. It yielded highest (2.5 t/ha) of all varieties in the less fertile and well-drained site at IRRI. IRAT113 resists Bl but is highly susceptible to ShB.

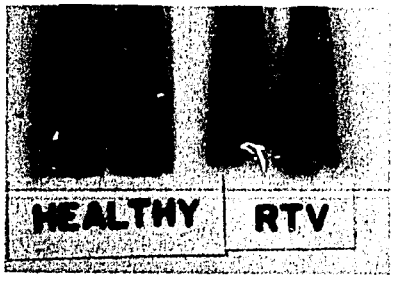
Control and management of rice pests

Purchased inputs such as fungicides, insecticides, and herbicides are increasingly expensive; often must be imported, which strains currency resources in less developed nations; and may increase the level of farmer risk in rice production. Although we continue to evaluate pesticide effectiveness at IRRI, much new research emphasizes biological control techniques such as IPM, crop cultural patterns, and pest monitoring. Controls such as those are particularly important as cropping intensity increases in rice areas around the world.

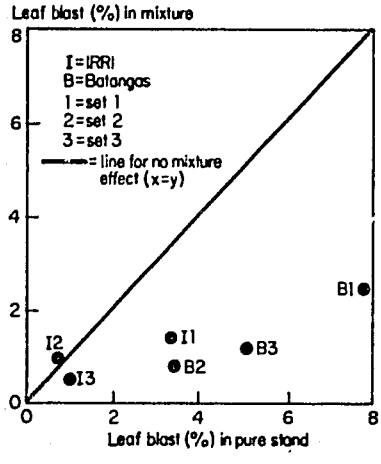
DISEASE CONTROL

Disease is a major and persistent constraint to increased rice production. In 1983 our plant pathologists continued to improve the RTV disease monitoring system in the Philippines and stressed research on the three major rice diseases RTV, BI, and ShB, with special emphasis on vector transmission of RTV and cultural practices to reduce BI.

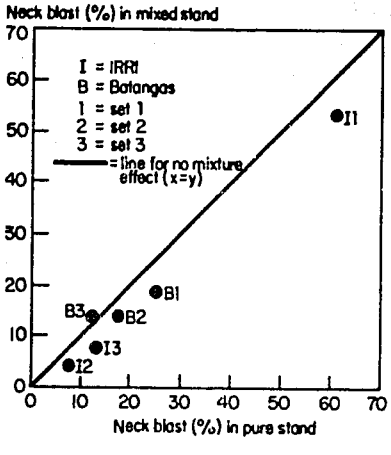
1. The Philippine tungro monitoring project trains field technicians in record-keeping and other monitoring aspects.



2. Reactions of healthy and RTV-infected rice leaves in the iodine starch test.



3. Effect of pure stand and mixed stand on leaf Bl values for 3 mixture sets at 2 sites.



4. Effect of pure stand and mixed stand on NBl values for 3 mixture sets at 2 sites.

Monitoring RTV in the Philippines

In 1981 we organized a collaborative RTV monitoring project in the Philippines with the Philippine Bureau of Plant Industry. Our goal is to develop an effective and comprehensive RTV monitoring system that will limit or prevent serious RTV outbreaks.

We have trained 85 Regional Crop Protection Center and Surveillance and Early Warning System personnel to monitor RTV in the field (Fig. 1). In 1983, we taught field workers how to use two simple tests to quickly and accurately diagnose RTV infection in the field. In the iodine starch test, sample leaves are cut and the cut ends dipped in common pharmacy iodine. If RTV is present, veins in the leaf turn black (Fig. 2). The latex test uses a RTV antiserum.

In 1981 we monitored 37 fields in 23 municipalities of 8 provinces; by 1983 we were monitoring 236 fields in 80 towns of 28 provinces. In 1981 and 1982, we found that most observation fields were RTV-free and correctly predicted that there would be no large-scale RTV outbreaks. In 1983 we observed comparatively high RTV incidence and vector populations at some localities, and our trained field workers helped rice farmers undertake appropriate disease control measures.

GLH transmission of RTV

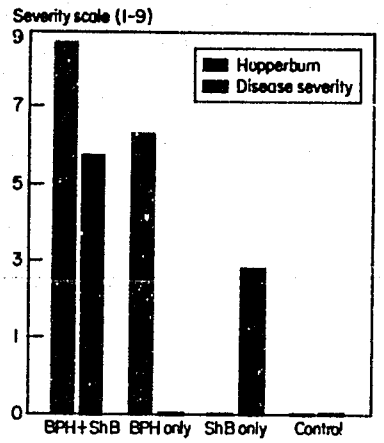
In 1983 we applied the latex test to determine virus presence in RTV-inoculated plants. We used antisera to rice tungro spherical virus (RTSV) and rice tungro bacilliform virus (RTBV). Inoculated plants contained either both viruses, RTBV or RTSV alone, or no virus.

Rice plants infected with RTSV did not show clear symptoms, but RTBV infected plants were moderately stunted and discolored. Rice plants infected with both particles were severely stunted and discolored.

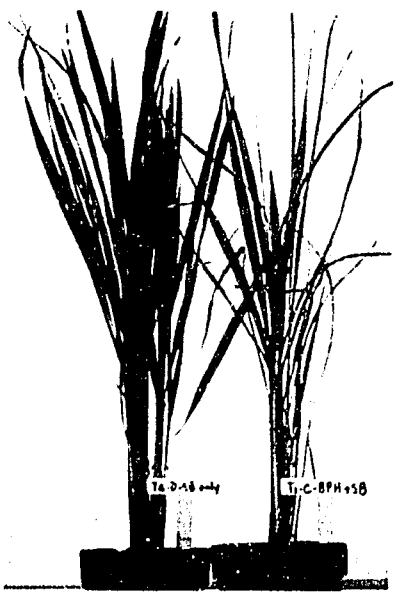
We also studied GLH transmission of RTBV and RTSV virus particles. GLH did not transmit RTBV from plants infected with RTBV alone, but efficiently transmitted RTSV. RTBV was transmitted only when GLH had fed on RTSV-infected plants. GLH could transmit RTSV only for 3 d, but could support RTBV for 7 d, which indicates that RTSV assists in RTBV infection.

Blast control using mixed cultivars

Planting a mixture of rice cultivars increases genetic diversity in a crop stand and greater genetic diversity may improve production stability. Malaysian scientists have successfully tested this strategy for Bl control in lowland irrigated rice. We tested cultivar mixtures for Bl control under more Bl-prone upland conditions.



5. Effect of BPH and ShB pathogen on hopperburn and disease severity in IR22.



6. Disease severity due to combined BPH and ShB and to ShB alone.

At IRRI and on a farm near Santo Tomas, Batangas, we tested three mixture sets, each composed of three cultivars or breeding lines. Set one was cultivars C22, UPLRi3, and UPLRi5. Set 2 was breeding lines IR3839-1, IR5931-110-1, and IR5929-12-3; and set 3 was IR6023-10-1-1, IR6115-1-1-1, and IR10011-16-3.

When mixed stand infection levels were compared to mean levels for pure stands, cultivar mixtures proved more effective against BI (Fig. 3) than NBI (Fig. 4). Future work will seek to improve NBI control by increasing the number of cultivars in the mixture and choosing cultivars with more diverse parentage.

Interaction of sheath blight and brown planthopper

To test for possible interaction of ShB and BPH, we infested IR22 at maximum tillering stage with 100 fourth-instar BPH, then inoculated *Rhizoctonia solani* after 7 d.

Hopperburn and ShB infection were significantly more severe on plants with BPH and ShB than on plants with only ShB or BPH (Fig. 5, 6). These results indicate that there may be a synergistic interaction between ShB and BPH.

Bacterial control of sheath blight

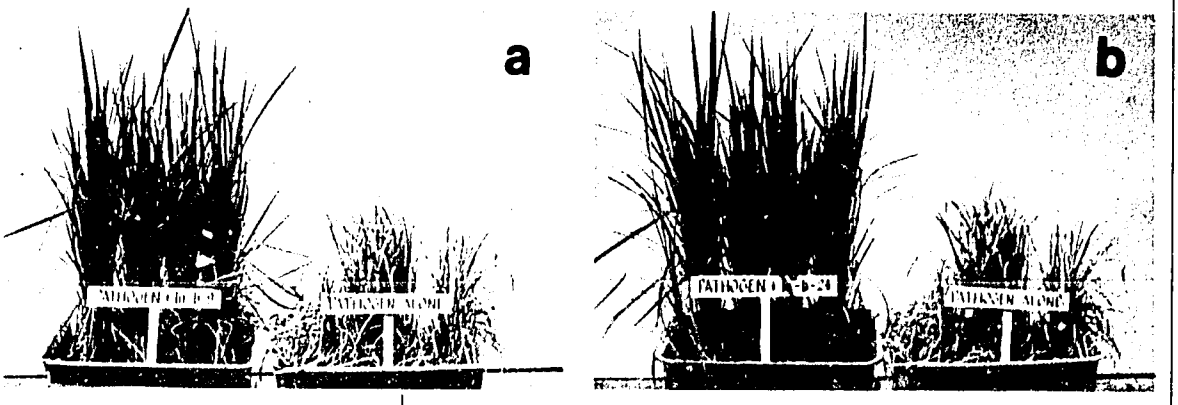
Fluorescent *Pseudomonas* and nonfluorescent bacteria isolated from sclerotia of the ShB fungus *Rhizoctonia solani* retard ShB development. To study the effect of bacteria, we soaked IR36 seeds in bacterial suspensions of fluorescent *Pseudomonas* and the other bacteria from the paddy field for 10 min, then sowed them in plastic trays filled with soil infected with inoculum of a 7-d-old *R. solani* culture LR-1. Plants from treated seeds grew more vigorously than those from untreated seeds (Fig. 7). Bacteria treatments substantially reduced ShB incidence and sclerotia viability.

INSECT CONTROL

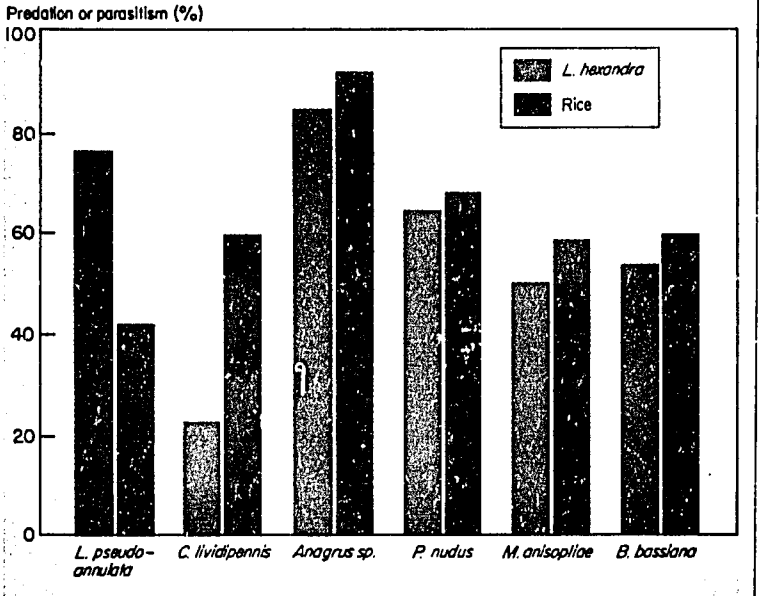
We are emphasizing research to develop insect management technology that is safe, effective, and economically efficient for small rice farms. In 1983 we studied natural vegetation that provides a habitat for beneficial insects when rice is not grown, continued to refine our knowledge of biological controls and predators of pests, and worked to develop a methodology for monitoring insect buildup on research farms.

Habitat for beneficial insects

Leersia hexandra, a weed that grows along rice field irrigation ditches, may provide a year-around habitat for predators of



7. Effect of a fluorescent pseudomonad (a) and a nonfluorescent bacteria (b) from rice fields on ShB infection of IR36.



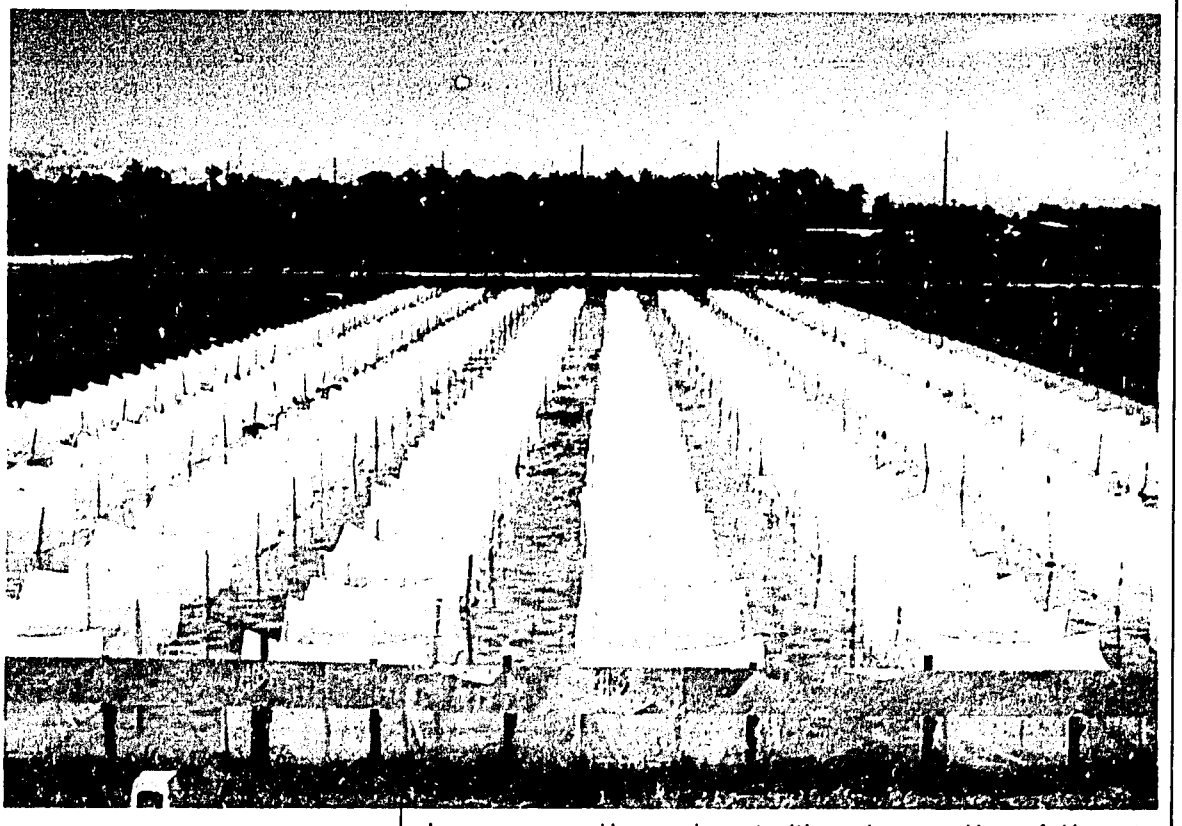
8. Predation, parasitism, and disease infection in BPH populations of *L. hexandra* and rice.

BPH, one of the most serious rice insects. In 1982 we found that a type of BPH that lives and feeds on *L. hexandra* cannot live on BPH-susceptible rice variety TN1. Those BPH may be food for predators in DS when no rice is grown, and an important food source for natural enemy populations that will colonize fields when rice is again planted.

In 1983 we found that the following predators attack the BPH on rice as well as *L. hexandra* hoppers: the spider *Lycosa pseudoannulata*, the mirid bug *Cyrtorhinus lividipennis*, the egg parasite *Anagrus* sp., the nymph parasite *Pseudogonatopus nudus*, and the fungal pathogens *Metarrhizium anisopliae* and *Beauveria bassiana* (Fig. 8).

Revising economic injury levels

Economic injury levels usually are based on populations or



9. Field cages used to study yield losses caused by single and multiple insect species infestation.

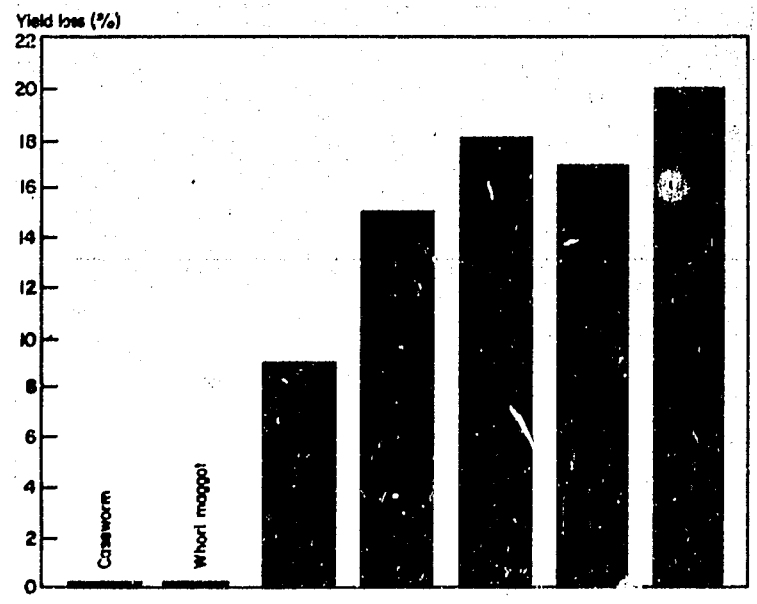
damage caused by one insect, although several harmful insects may be present. Our research shows that the cumulative effect of multiple insect damage should be considered when setting economic injury levels.

In 1983 we evaluated IR36 yield as affected by CW, RWM, and YSB, alone or in combinations (Fig. 9). At the populations tested, CW and RWM caused no yield loss and YSB caused 9% yield loss. When two or more of the insect species were on rice, yield loss was 15-20% (Fig. 10).

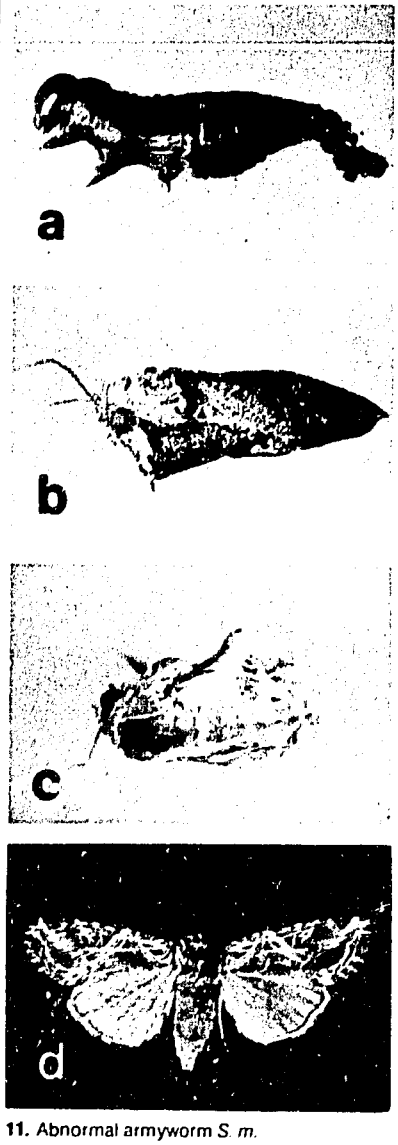
Chemical controls

Evaluation of neem (*Azadirachta indica*) seed derivatives for control of insect pests of rice continued in collaboration with the International Centre of Insect Physiology and Ecology in Kenya, the University of Giessen, and the Max-Planck Institute, West Germany.

Hemipterous (BPH, WBPH, GLH, and RB) and lepidopterous (LF, armyworm, and ear-cutting caterpillar) insects were found susceptible to neem derivatives. Although neem seed oil and neem oil extracts do not kill outright, they incapacitate the insects by interfering with feeding activities and by disturbing growth and molting processes (Fig. 11). Even when insects



10. A single insect species at a given population may not cause significant yield loss; however, a combination of two or more species at those populations caused significant yield loss.



11. Abnormal armyworm *S. m. acronynctoides* larvae when third- and fifth-instar larvae were fed rice leaf cuts sprayed with neem oil: a) pupa with larval skin and head capsule still attached to posterior and anterior body parts, b) adult unable to emerge from pupal case, c) deformed adult, d) normal adult

were on neem-treated plants for only a short time and then removed to untreated plants, their behavior and physiology were disturbed for several days. For example, a 3-d exposure of BPH, WBPH, and GLH nymphs to rice plants grown in soil in which neem extract was incorporated significantly reduced fecundity of emerging adults.

Neem derivatives are harmless to beneficial arthropods such as spiders, mirids, microveliids, and hymenopterous insects. Rice fields sprayed with neem oil with 1% carbon gave significantly higher yields than unsprayed fields.

Seed oils of other meliaceous plants such as chinaberry (*Melia azedarach* and *M. toosendan*) are being evaluated by Chinese scholars at IRRI. Seed oil of custard-apple (*Annona squamosa*), a common plant in the Philippines, effectively controls rice leafhoppers and planthoppers.

Judicious use of insecticides

In 1983 we jointly sponsored the FAO-IRRI Workshop on Judicious and Efficient Use of Insecticides on Rice. Twenty-eight invited and nine IRRI scientists discussed the consequences of escalating insecticide use, trends and developments in chemical insecticide research, and the economics of insecticides for small farms. Key papers presented and recommendations of the working groups have been published.

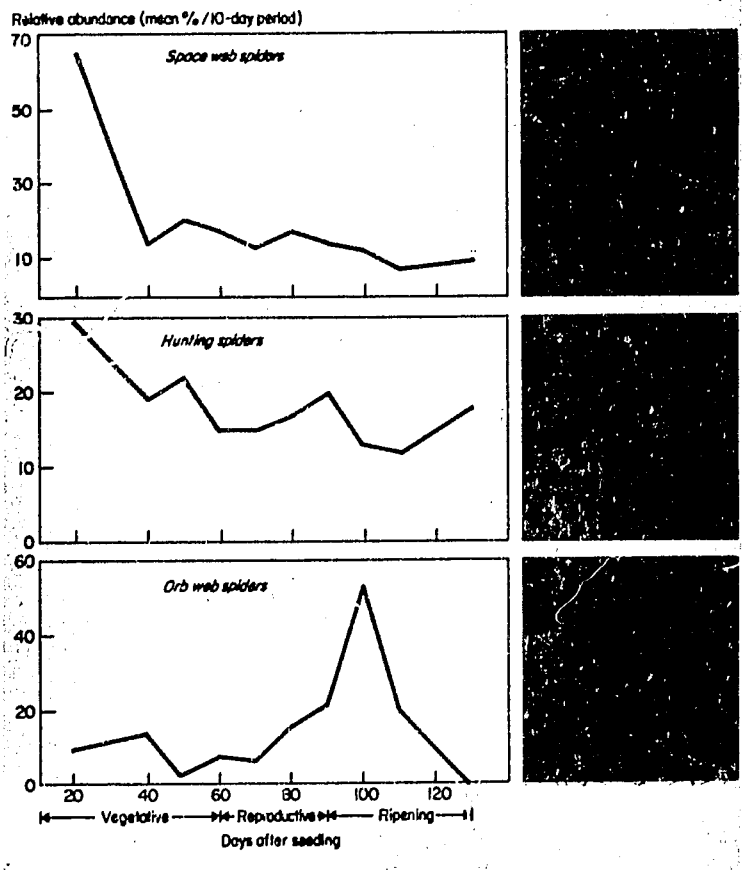
Pest monitoring at IRRI

Because continuous cropping of rice on the IRRI farm encourages large populations of many rice insects, we depend

upon insecticides for pest control. To assure wise insecticide use, we established an integrated pest monitoring group in 1983. Twenty IRRI staff members from research departments and the farm department produce monthly reports on insect populations and damage to rice based on light and suction trap catches and actual sampling of field plots. Insecticide is applied when pest populations exceed the threshold of economic injury. We feel what we are learning about insect pest surveillance and timing of insecticide applications will not only make our use of insect controls more effective, but also help develop a methodology for use on other research farms.

Biological control

Spiders are important natural enemies of rice pests — particularly planthoppers and leafhoppers — not only because of their voracious appetites but because of their prevalence in rice field environments. We surveyed rice fields in the Philippines and found that of 51 spider species collected, almost half the species and two-thirds of the individuals are orb weavers.



12. Space web and hunting spiders are early colonizers of rice fields because they readily find shelter in grassy rice bunds or fallow areas during land preparation. Orb weaver populations, although larger, occur too late in crop development to effectively stop pest multiplication.

Despite their predominance, orb weavers do not control insect pests as effectively as hunting and space web spiders because they require tall rice foliage to suspend their webs and therefore are prevalent at the later growth stages after most pest damage occurs (Fig. 12).

Lycosa pseudoannulata, the most common hunting spider, is large, aggressive, and preys on hopper adults as they fly into fields before egg laying. *Callitrichia formosana*, the most common space web spider, is small and catches hopper nymphs directly or in the irregular webs it spins at the base of rice plants. Space web spiders complement hunting spiders in reducing pest numbers at early crop development.

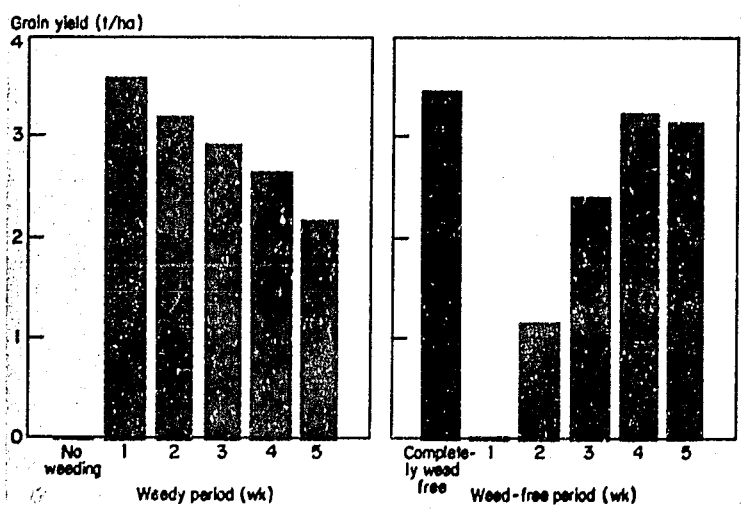
WEEDS

Our work in weed control stresses testing of herbicides and herbicide applicators suitable for use on small rice farms. Increased importance is being placed on testing for broadcast-seeded and upland rice.

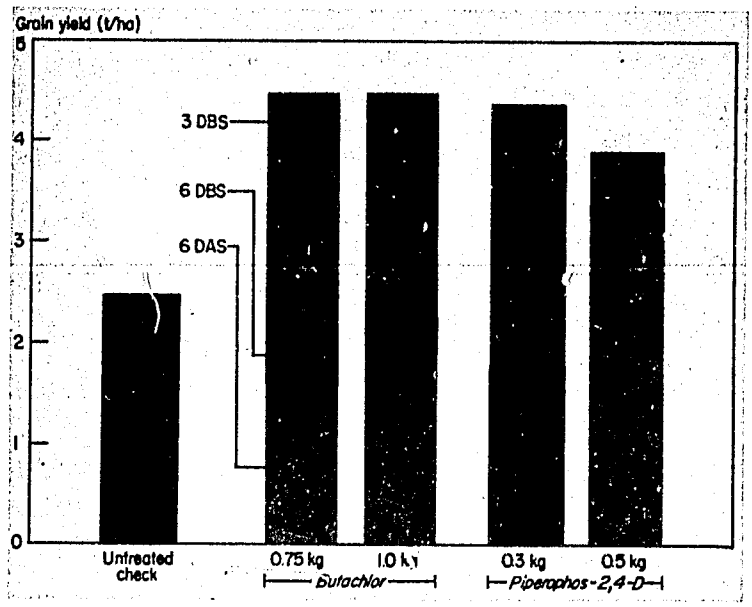
Cooperative testing

In 1968 we began cooperative herbicide testing with national programs. After preliminary tests at IRRI, sets of promising herbicides are sent to cooperators for location testing. National programs in 37 African, Asian, and Latin American countries have tested 1,221 sets of herbicide samples for transplanted (474), direct-seeded flooded (406), and upland (341) rice.

The results have encouraged broad usage of butachlor (22 countries) selected at IRRI in 1968 and thiobencarb (56 countries) selected in 1969. Although they are most important



13. Keeping the plots free of *S. maritimus* for 4 wk after transplanting or thorough weedings 3 wk after transplanting increased IR36 grain yield.



14. Rice yield was higher when butachlor and piperophos — 2,4-D were applied 3 DBS.

in South and Southeast Asia, they are also used in Latin America.

Weeding time

We related duration of *Scirpus maritimus* competition to transplanted rice yield. We obtained optimum yield by keeping the crop free from *S. maritimus* for 4 wk after transplanting or by letting weeds grow for 3 wk, then doing thorough weedings (Fig. 13).

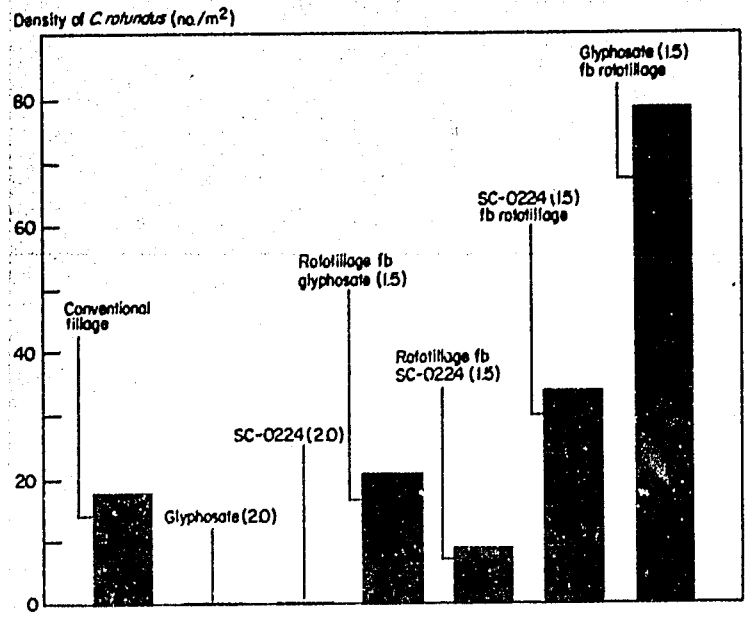
2,4-D for *S. maritimus* control

We continued evaluating 2,4-D for control of *S. maritimus* in direct-seeded flooded rice. We found that although 2,4-D and bentazon controlled the perennial sedge better, combining the herbicides did not increase grain yield significantly. Low-cost 2,4-D alone can control *S. maritimus* effectively.

Timing herbicide application

Direct-seeded flooded rice has become increasingly important in the Philippines and other Asian countries such as Malaysia and Thailand, but difficult weed control has slowed its adoption. Timing of herbicide application is critical. Herbicides normally are applied soon after weed emergence (6 DAS) to minimize crop injury.

We evaluated butachlor and piperophos - 2,4-D for control of a mixed population of *S. maritimus* and annual grassy weeds. Applying herbicides 3 DBS onto puddled fields gave better weed control and higher grain yields than when they were



15. Herbicide alone or in combination with cultivation provided adequate to excellent control of *C. rotundus* in upland rice

applied at either 6 d before or after seeding (Fig. 14).

Cyperus rotundus L. control

We continued to seek suitable control methods for *C. rotundus*, one of the weeds most damaging to upland rice. When we applied 1.0 kg 2,4-D/ha 20 DE to plots with different preplant weed control treatments, a preplant application of either 2 kg glyphosate or the coded herbicide SC-0224 per hectare gave complete control (Fig. 15).

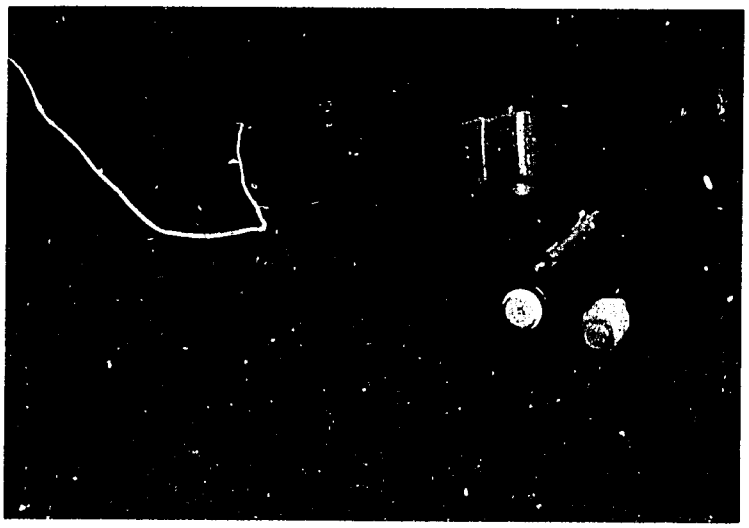
Control of *Rottboellia exaltata*

R. exaltata is a potentially dominant grassy weed in upland rice. We found that one tank-mix application of pendimethalin and fluazifop-butyl (1.0 + 0.08 kg ai/ha) 12 DE provided excellent *R. exaltata* control and significantly increased rice yield compared with the untreated and hand-weeded checks or a single application of either herbicide.

Improved herbicide sprayers

Method of application substantially affects herbicide efficiency. We compared five sprayers with different volume delivery and design for application of butachlor and 2,4-D.

The birky (Fig. 16), a new, low-volume pneumatic sprayer, performed significantly better than the conventional knapsack sprayer, as did the micron-herbi (a battery-operated ultralow-volume disc applicator) and the single nozzle knapsack sprayer, which performed similarly. The VLV-50, which is a nozzle and

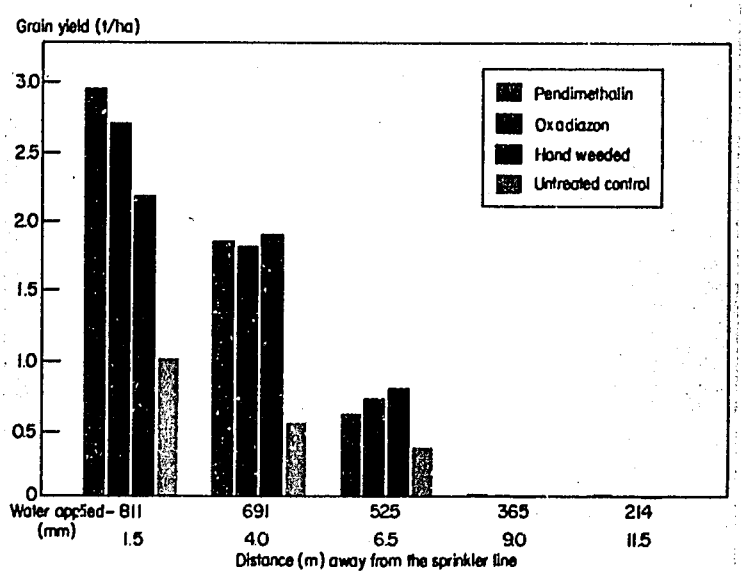


16. The birky (a) and micron-herbi (b) performed significantly better than the conventional knapsack sprayer (c).

regulator unit that converts a common knapsack to a very-low-volume sprayer, gave poor results.

Soil moisture-herbicide relationship

Soil moisture status governs the success of chemical weed control in upland rice. In 1983 DS we used a line source sprinkler system to regulate soil moisture while evaluating the effectiveness of pendimethalin and oxadiazon. With both herbicides IR36 yields were similar to those of the hand-weeded check at high moisture levels (811 and 691 mm). But when moisture level dropped below cumulative pan evapora-



17. Effect of herbicides on grain yield of upland rice (IR36) at different soil moisture regimes. Although oxadiazon was the next best herbicide, it caused 20% reduction of rice stand.

tion (668 mm), yields with chemical and hand weeding were similar to those in the unweeded check (Fig. 17). Below 525 mm there was no grain yield although herbicide and hand weeding effectively controlled weeds. Results indicate that herbicide application is wasteful unless adequate water is available for crop growth.

Irrigation water management

Inefficient operation and underutilization of costly irrigation systems are major constraints to increasing crop production and farmer income through the adoption of modern rice technology in South and Southeast Asia. In 1983, we continued our assistance to national irrigation research and management agencies with goals to develop and implement improved irrigation strategies to benefit more farmers. Our studies were concentrated in Bangladesh and the Philippines.

Bangladesh

The Bangladesh program, which began in 1982, seeks to improve the use of available irrigation water and to increase crop production. We have worked with the North Bangladesh Tubewell Irrigation System, which uses groundwater from a cluster of 378 deep tubewells, and the Ganges-Kabodak Irrigation System, which pumps water from the Ganges River and distributes it through gravity canals. We are emphasizing increased efficiency for both systems because capital and energy costs are high.

We collaborate with the Bangladesh Rice Research Institute (BRRI) and the Bangladesh Water Development Board (BWDB) in those projects. Research is conducted by multidisciplinary teams of professionals from both local institutions. We provide the methodology on which planning and design, field assessment, data analysis, and reporting are based, and give tactical support to the BRRI and BWDB staff.

North Bangladesh Tubewell Irrigation System. We studied production practices and constraints, irrigation water use, and the operation schedules for 12 tubewells selected to represent the irrigation system. The following goals for field research were developed:

1. In Bangladesh we work to strengthen water user's organizations and to encourage cooperative maintenance and management of irrigation systems

- improve the reliability and scheduling of water delivery;
- introduce and encourage the adoption of suitable MVs through the extension program;
- test and recommend rice-based cropping patterns that will increase food production and farmer income; and
- create and promote water users' organizations to continue the development process (Fig. 1).

Our field research helped reduce conveyance loss by an average 78%, and expand the service area of the 12 pilot tubewells from 175 ha in 1981 aman (benchmark) to 435 ha in the next aman season, and from 95 ha in 1982 rabi (benchmark) to 190 ha in 1983 rabi. Total area served by the 12 tubewells increased by 210 to 250% in subsequent seasons. Likewise, the proportion of MVs planted increased from 15% in 1981 aman to 55% in 1982 and 60% in 1983.

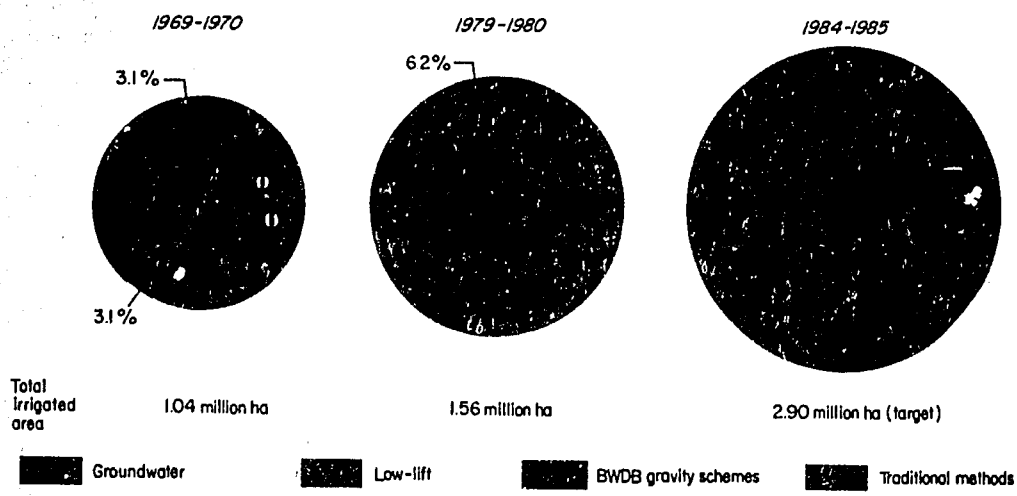
Groundwater for Bangladesh agriculture. Expanded use of groundwater for irrigation is a key agricultural development strategy in Bangladesh. Groundwater is pumped from deep, shallow, and hand pump tubewells. The increasing importance of groundwater and low-lift pumping irrigation is shown in Figure 2.

We analyzed the implications of the projected growth of

A Bangladeshi farmer works in a well-watered field of the tubewell irrigation system.

groundwater irrigation with respect to critical issues such as scale (deep, shallow, or hand pump tubewells), construction quality control, and maintenance facilities and skills. We also studied the trend toward private ownership in the deep tubewell sector and the shifting emphasis from deep to shallow tubewell development. The importance of continuous, careful monitoring of water table levels where groundwater irrigation predominates was emphasized.

We also examined present policies and implementation procedures with regard to standardization of equipment and materials used in tubewells; zoning of irrigable areas suited for

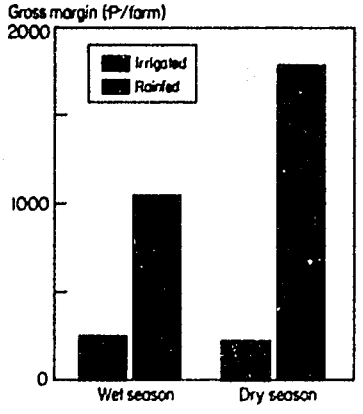


2. Use of groundwater for irrigation is increasing rapidly in Bangladesh.

hand pump, shallow, and deep tubewells; development of private sector maintenance services; and coordination among implementing agencies to promote growth but eliminate overcrowding and incompatible mixes of tubewell types.

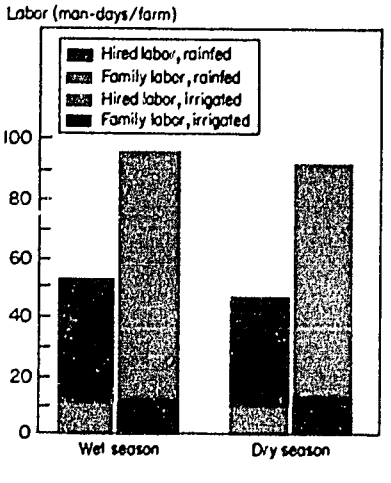
Philippines

In the Philippines we collaborate with the National Irrigation Administration, which is the planning, implementing, and operating agency for all national irrigation systems. Research is concentrated in Central Luzon, which is an intensively irrigated rice bowl of the country, and Camarines Sur (Bicol region), which is one of the least developed areas. A major pumping system in Camarines Sur was recently developed to supply river water to irrigate about 3,900 ha of previously rainfed farms.



3. Higher yields and cropping intensity of irrigated farms resulted in a higher gross margin per farm than in rainfed areas of LCPIS

This farmer cooperator harvested 7 t ha in 1983 aman by adopting a recommended variety, water management, and inputs



4. Irrigation increased area planted to rice and cropping intensity, which increased demand for hired labor. Data are averaged for LCPIS 1981-83

Our objectives for activities in the Libmanan-Cabusao Pump Irrigation System (LCPIS) in Camarines Sur are

- to develop a system water management model that is effective, efficient, and easily implementable by the farmers' association;
- to monitor and analyze the economic and institutional changes resulting from introduction of irrigation water;
- to assess crop production constraints; and
- to help develop the farmer association's capacity to manage the system, and improve farmers' knowledge and skill in modern rice technology.

The Bicol River Basin Development Program office collaborates with IRRI in this project.

Irrigation in Camarines Sur. We determined the impact of irrigation on rice production for the LCPIS using the *with* and *without* comparative method of project analysis. Farm production, labor, and input use data for two crop years (1981-82, 1982-83) were analyzed for irrigated (with) and rainfed (without) farms.

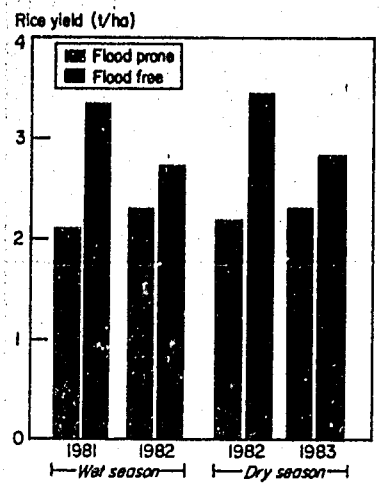
Introducing irrigation in Camarines Sur significantly improved yield, increased cropping intensity, improved labor use efficiency, and increased inputs. Yields on irrigated farms were more than one tonne more than on comparable rainfed farms for WS and DS. The area planted on irrigated farms was 37% higher than on rainfed farms in WS and about 50% more in DS. In WS, irrigated farms netted a gross margin four times that of rainfed farms. In DS, when water supply is critical, the difference was much larger, about ₱1,500 (Fig. 3).

Introducing irrigation also influenced the input use of rice farmers. Irrigated farms used significantly more fertilizer, particularly N fertilizer, than rainfed farms. They also spent ₱20 more for insecticide. Expenditures for herbicide, however, were similar.

Labor requirements on irrigated farms are much higher than on rainfed farms (Fig. 4), because more land is planted and cropping intensity is greater. Hired labor is in greater demand, which increases area employment opportunities.

Drainage in the LCPIS. The LCPIS has flood protection dikes, flap gates to protect the service area from seawater intrusion, and a network of drains to carry and discharge excess water from the service area to the river and the sea. Despite these facilities, parts of the system were flooded and waterlogged after major typhoons in each of the last 3 yr (1981-83). In 1982 and 1983, flooding and waterlogging damaged about 600 ha of the service area.

We analyzed the drainage problem with respect to hydrology and its effects on rice production, and found that the LCPIS

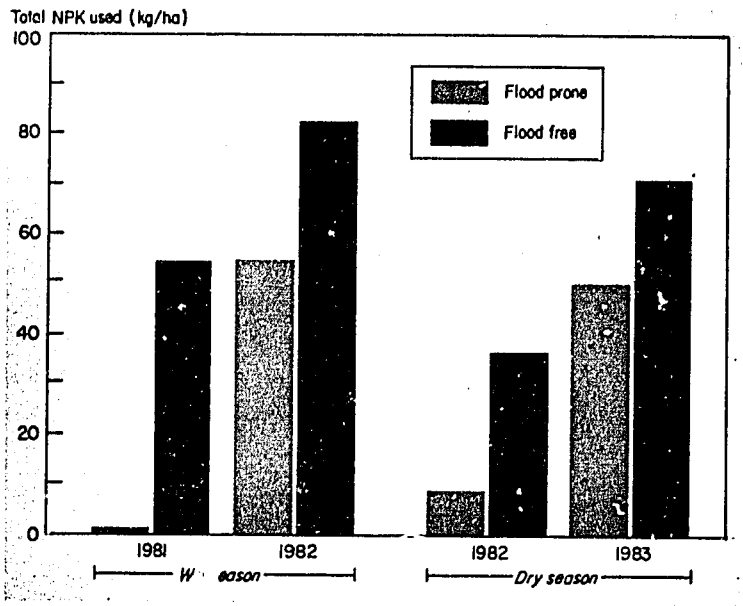


5. Rice yields in the flood-prone areas of LCPIS are less than in the flood-free.

drainage facilities are inadequate and allow prolonged flooding. Moreover, inspection and maintenance work are difficult because the primary drainage canals do not have service roads.

We found that flooding and waterlogging

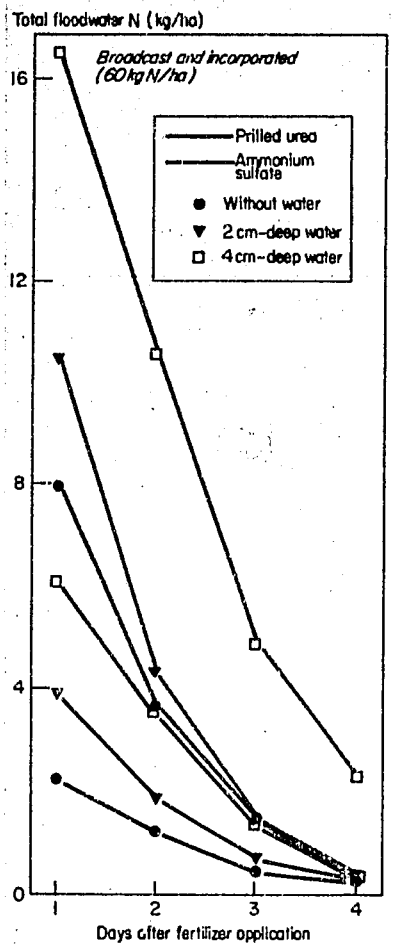
- destroy standing crops in areas where waterlogging is deep and prolonged;
- cause cropping intensity to be less because some flooded areas cannot be planted on time or at all in WS; and
- limit rice yields (Fig. 5). Farmers in flood-prone areas use less inputs (Fig. 6).



6. Farmers in the flood-prone areas of LCPIS use less inputs than those in the flood-free.

Soil and crop management

IRRI soil and crop management research seeks to develop optimum rice crop production methods. Management studies in chemical and biological soil fertilization and amelioration and tillage practices are designed to enhance the productivity of traditional and modern rice varieties in irrigated and rainfed conditions.



1. Effect of N sources and water depths at fertilizer application on total floodwater N.

FERTILIZER MANAGEMENT

Minimizing fertilizer nitrogen losses

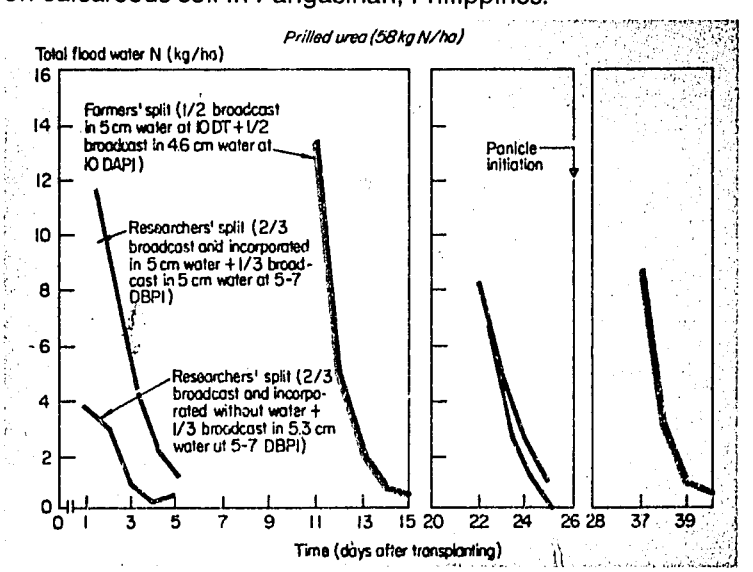
We evaluated the effect of N source and water depth during fertilizer application on total floodwater N in unplanted plots at IRRI. When flooding followed B&I of 60 kg urea N/ha in fields without standing water, 13% of the N applied (Fig. 1) was found in the floodwater 1 d after incorporation. When an equal amount of N was broadcast on 4 cm of standing water, floodwater N content doubled (27%). The trend was similar for ammonium sulfate, but N level in the floodwater was lower. If water is present, fertilizer cannot be incorporated into the soil because most of it dissolves when it hits the water.

In field trials evaluating N fertilizer efficiency B&I without standing water produced 4.6 t/ha, 0.6 t/ha more rice than was harvested when urea was broadcast and the soil cultivated with 5 cm standing water. Attempted incorporation of N fertilizer with 5-cm-deep water produced grain yields similar to those with farmers' practice. The farmers' practice of broadcasting the first N application into floodwater 10 DT gave the highest levels of floodwater N (Fig. 2).

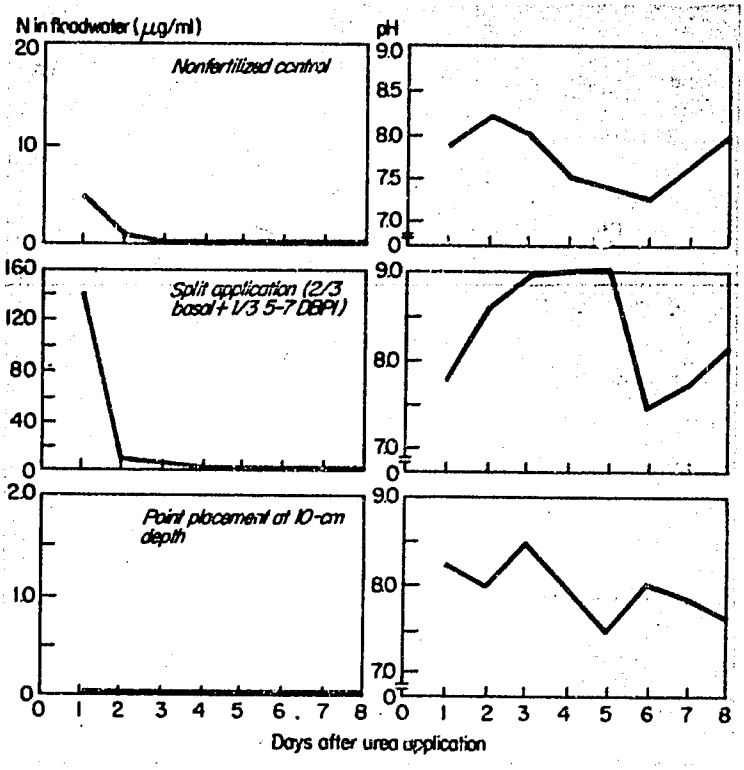
Our results suggest that attempting to incorporate N fertilizers in soils with standing water before transplanting will cause high N losses and lower grain yields unless a suitable fertilizer placement machine that covers the fertilizer and prevents its escape into floodwater can be developed.

Nitrogen efficiency in calcareous soil

We evaluated efficiency of N sources and application methods on calcareous soil in Pangasinan, Philippines.



2. Urea fertilizer surface broadcast or incorporated with standing water produced high N levels (urea-N + NH_2^+-N) in the floodwater.



3. Effect of methods of urea application on pH and total N concentration of floodwater on a calcareous San Manuel clay loam.

When fertilizer was split-applied floodwater pH rose to 9.1 5 d after N application, but dropped to pH 7.5 the following day (Fig. 3). Total urea + NH_4^+-N in floodwater the first day after fertilizer application was 140 ppm, but it dropped to a negligible level the following day. We did not record any N in the floodwater after deep point placement.

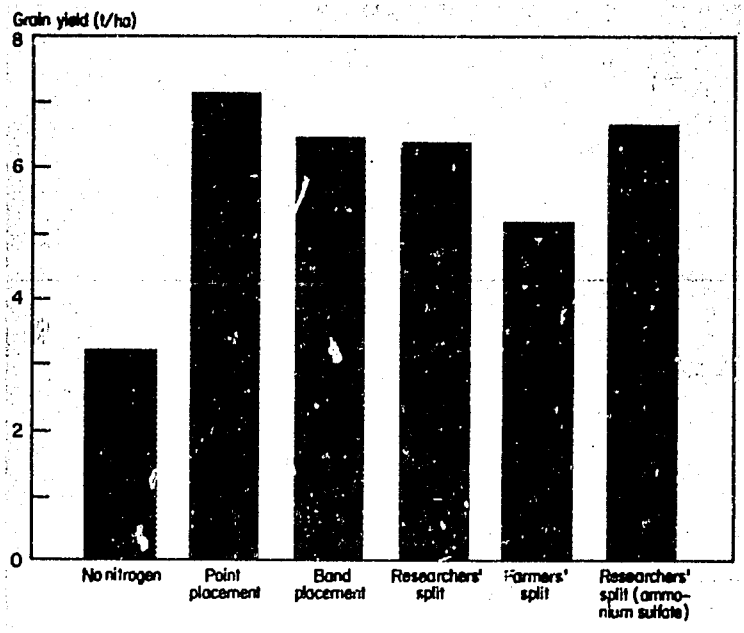
Ammonium sulfate produced yields similar to those of urea. Deep point placement at 10 cm gave the highest grain yield (Fig. 4). Our results suggest that even in a calcareous soil, deep placement of N fertilizer results in minimal N losses and highest grain yields.

Ammonia volatilization

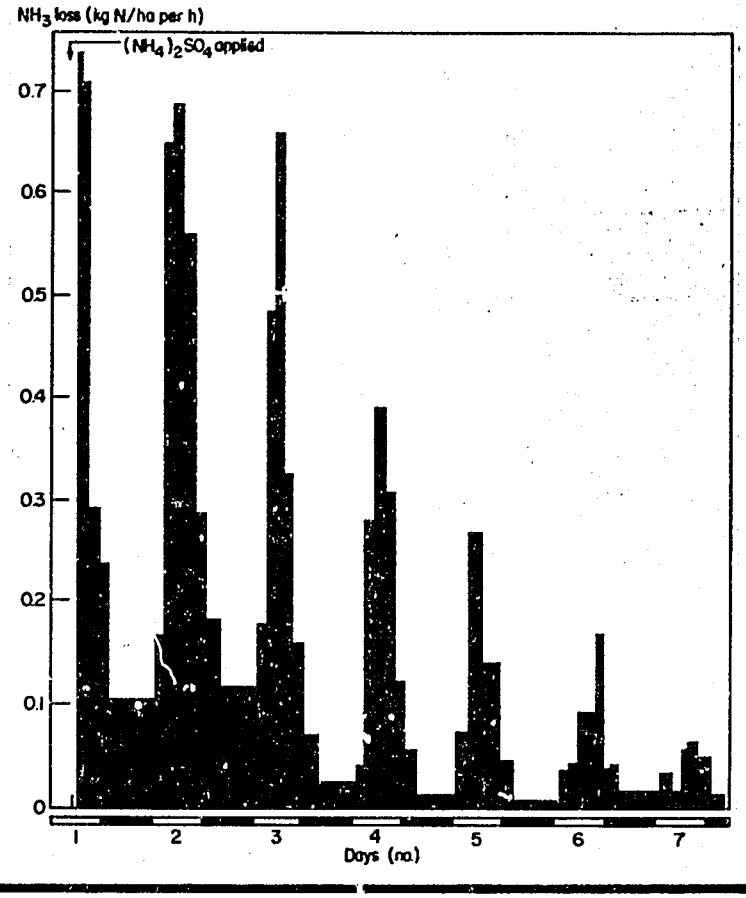
In the field, we continued to use micrometeorological techniques to evaluate the effect of urea or $(NH_4)_2SO_4$ on the rate of NH_3 volatilization. We sought to determine the extent of NH_3 loss from $(NH_4)_2SO_4$, and to confirm the importance of NH_3 volatilization as a N loss mechanism where urea is used. Ammonia flux from urea and $(NH_4)_2SO_4$ were measured concurrently.

NH_3 fluxes were substantial when $(NH_4)_2SO_4$ was applied to the floodwater 18 DT. Maximum NH_3 flux was immediately after

4. Effect of methods of urea (87 kg N/ha) application on IR58 grain yield on calcareous San Manuel clay loam.



5. Ammonia fluxes in $(NH_4)_2SO_4$-amended field.



INSFFER trainee at IRRI learns to apply N fertilizer with a deep placement machine.

$(NH_4)_2SO_4$ was applied (Fig. 5). Ammonia loss continued to be high on days 2 and 3 of the experiment, but declined rapidly after day 4 and was negligible after 7 d. Thirty-seven percent of the applied N was lost.

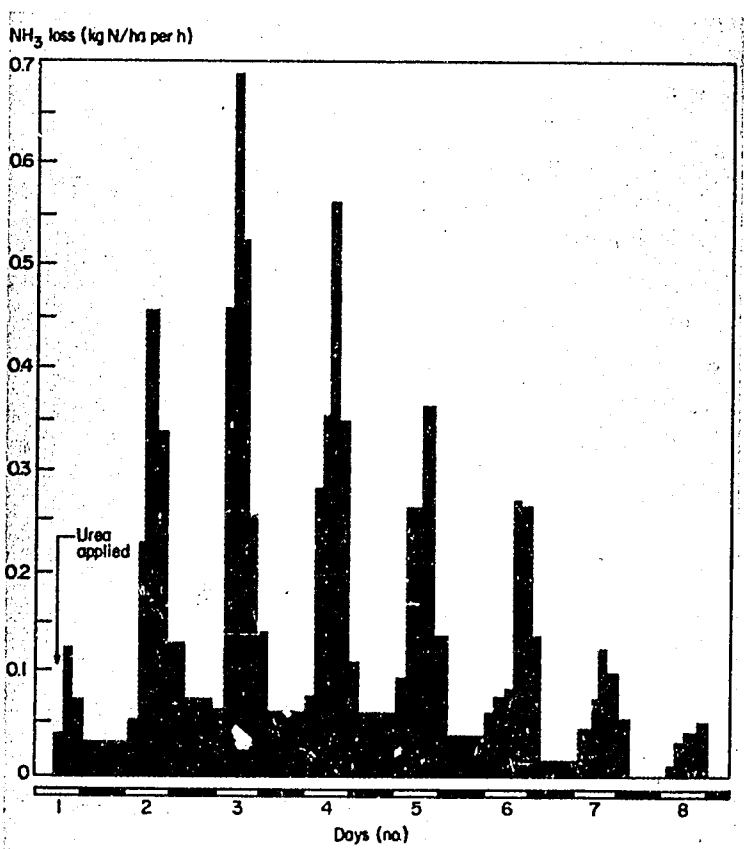
In contrast, NH_3 fluxes from urea-amended floodwater were maximum 3 d after urea was applied, and then declined steadily over the next 5 d (Fig. 6). Total NH_3 was 36% of the N applied.

We concluded that biological activity in the flooded soil system contributed to both the pH (intensity) and the alkalinity (buffering capacity) in the floodwater, and that these factors markedly affected NH_3 loss from both N sources.

Use of a urease inhibitor to control nitrogen losses

We evaluated the effect of phenyl phosphorodiamidate (PPD) on the rate of urea hydrolysis, plant N uptake, ^{15}N recovery, and NH_3 volatilization in a series of experiments at the Maligaya Rice Research and Training Center (MRRTC) and at IRRI.

PPD delayed urea hydrolysis and retarded the buildup of ammoniacal N (AN) in all studies. However, floodwater pH was not affected and displayed a diurnal pattern throughout.

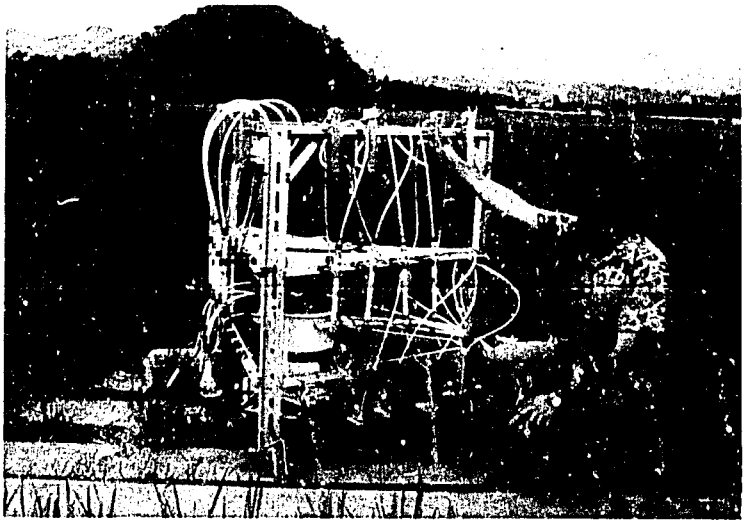


6. Ammonia fluxes in urea-amended field.

I. R. Fillery, visiting scientist in soil chemistry, adjusts the flow rate of air through ammonia traps in the field. Air is drawn from air samplers at 8 heights above the field.

The ammonia is recovered by carefully back leaching each glass bead/glass wool trap with deionized distilled water, as undertaken by Manuel Bantasan.

Ammonia content in each trap is determined using a specific ion ammonia electrode, as operated by Marilou Del Rosario, with Bing Huan Chen, from Fuzhou, China.



Application of PPD with urea significantly increased plant N uptake and grain yield in an IRRI experiment where urea or urea + 1% PPD were topdressed 26 DT. Grain yield was not enhanced by the application of PPD in a comparable experiment at the MRRTC where urea or urea + 1% PPD were applied 18 DT.

^{15}N balance studies at the MRRTC and IRRI evaluated the effect of PPD on N loss from topdressed urea. Application of PPD (1% wt/wt) with urea increased ^{15}N recovery of applied N by 14% at IRRI and 12% at MRRTC.

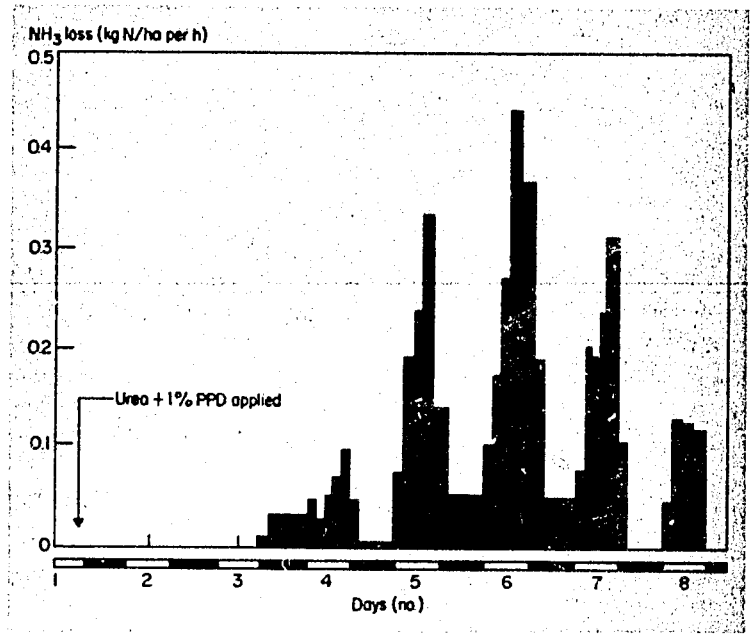
At IRRI, the increased ^{15}N recovery was in the plant pool. At MRRTC the exchangeable NH_4^+ fraction contained more ^{15}N when PPD was applied with urea.

In a micrometeorological study, applying PPD (1% wt/wt) with 58 kg urea/ha broadcast in floodwater 18 DT reduced the NH_3 loss from 22 kg N/ha to 12 kg N/ha. Floodwater AN was maintained at low concentrations for 3 d after, but substantial concentrations were detected on day 4. Maximum AN concentration (12 μg N/ml) was obtained on day 6 (Fig. 7). We will continue to work with PPD for it shows promise as an amendment to control N losses from urea.

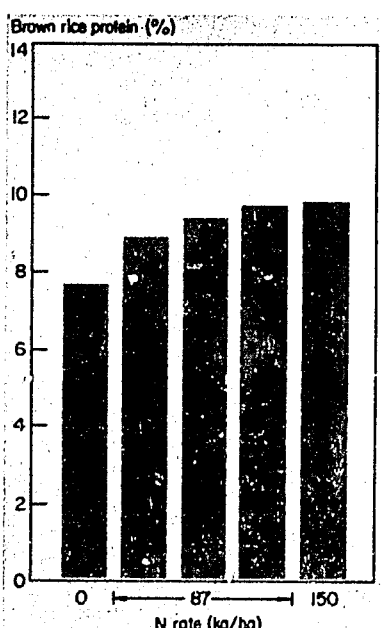
Increasing protein content

We know that N application in split doses significantly increases the protein content of brown rice. Contrary to earlier beliefs, a single incorporation of slow-release SCU and deep point placement of USG fertilizers significantly increased the percentage of brown rice protein (Fig. 8).

In a farmers' field trial in Calauan, Philippines, IR36 yielded 9.8 t/ha when the crop received 175 kg N/ha as USG (2/3 deep



7. Ammonia fluxes from urea + 1% PPD amended field.



8. Increasing level of applied N in split doses increased the protein content of brown rice (average 14 rices). At 87 kg N/ha, slow-release SCU and deep point-placed USG increased brown rice protein content by 0.9 and 0.7%.

placed) + PU (1/3 DBPI). Brown rice protein content was 10.5%.

Effect of applied zinc

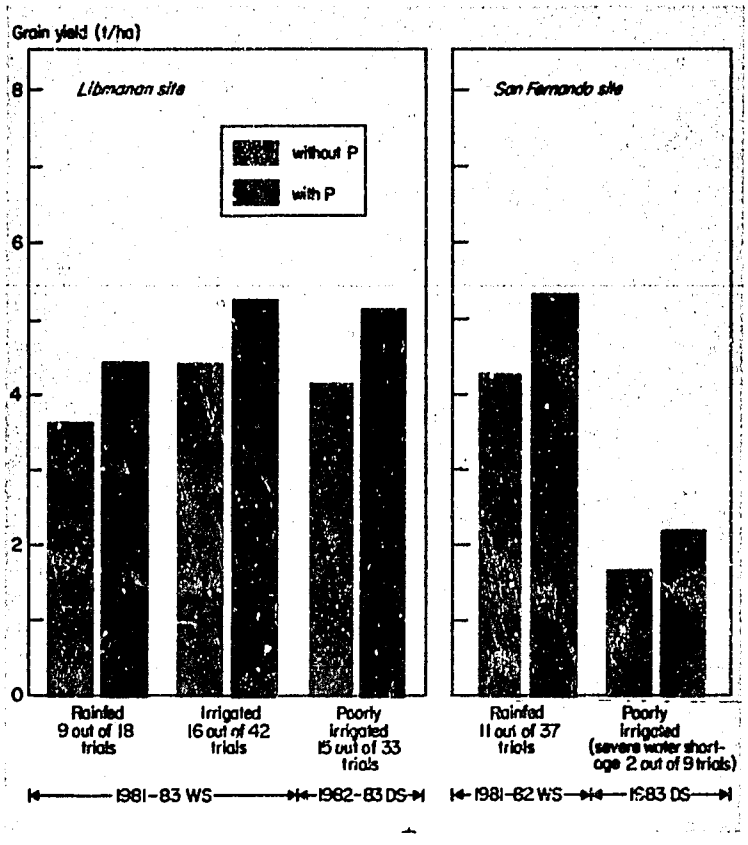
We evaluated the effect on rice yield of Zn either as a seedling root dip of 2% ZnO suspension before transplanting or as a basal incorporation of 5-30 kg $ZnSO_4$/ha in rainfed and irrigated sites in Tarlac, and at Libmanan and San Fernando in Camarines Sur. Although the available Zn content of almost all test soils was below the critical 1.0 ppm limit, Zn application did not improve yield. Results suggest that Zn application is not necessary where soil pH is below 7.0 ppm if IR36, IR50, and IR56 are planted.

Response to applied phosphorus

As part of our studies of constraints to maximizing yields, we compared the effect of applied P on rice yield in rainfed and irrigated areas. Rice yields increased significantly when 13 or 20 kg P/ha was applied in Camarines Sur (Fig. 9). Thirty-seven of 40 sites in Libmanan and all sites with significant P response in San Fernando had less than 10 ppm available P. Results suggest that P should be applied with N, where significant grain yield response to P is recorded, even in rainfed sites where the risk of yield loss because of drought is serious.

Management of organic manures

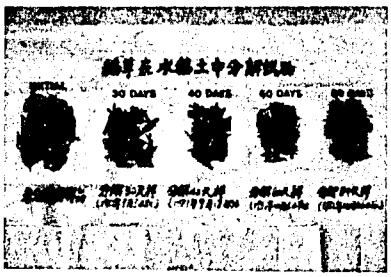
Decomposition of rice straw in submerged soils. Farmers can



9. Rice yields responded significantly to applied P (13 or 20 kg P/ha) in rainfed and irrigated areas in Libmanan and San Fernando, Camarines Sur, Philippines, where the available soil P was below 10 ppm.

reduce their dependence on expensive inputs by using organic manures. To use organic manures to advantage, it is essential to understand their decomposition rate. We incorporated ^{14}C-labeled rice straw into the soil at different depths at IRRI and monitored the remaining ^{14}C over time. Straw decomposed rapidly in the submerged soil as indicated by a ^{14}C half-life of only 48 d. In the puddled layer, 90% of the incorporated straw decomposed and was lost after 1 yr, but as depth of incorporation was increased, decomposition slowed. The continuous input of biomass in floodwater seems to be important to the maintenance of adequate N content in Maahas clay at IRRI.

In another experiment we used a simple technique to measure decomposition of straw in flooded soil at various sites in Asia. Air-dried rice straw was cut into 2-3 pieces. One gram was put into a 5 × 7 bag made of nylon net with a 0.7 mm opening. Bags were sterilized and sent to the collaborators who covered them with 10 cm of soil in the field. Groups of five bags were taken out at intervals and gently rinsed in distilled water. Dry weight and ash content were measured. OM was determined by ignition loss.



10. An example of information received from Asian cooperators in a project to determine the decomposition rate of rice straw in flooded rice soils. This information is from Fuzhou, China, and was provided by the Fujian Academy of Agricultural Science.

We found that OM content decreased rapidly during the first 10 d of decomposition, followed by a gradually decreasing decomposition rate (Fig. 10). Although decomposition was somewhat slower in temperate regions, the difference was small. After 80 d, 75% or more of the OM had decomposed.

Optimum OM content in submerged soils. We continued to develop a model to tailor N recommendations to soil and crop needs using values of effective root depth, soil C or soil N content, and N fertilizer rate.

The model helps determine optimum possible yields for given soil C levels and fertilizer rates, and also identifies optimum OM content at different N fertilizer rates for maximum yields.

To achieve maximum yields of 4 to 9 t/ha with 0 and 210 kg N/ha, OM content should be 4 and 5%, respectively. Increasing OM further does not increase yields.

Effect of straw incorporation on Zn availability. In the greenhouse, we studied the effect on rice growth of increasing amounts of straw (0-0.9% by weight) incorporated into calcareous, neutral, and acid soils (Fig. 11).

We found that adding more straw increased NH_4^+ and K^+, but markedly decreased Zn.

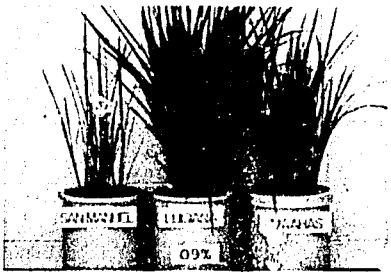
Straw incorporation caused Zn deficiency in the neutral and calcareous soil, but not in acid soils. If straw is incorporated in marginally Zn-deficient soils, Zn fertilizer is necessary when deficiency-susceptible rices are planted; but varieties that tolerate Zn deficiency will benefit from straw incorporation without additional Zn.

Azolla as organic manure. A severe 8-mo drought in late 1982 through mid-1983 temporarily limited azolla use by farmers in South Cotabato, Philippines, where it is grown on more than 2,000 ha. Farmers returned to growing irrigated lowland rice after the drought, and by late 1983 were again widely using azolla as an organic manure. *A. microphylla* is well adapted to the area and has largely replaced *A. pinnata*, the indigenous azolla species.

IRRI's azolla collection now includes 88 populations of 7 species: *Azolla pinnata* var. *imbricata*, 58 populations; *A. pinnata* var. *pinnata*, 4; *A. filiculoides*, 7; *A. mexicana*, 4; *A. caroliniana*, 5; *A. microphylla*, 9; and *A. nilotica*, 1.

Species identification is tentative, but work continues to refine taxonomic criteria. We collaborated with Professor K. Fowler of Portsmouth Polytechnic, UK, who, through examination of leaf and sporocarp morphology, identified some heretofore misnamed species and isolated an unknown species.

Samples of azolla populations are distributed upon request.



11. Effect of straw incorporation in calcareous, neutral, and acid soils.

In 1983, about 200 collections were provided to collaborators in the Philippines, Vietnam, India, and China.

RICE CROP CULTURE

Amelioration of acid sulfate soils

In the greenhouse, we studied the effects of $CaCO_3$, MnO_2, and straw incorporation on an acid sulfate soil from Albay, Philippines. Applying $CaCO_3$ immediately increased the pH and depressed the formation of excessive Fe^{2+} and Al^{3+} in the soil solution. Straw incorporation only slightly increased pH, but markedly depressed the Fe^{2+} concentration after 2 wk, causing Fe toxicity symptoms early in the growth cycle. Applying MnO_2 did not affect the chemical kinetics of the soil solution.

Lime treatments in all combinations gave highest straw and grain yields for the first crop. Next highest yields were those with straw and Mn. When the soil remained submerged, the residual effects of the different amendments caused N deficiency, which depressed growth of the second rice crop in the lime and straw treatments 4 wk after transplanting. N fertilization on ameliorated acid sulfate soils seems essential, especially for a second crop.

Growth regulators

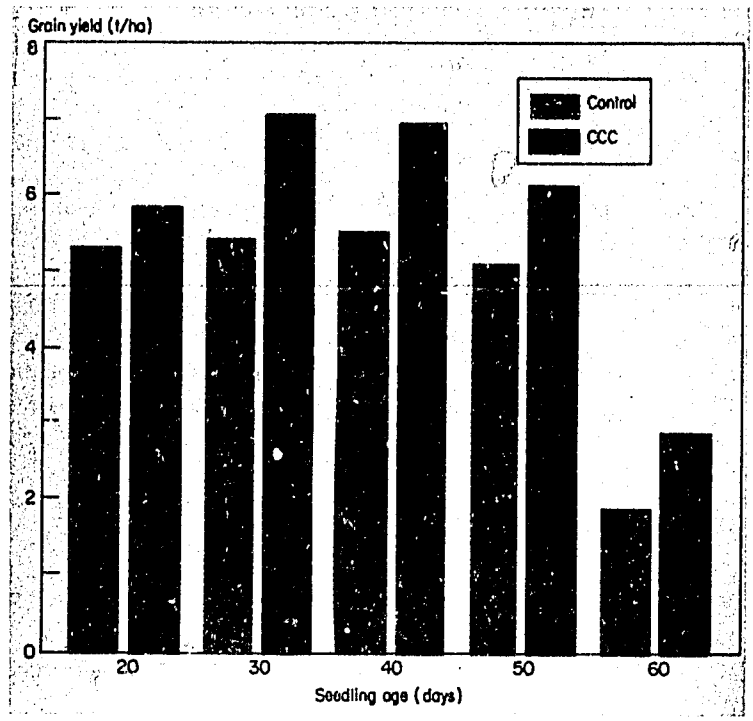
We applied the plant growth regulator CCC (cycocel) to IR58 and IR42 seedlings at 2- to 3-leaf stage in the seedbed and observed the effect on grain yield. We compared untreated seedlings with CCC-treated seedlings transplanted at 20, 30, 40, and 50 d.

Treating seedlings with CCC and transplanting at 30 and 40 d significantly increased grain yield of IR42 (Fig. 12), but did not significantly improve IR58 grain yield.

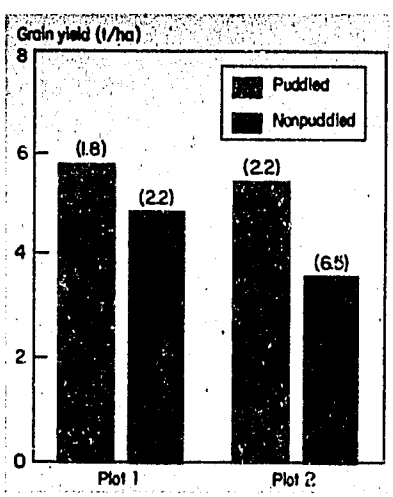
Percolation losses

We conducted greenhouse and field experiments to assess the importance of percolation losses to production of lowland rice IR36. In the greenhouse we varied percolation rates (0, 5, 10, 15, 20, 40, and 80 mm/d) in clay loam, loam, and sandy loam using a hose cock clamp and hypodermic needles. Neither grain yield nor yield components showed any significant dependence on percolation rate.

In the field experiment we found slow percolation rates for puddled and nonpuddled treatments at two IRRI locations: 1.8 ± 0.5 and 2.2 ± 0.5 mm/d, and 2.2 ± 0.7 and 8.5 ± 1.9 mm/d. Puddling decreased bulk density, soil strength, saturated hydraulic conductivity, percolation rate, maximum



12. Grain yield of IR42 as effected by treating seedlings with CCC growth retardant at 2- to 3-leaf stage and transplanting at different seedling age.



13. Effect of puddling on IR36 yield on 2 plots at IRRI. (The figures in parentheses denote the percolation rates in mm/day.)

and minimum soil temperature to 15-cm depth, oxidation reduction potential, and leaching losses, especially of N, P, K, and Zn. Puddling significantly increased grain yield (Fig. 13) and plant uptake of N, P, K, Mn, and Zn.

INTERNATIONAL NETWORK ON SOIL FERTILITY AND FERTILIZER EVALUATION FOR RICE

Sixty cooperating scientists from 17 countries received from INSFFER 215 sets of fertilizers and fieldbooks in 1983.

Using a multifertilizer response model to evaluate data received from network cooperators, we found that B&I SCU and deep point-placed USG were 25-30% more efficient than PU best split. N use efficiency of SCU and USG was 1.3 to 1.4 times higher than that of PU.

Experiments at 16 sites in 8 countries showed that incorporation of fresh azolla at 20 t/ha plus basal application of 30 kg N/ha as PU produced yields comparable to those with split application of PU at 60 kg N/ha. Azolla alone, applied before or after transplanting, produced yields comparable to those with urea at 60 kg N/ha.

Residual effects of different P sources were observed up to five crops after five consecutive P applications. Residual P increased yield an average 1.1 t/ha at 4 sites.

With 25 of our collaborating scientists we visited 14 INSFFER

trials in Indonesia and organized a 2-d workshop to discuss current soil fertility and fertilizer management practices, N fertilizer efficiency studies, and future collaborative work. It was agreed that the wide success in placement of granular urea to increase N use efficiency justified changing the emphasis to adaptive research in the extension phase and allowing INSFFER activities to concentrate on other research methods, and making placement of granular urea the efficiency standard.

Climatic environment and rice

Rice grows in strikingly different environments. It is cultivated where there is more than 3,000 mm of rainfall during the growing season, and on arid land with less than 50 mm during growth. Rice also is grown where mean monthly temperature is higher than 33°C and where average seasonal temperatures are only slightly higher than 17°C. Radiation values vary from less than 300 to more than 600 mWh/cm^2 per day.

On low-lying alluvial plains, rice may be flooded up to several metres deep. On steep terraced slopes and elevated plateaus it may be out of reach of flood or irrigation water. Rice also is grown as an upland crop.

Rice soils range from deep, heavy clay or peat soils to shallow, mostly eroded topsoils with underlying impermeable hard pan or highly acidic subsoil.

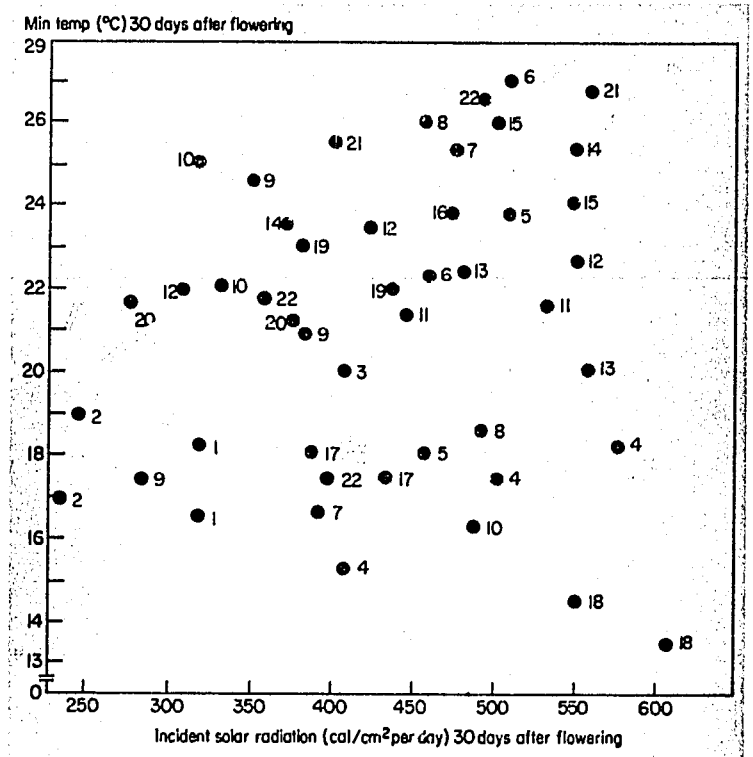
The physical environment of rice growing areas can only be described satisfactorily if we simultaneously consider climate, soil, and landscape.

Environmental characterization

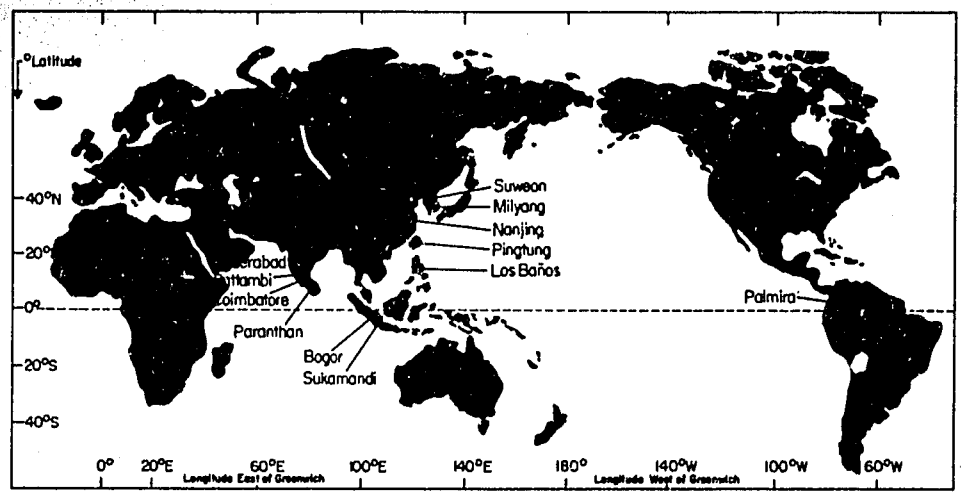
Studies of the physical environment for rainfed rice must emphasize water availability. We are characterizing rice growing environments in terms of available water, which varies in space and time, and are studying the interaction between rice productivity and the physical environment. The Rice-Weather Project will help us better understand the combined effects of total radiation and air temperature on rice productivity.

In close cooperation with national programs, we selected 22 sites in 16 countries that represent a cross-section of the radiation and temperature conditions under which rice is

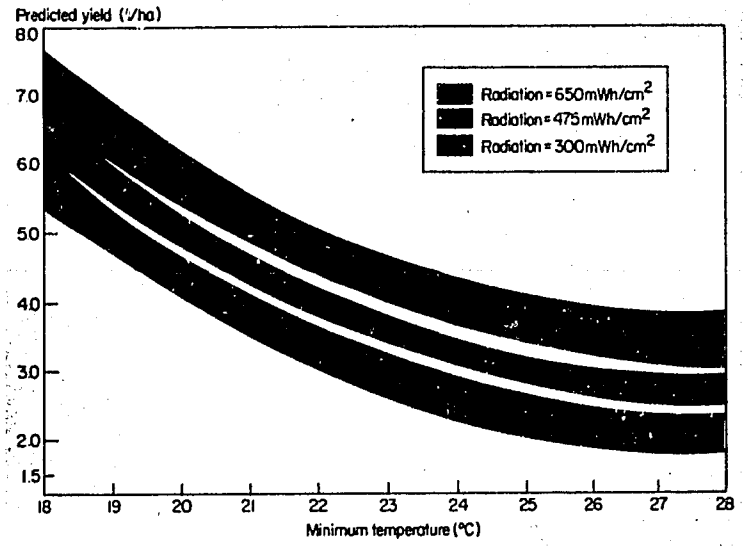
1. Distribution of radiation and minimum temperature combinations for 24 locations. 1 = Suweon, S. Korea; 2 = Yeongnam, S. Korea; 3 = Nanjing, China; 4 = Sakha, Egypt; 5 = Kapurthala, India; 6 = Dokri, Pakistan; 7 = Parwanipur, Nepal; 8 = Joydebpur, Bangladesh; 9 = Pingtung, Taiwan, China; 10 = Mandalay, Burma; 11 = Chieng Mai, Thailand; 12 = Los Baños, Philippines; 13 = Coimbatore, India; 14 = Pattambi, India; 15 = Paranthan, Sri Lanka; 16 = Ibadan, Nigeria; 17 = Palmira, Colombia; 18 = Ahero, Kenya; 19 = Sukamandi, Indonesia; 20 = Bogor, Indonesia; 21 = Cuttack, India; 22 = Hyderabad, India.



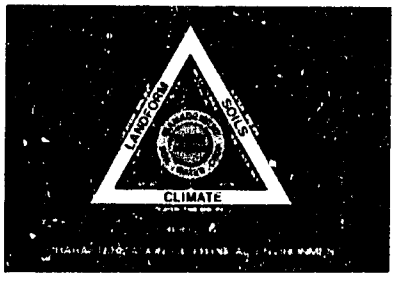
2. IRTP nurseries for rice-weather studies.



cultivated (Fig. 1, 2). Agrometeorological monitoring equipment was installed at all sites, and an International Rice Weather Yield Nursery (IRWYN) was grown at each location. The results of the nurseries will improve the basis for the interpretation of rice varietal response to weather variables (Fig. 3), and should



3. Yield response curve. The curves are calculated from a prediction equation that includes minimum temperature (°C) and solar radiation (mWh/cm²) during ripening (30-d period after flowering). The shaded area for each radiation value is the 90% confidence interval on the mean response (t/ha). The equation was developed using data from IRTP nurseries, and will be improved as more precise weather data are obtained.



The physical environment of rice growing areas can only be described satisfactorily if climate, soil, and landscape are considered.

enable us to reduce the need for wide testing of many entries in the IRTP nurseries.

Maps of rice by culture type

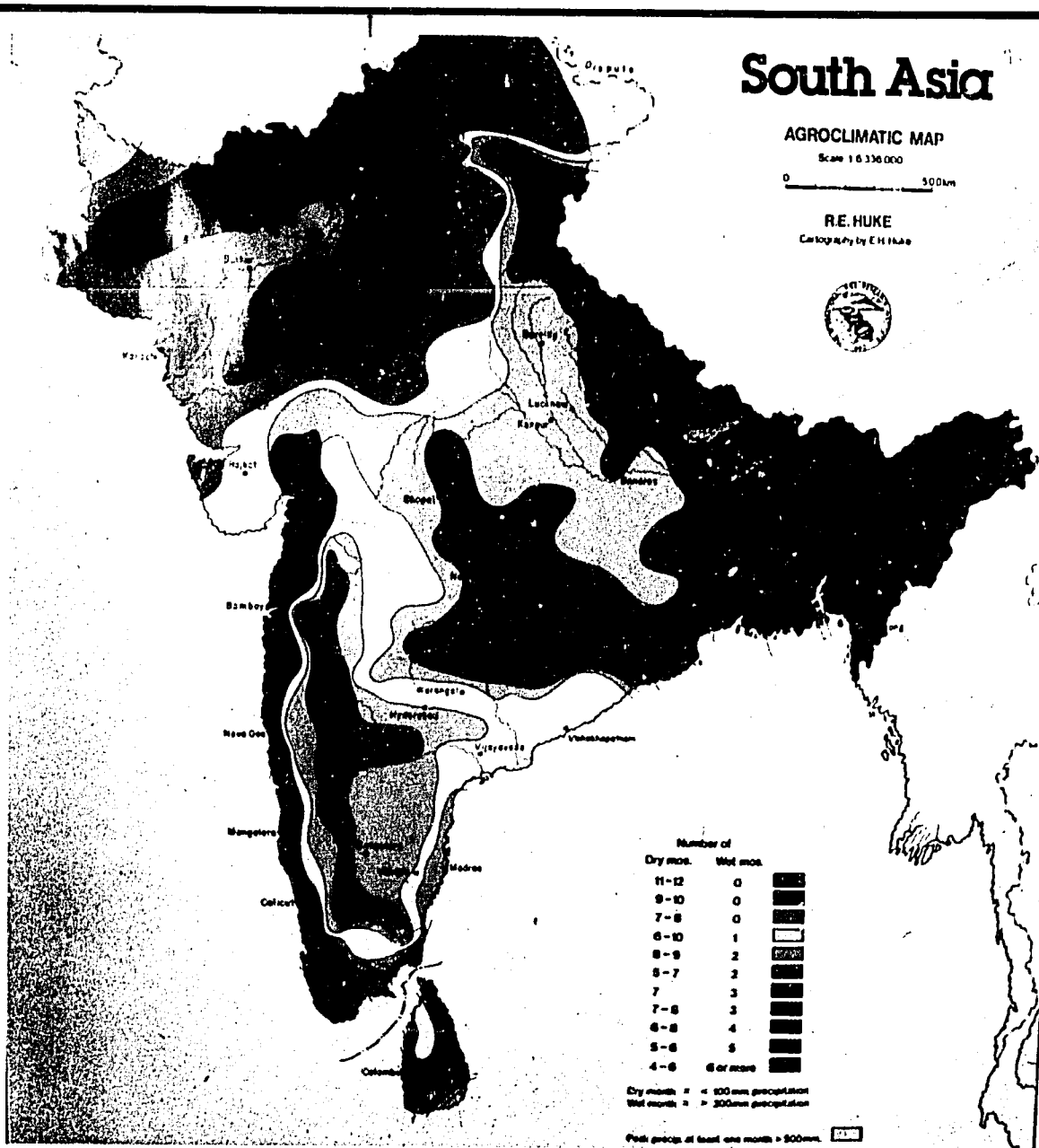
How to wisely allocate research funds for rice improvement can be decided only after answering questions about the rice farmer, his farming environment, and local or regional water control conditions.

Lack of adequate water control is the most serious physical constraint to consistently high rice yields. How can water regimes be classified? How extensive is each? Where are they located and how are they distributed spatially? How many people depend on each?

One way of answering those questions is by analyzing maps recently completed at IRRI that address questions of rice distribution by culture type. The maps of South Asia, Southeast Asia, and China-Korea were done at a common scale of 1:4,500,000 (Fig. 4). Colors were chosen to portray the character of the six mapped rice production systems. Tan mimics the lack of water and the moisture stress of upland rice. WS irrigated rice is shown in green and a second season irrigated crop is in blue.

Each dot represents 3,000 ha of rice and covers a proportional share of the map surface. Use of more than one dot indicates area planted to two or three crops each year.

The maps were based on government data showing area planted to rice. The data were allocated spatially within the various mapping units by combining clues from various sources. Topographic maps provided information on relief,



4. IRRI scientists and national program leaders use maps such as this map of South Asia to plan breeding strategies for diverse environments.

slope, and drainage. FAO-UNESCO maps and text provided information on the distribution of soil types and their suitability for rice production. Imagery from Landsat satellites indicated cropped areas and standing water.

Ground truth was achieved through site visits, and verified with information from IRRI visitors from all of Asia, who offered valuable advice on the distribution of culture types within their home areas.

Irrigated
Irrigated, with favorable temperature
Irrigated, low-temperature, tropical zone
Irrigated, low-temperature, temperate zone

Rainfed lowland
Rainfed shallow, favorable
Rainfed shallow, drought-prone
Rainfed shallow, drought- and submergence-prone
Rainfed shallow, submergence-prone
Rainfed medium deep, waterlogged

Deepwater
Deepwater
Very deepwater

Upland
Favorable upland with long growing season (LF)
Favorable upland with short growing season (SF)
Unfavorable upland with long growing season (LU)
Unfavorable upland with short growing season (SU)

Tidal wetlands
Tidal wetlands with perennially fresh water
Tidal wetlands with seasonally or perennially saline water
Tidal wetlands with acid sulfate soils
Tidal wetlands with peat soils

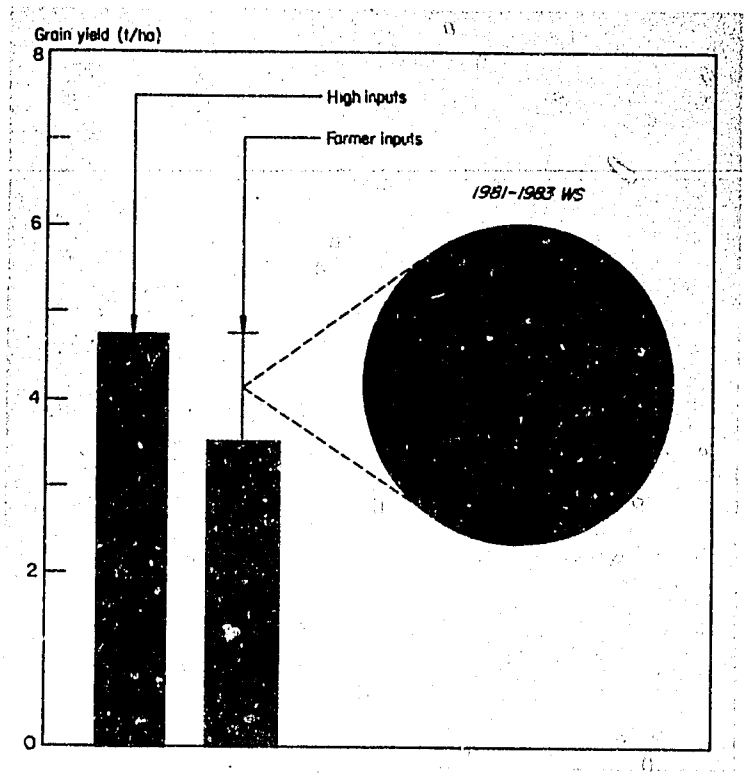
5. Terminology for rice growing environments.

Terminology for rice environments

To assist us further in focusing our rice breeding and management efforts for less favored environments, we have established an international corresponding committee to develop a standard terminology for describing different rice cultural types around the world. A tentative terminology has been agreed upon (Fig. 5) and is now being used in all IRRI programs. The committee will continue to develop the terminology as further information is collected about rice environments.

Constraints on rice yields

Although some national average rice yields have increased substantially, many remain below practical and potential levels. IRRI constraints research seeks to identify factors that limit yields, and determine if they can be economically removed. This research highlight summarizes IRRI research in the Philippines. We conduct similar research with national programs in eastern India and Pakistan.



1. Average yields with farmer and high inputs and contributions of fertilizer, insect control and weed control to the 1.5 t yield gap/ha on 84 rainfed farms in Tarlac, Libmanan, and San Fernando.

Yield constraints in rainfed areas

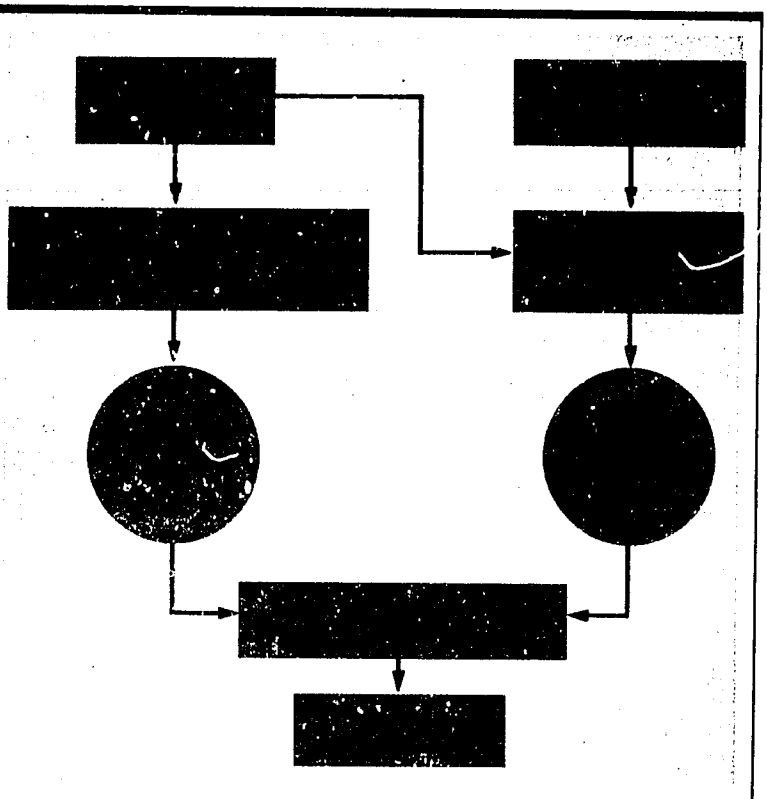
Farm-level constraints research was initiated in 1974 to identify and quantify the major constraints on MV yields. Our first research focused on irrigated rice. In 1981 our major emphasis shifted to rainfed areas. Rainfed trials were conducted in Tarlac, Central Luzon, and Libmanan and San Fernando, Camarines Sur, in the Bicol region.

Across 3 sites in 1981-83, average yield was 3.4 t/ha with farmer inputs and 4.8 t/ha with high inputs. Of the 1.4 t yield gap, 57% was from more fertilizer and improved timing (Fig. 1). Results suggest that yields in rainfed areas can be increased by increasing inputs, particularly fertilizer. However, fertilizer N must be applied at the proper time and with a method that gives the most grain yield per unit of applied fertilizer.

Technology adoption

In irrigated Asia, most riceland is planted to MVs, but in deep water and upland areas, where short-statured MVs are poorly adapted, traditional varieties dominate. In other rainfed areas, such as the vast Gangetic Plains, MVs have been partially adopted.

Using limited dependent variable regression models, we analyzed factors that influence MV adoption and fertilizer use in



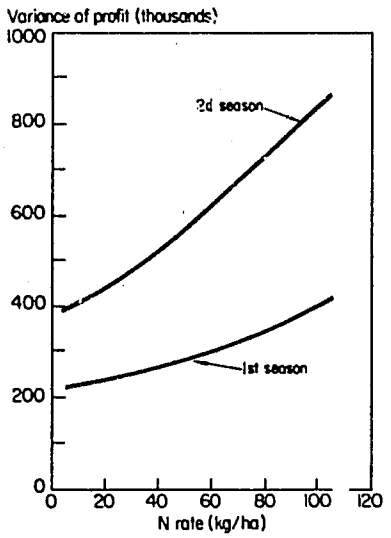
2. Yield and profit function distributions were estimated from a response factor relating yield to N rate, managed factors, and moisture stress. The incidence of moisture stress over time was estimated using a water balance simulation model.

the Terai of eastern Nepal. Results were consistent with earlier studies. The probability of MV adoption was higher for farmers with irrigated lands and owners with irrigation had higher adoption probability (85%) than tenants (32%). Credit users were 20% more likely to adopt MVs than farmers without credit. Owners and tenants without irrigation had low (13% and 2%) adoption probabilities. Extension contact, but not formal schooling or farm size, was associated with MV adoption and the real price of fertilizer.

Farmer fertilizer management

Why are farmers unwilling to apply more fertilizer where analysis of on-farm experiments and farm survey data implies it is profitable? At current prices and 100% interest rates at our Bicol rainfed site where drought stress is common, the optimal N rate is about 50 kg/ha. Those facts suggest that risk considerations may partly explain why more than 75% of the rainfed area farmers do not apply fertilizer.

A stochastic production function model, which explicitly incorporates variability in N response over time, was estimated for the Bicol site. It combined N response data from on-farm trials with moisture stress distributions generated by a rainfall simulation and water balance model (Fig. 2).



3. As N rates increase, the variance of profit increases at an increasing rate. It increased more in the second season when the probability of drought stress is higher.

The analysis showed that as N rate increased, profit variability rose at an increasing rate. In the second season, when moisture stress is more likely, rate of increase was greater (Fig. 3). The implied risk neutral N rates were 51 kg/ha in the first season and 44 kg/ha in the second season. For a moderately risk-averse farmer the optimal N rates were 4 and 7% below the risk neutral optima for the first and second season, respectively. These results, consistent with others in the Philippines, imply that risk aversion may not be the major reason for low fertilizer use in the non-flood-prone Bicol sites.

Bicol farmers are poor and seek to maximize returns to scarce household capital from all possible capital investments. We are therefore examining the impact of internal and external capital rationing on allocation of household funds within rice production and between agricultural and nonagricultural enterprises.

Rice productivity relations

We examined farm size-resource productivity relations for Bicol farmers using a variation of whole-farm production analysis. The estimate of the constant term in the production function decreased from 90 on small farms to 26 on large farms, indicating that technical efficiency decreased as farm size increased. Conversely, the estimated coefficient for labor productivity increased from 0.2 to 0.6 as farm size increased, indicating that labor productivity increased with size. The marginal value products of labor increased as farm size increased; that for animal power remained uniformly low across farm sizes; and that for agrochemicals was uniformly high.

A profit function analysis of rainfed rice production in Bicol implies that farmers efficiently allocate inputs, given local technology and prices. Rice supply was sensitive to rice price. If paddy price increased 10%, farmers produced 8% more rice. Labor demand was also price elastic with respect to rice price. Therefore, even in less favorable rainfed environments increases in the real price of rice may increase labor demand and rice supply. Because rice prices tend to be lower, and chemical input prices higher, in Bicol than in most of Luzon, we are studying whether the Bicol market structure is an important constraint to increased rice productivity.

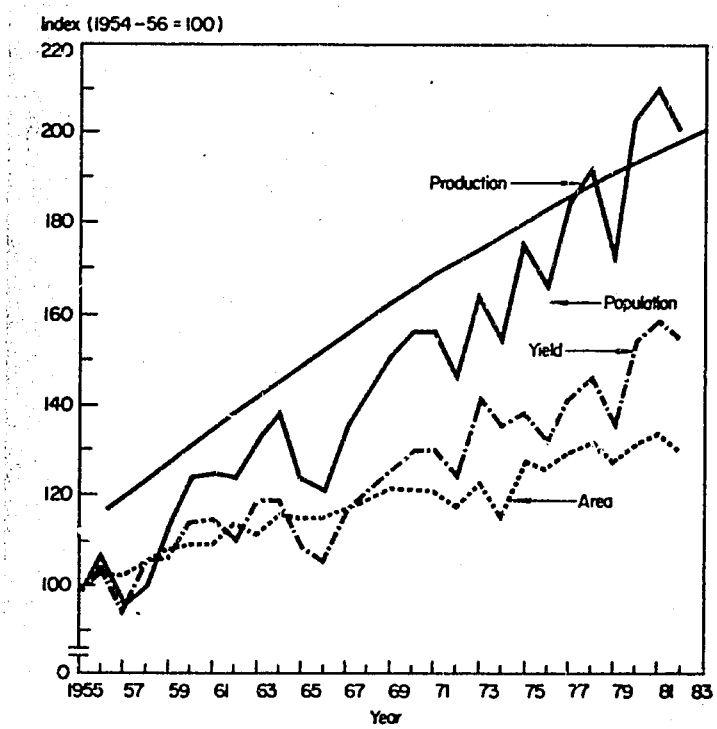
Consequences of new technology

We are assessing the impact of new rice technology on rice production, income, income distribution, employment, and social welfare so that biochemical and mechanical technology to meet the relevant needs of rice farmers can be designed. Macro- and micro-level studies evaluate the implications of new technology for economic policies, sociocultural and political institutions, distribution of resource control, and the physical environment.

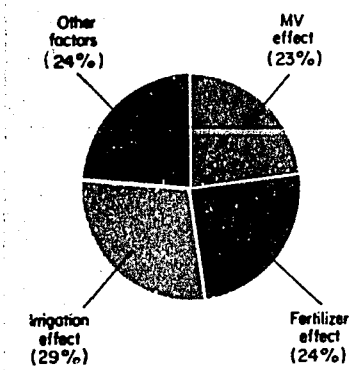
Technological change and productivity

We examined the impact of MVs, fertilizer, and irrigation on the sources of increased rice production, self-sufficiency goals, and the real price of rice in South and Southeast Asia.

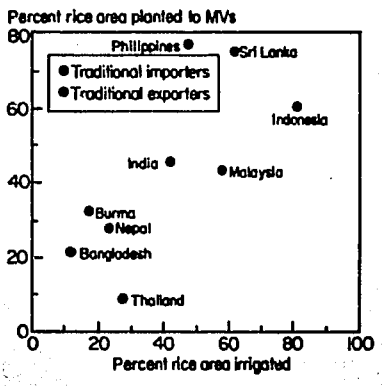
Increased productivity. Long-term growth of rice production rose moderately from 2.4% to 3% after MVs were introduced in



1. Trends in population, paddy production, area, and yield in South and Southeast Asia, 1955-83.



2. Rice output in the 8 major rice producing countries of the world — Burma, Bangladesh, China, India, Indonesia, Philippines, Sri Lanka, and Thailand — increased by nearly 120 million tonnes between 1965 and 1980. Variety, fertilizer, and irrigation contributed almost equally to the increase. Each factor increased production value by $4.5 to 5.0 billion.

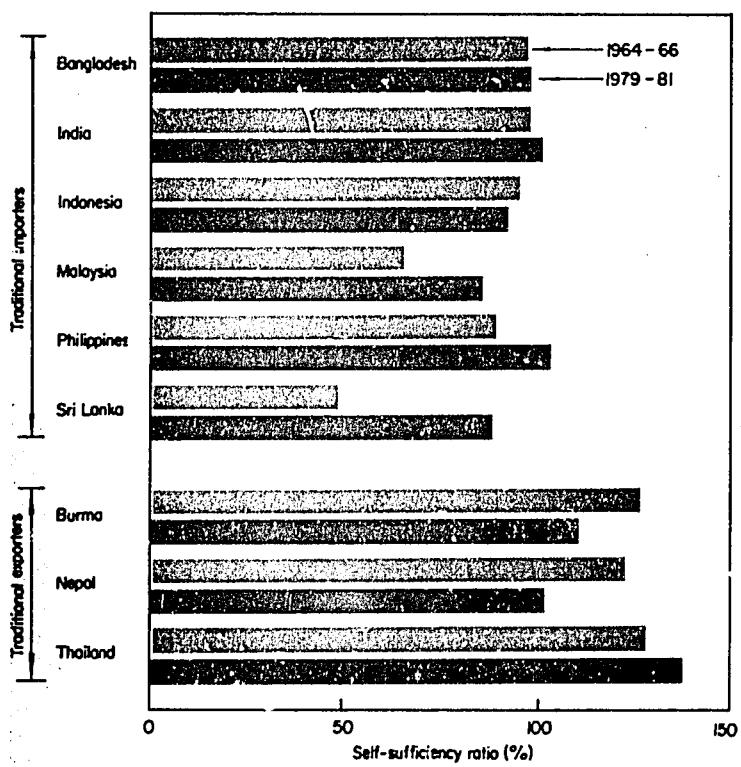


3. Percent of irrigated rice area planted to MVs in 1980.

1966 (Fig. 1). Rice production is now increasing faster than population growth whereas both grew about equally in 1950-60. Increased production has been achieved with relatively less land as yield increases have outdistanced area expansion since the late 1960s. Before 1965, increases in crop area accounted for about 60% of the growth in rice production. Between 1965 and 1980, 75% of rice production growth was due to yield improvements and 25% to area expansion. MVs and fertilizer each accounted for about 23% of yield improvement and irrigation accounted for 30% (Fig. 2).

By 1980, 40% of the rice area was planted to MVs and fertilizer use had quadrupled. Although irrigated areas increased more slowly, irrigation increased fertilizer efficiency and raised the productivity of MVs. Our measure understates the contribution of MVs to increased production because MV adoption partly encouraged greater fertilizer use and increasing irrigation investments. Moreover, as short-growth-duration MVs were adopted, part of the area effect was from a second, rainfed crop.

Regional self-sufficiency. In Thailand and Bangladesh area expansion continues to be the major source of increased production. MVs are adopted more slowly in traditional ex-



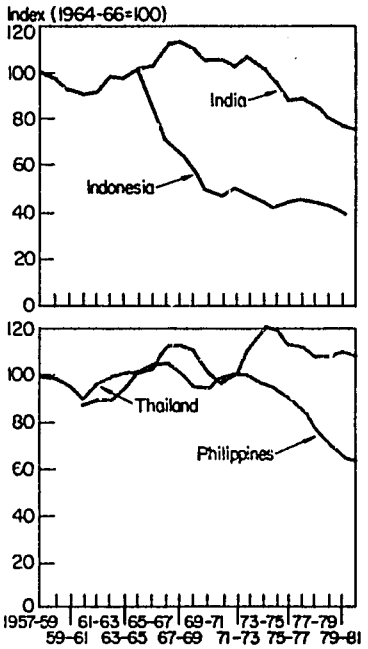
4. Changes in self-sufficiency ratio, production ÷ (production + net imports), among traditional Asian importers and exporters, 1964-66 and 1979-81.

porting countries such as Thailand and Burma, and in Nepal and Bangladesh, where the irrigated rice area is also relatively low because developing effective irrigation systems is difficult (Fig. 3). Traditional rice importers, such as India, Indonesia, Malaysia, the Philippines, and Sri Lanka, where irrigation development was less costly, have adopted MVs more rapidly.

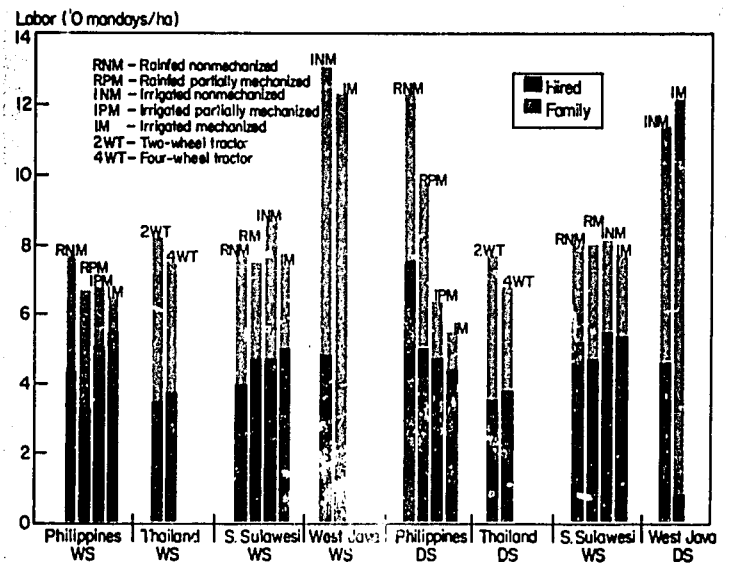
Because the first MVs were better suited to irrigated conditions and because of the strong national drive for self-sufficiency in importing countries, MV adoption has lessened the comparative advantage of traditional rice exporters.

Self-sufficiency ratios for Malaysia, Sri Lanka, and the Philippines improved substantially by the late 1970s (Fig. 4). Export surpluses declined in Burma and Nepal but increased in Thailand. However, because this crude measure of self-sufficiency is to some extent defined by government trade and price policies, it is important to ask: self-sufficiency at what price?

The real price of rice. Benefits of technological change are reflected in increased production and lower prices. Average world rice price was 11% less in the 1970s than in the 1960s. If we exclude the unusually high prices in 1973-75, world price fell 27% over the period. As countries such as Indonesia, the Philippines, and India achieved self-sufficiency, the real price of rice decreased significantly (Fig. 5). The decline in Indonesia was sharper because of liberalized import policies. In Thailand, where rice is a major export, adjustments in the export duties prevent its domestic real price from closely following the decline in real world price.

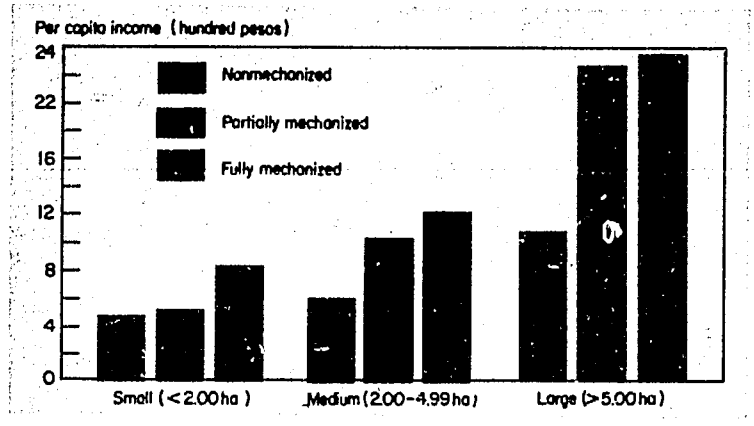


5. Trends in price of rice at constant prices in selected countries.



6. Hired and family labor by mechanization class and country.

7. Per capita income by mechanization class and farm size.



The importance of the falling real price of rice to the poor of Asia is hard to overemphasize.

Use of mechanical technologies

The use of machinery on small rice farms is increasing in most of Asia. In Indonesia, Thailand, and the Philippines we evaluated the impact of mechanization on rural employment and income opportunities and its contribution to production. We found less labor was used on farms with mechanized land preparation than on traditional farms. Although machines displaced family labor, in some countries, such as the Philippines, mechanized farms used more hired labor than nonmechanized farms (Fig. 6). Labor productivity was higher for mechanized farms, but output per unit of cash costs was lower, reflecting a higher degree of monetization.

Across all four sites, we were unable to observe any discernible yield or cropping intensity differences that were directly attributable to mechanization. Irrigation appeared to explain most yield and cropping and intensity differences within individual sites.

In the Philippines there was little difference in income between mechanized and nonmechanized farms up to 2.5 ha. On larger farms, cost savings from machines became significant (Fig. 7). We also found that mechanized farms do not earn more nonfarm or off-farm income than nonmechanized farms. The productivity of land is no higher, total labor requirements are lower, and cash costs are higher on tractor farms.

Use of IRRI-designed threshers increased substantially in Thailand and the Philippines from 1975 to 1983. Private rates of return are high for threshers, with payback periods often less than 1 yr. The social profitability also is positive, even though mechanical threshers tend to displace hired rather than family labor.

Cropping systems

Although rice is the staple food in much of Asia, local environments often limit farmers to one or two rice crops a year, after which the land may remain fallow. As population pressure increases, more food must be produced. Our cropping systems program stresses efficient land use before and after rice, particularly in adverse environments. In 1983 we evaluated rice varieties and other crops for drought- and submergence-prone environments in the Philippines, and component technologies. We also improved and tested the performance of a rolling injection planter developed for rice and other crops, continued our work with computer simulations of rice crop growth, and evaluated tillage practice effect on root penetration in compacted puddled soils.

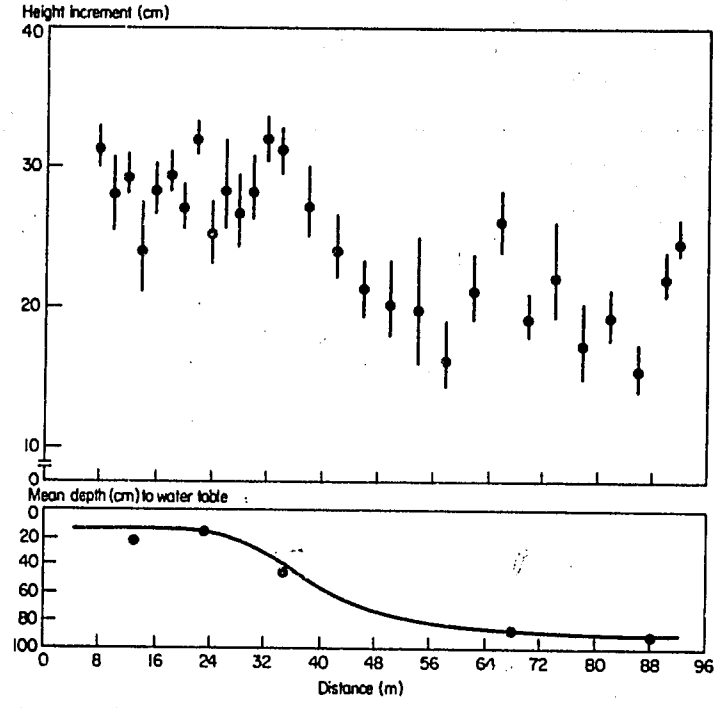
ANALYSIS OF THE PHYSICAL AND BIOLOGICAL ENVIRONMENT

Growth and yield of rice on a toposequence hill slope

In upland rice culture, plants grown at different positions up a hill may have different amounts of available groundwater or nutrients, or both, and hence differ in growth and yield. Soil temperature, which affects root and seed physiology, and microclimatic conditions that promote disease incidence, may be affected.

In 1983 WS, we monitored soil and microclimatic physical variables and growth increments of dry-seeded IR36 at various distances up a gently sloping unterraced toposequence. For each growth increment, we found that plant height corresponded with plant position on the hill slope and the mean depth to the water table (Fig. 1). Rice yield showed a similar tendency, with yield declining at higher elevation with deeper water tables.

We found also that BI incidence increased with distance up the slope, although we used fungicide sprays to minimize any effects on rice growth and yield. Soil temperature, averaged over the season for 5- to 30-cm soil depth, increased 0.05 K/10 m of up-slope distance. At depths shallower than 5 cm, it exceeded 35° C and approached 40° C, at which temperature germination of rice seeds is much reduced.



1. Increment in IR36 plant height and mean depth to water table at various distances up a toposequence slope.

ANALYSIS OF THE SOCIAL AND ECONOMIC ENVIRONMENT

Cost of lowland-upland mode shift

Interseasonal conversion of land between wet and dry crop production modes entails higher land preparation costs than leaving land in the same mode year-around. If thorough puddling is not done for lowland rice following an upland crop, yields may be reduced. Similarly, yields of upland crops may be lower if a loose, friable textured seedbed is not established after lowland rice. Whether a farmer incurs higher costs for thorough land preparation, or experiences lower yield because of inadequate land preparation, the result is reflected in the profit from a cropping pattern.

A farm with land that can be cultivated as lowland all year (by using irrigation in DS), or land that is well-drained for upland crops during WS, or a combination of both land types is significantly more profitable than a farm with land that can only grow lowland rice in WS and an upland crop in DS.

We collaborated with the National Food and Agriculture Council of the Philippines in examining returns across many cropping systems in different physical environments. The

economic performance of 63 farmers and experimental cropping patterns reported by Regional Integrated Agricultural Research System technicians were analyzed by a regression that related total per-hectare value of crops produced in an annual cropping pattern to the number of upland-lowland mode shifts, the number of crops grown without shifting mode, the per-hectare cost of labor and materials, and the sites from which data were taken.

Shifting from upland to lowland or vice versa reduces production by about $184/ha compared with stable upland or lowland cropping. For each crop grown in the shift to upland mode, farmers earned $230. The $176 estimated earnings for each lowland crop grown in the shift to lowland mode was not statistically significant.

Apart from the gains from maintaining a stable production mode, our results showed that farmers in several locations have about a 2:1 rate of return on the value of both labor and materials invested in crop production, a rate widely realized in Philippine agriculture. Whether a cropping pattern was grown by a farmer or a researcher did not significantly affect returns. The quality of resources, however, affected returns.

PEST CONTROL IN RICE-BASED CROPPING SYSTEMS

Tillage and diseases

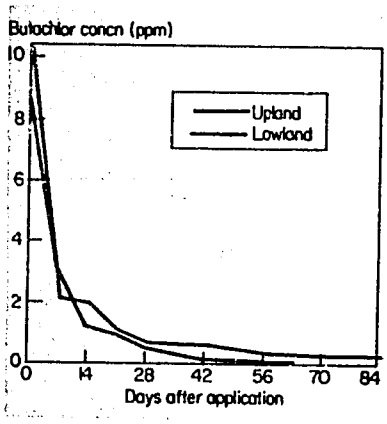
In upland crop management, we found that zero tillage sufficiently reduced *Fusarium* infection of cowpea planted after upland rice. On 7.5-m^2 plots, cowpea stand was on the average 3 times greater and grain yield almost 4 times higher with zero tillage.

Effect of land preparation on weed flora

The residual effects of weed control treatments over the past 4 yr were examined in a fifth crop of dry-seeded lowland rice. When land was prepared in DS, 66.9% of the weed flora, based on weed weight, was *Melochia concatenata* and 32.6% was *Echinochloa colona*. When land was prepared when rains began, 32.7% of the weeds were *M. concatenata* and 63.7% were *E. colona*.

Butachlor degradation

Butachlor degradation following application of 2 kg ai/ha in July 1983 was rapid and similar for upland (silty clay loam) and dry-seeded lowland (loam) soils (Fig. 2). One hour after herbicide application, 8-10 ppm butachlor were detected in the top 10 cm of soil. One week later only 2-3 ppm were detected,



2. Butachlor degradation in upland and lowland soils at IRRI.

and 21 d after application only about 1 ppm could be detected. This information explains why the weed control effect of butachlor is often short-lived in DSR.

Effect of ratooning rice on insect populations

We continue to be interested in the possibility of obtaining ratoon crops of rice. A 50- to 60-d ratoon rice crop following a 120-d transplanted crop extends the effective period of insect pest buildup from 3 to 5 generations. Because insect numbers increase exponentially with each generation, hoppers and SB, which are not restricted to specific crop stages, might be favored by a ratoon crop.

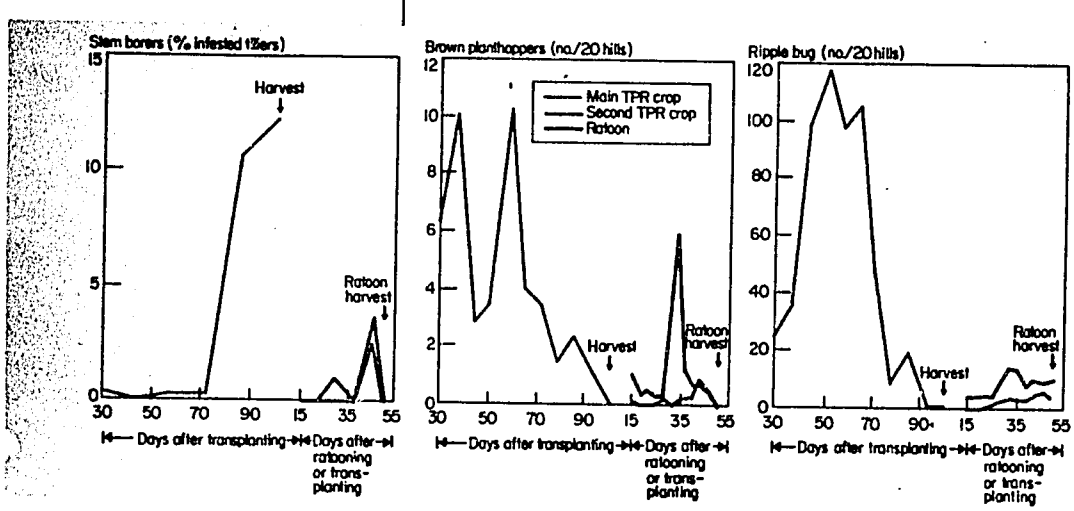
We found, however, that hopper populations decline naturally as the main crop matures because of outward migration and natural enemies (Fig. 3). More spider and ripple bug predators lived in the ratoon than in a TPR second crop. They effectively controlled BPH in the middle of ratoon growth. We found no difference in BPH, WBPH, and GLH populations between the ratooned or TPR crop.

In contrast, SB populations increased dramatically at harvest but their numbers were so decimated (91% population decline) through straw removal to 15-cm stubble height that their populations did not recover.

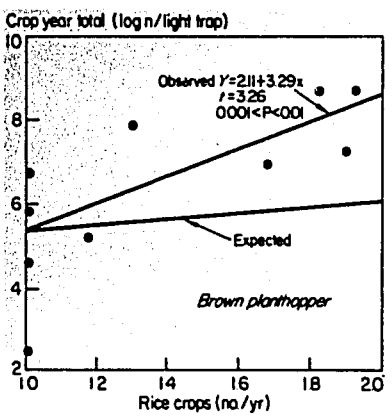
Populations of insects that attack only vegetative stage rice either were unaffected by a ratoon (green semilooper and hairy caterpillar) or declined (RWM and CW). RWM and CW were less attracted to and suffered higher mortality on ratooned rice.

Offsetting these insect control advantages for a ratoon crop is the increased threat of virus diseases transmitted by insects. Virus diseases are extremely difficult to control by methods other than varietal resistance (Fig. 4).

3. Insect pest numbers on a ratooned rice crop were low.



4. Systemic virus diseases such as RTV and YD acquired during main crop can be carried over to the ratoon. Resistance to virus diseases is of prime concern in the development of ratooning rice.



5. Comparison of the observed exponential versus expected doubling of BPH abundance per crop as rice cropping intensity increases from 1 to 2 crops per year, as determined from annual kerosene light trap catches at Philippine cropping systems sites.

Factors of rice intensification that increase insect pests

Many explanations have been given for the increased rice insect pest epidemics in Asia in the past 20 yr. Although variety, crop maturity, and agrochemical use have been said to cause increased insect pest populations, multiple regression analysis indicated that such effects are insignificant. Our data from five Philippine cropping systems sites indicate that insect pest epidemics have increased because there are more rice crops planted and because more area is being planted to rice.

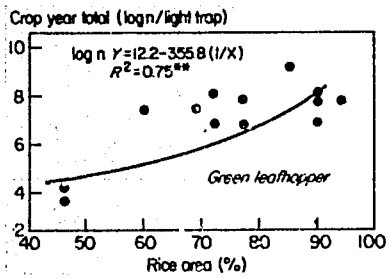
Increasing the number of rice crops per year has a greater effect on insect populations than expanding rice area. BPH and other pests increased exponentially when two rice crops instead of one a year were planted (Fig. 5). Expanding the rice area beyond 75% (Fig. 6) did not produce a linear response in pest numbers. These results indicate that, when 75% or more of land is planted to rice, fewer new insect pest problems are likely to result from expanding riceland 33% than from increasing the number of rice crops per year by 33%.

ON-SITE CROPPING SYSTEMS RESEARCH

Solana farming systems project

In 1983 we completed a 4-yr on-site farming systems study in Solana, Philippines. Solana is in an ecological zone where rice scientists had had little field experience. Farmers in Solana grow crops that are stricken almost annually by either drought or flooding. Their problems are similar to those of farmers in parts of Laos, Kampuchea, and Thailand.

Through our work at Solana we identified rice varieties and cultivar types with good potential for Solana and similar



6. GLH populations rise progressively less steeply as the area devoted to rice increases beyond 50%. Each point on the figure is a 1-yr catch in a kerosene light trap. Rice area was calculated within a 1-km radius of each light trap, which is the effective flight range of most rice insects.

adverse environments. We also identified component technologies and cropping patterns that may assist farmers to increase production and improve their standard of living.

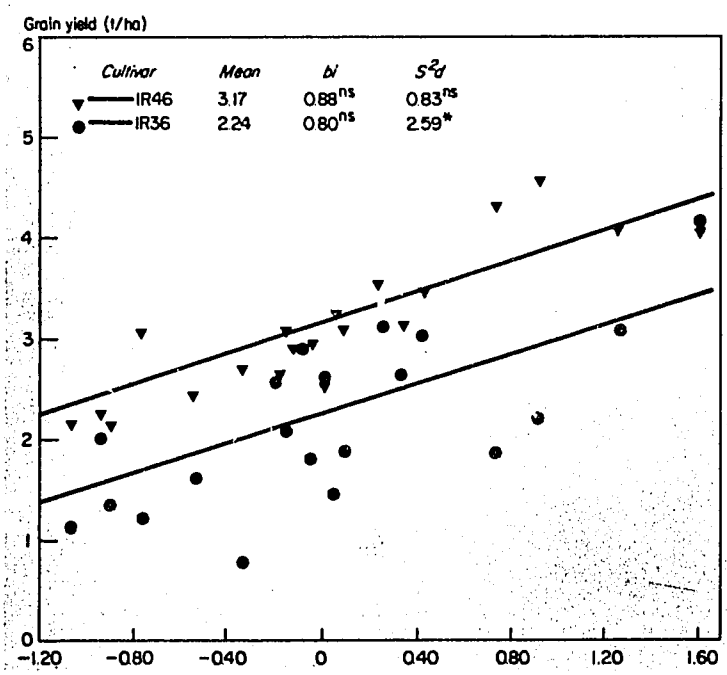
Although our major work in cropping systems at Solana is complete, in 1984 we will continue to test some component technologies and to evaluate the social impact of introduced technologies.

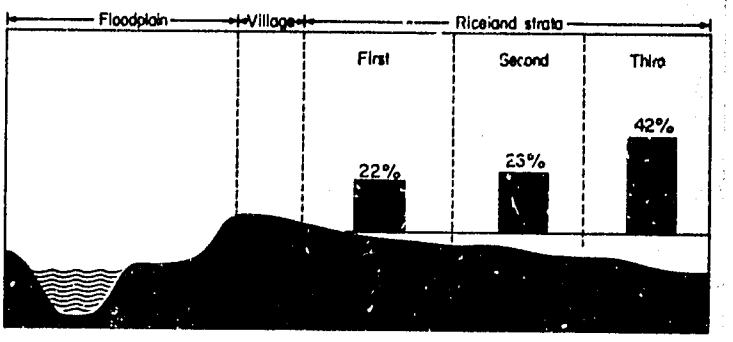
Varietal performance. Experiments conducted in the first 2 yr of research at Solana showed that rice cultivars differed in susceptibility to flood damage. Earlier experiments had suggested that plant height influenced susceptibility.

In 1982 WS we tested 6 intermediate height and 2 short MVs in 20 experiments in farmer fields. Experimental plots and planting dates were selected to expose the varieties to a range of submergence and drought conditions.

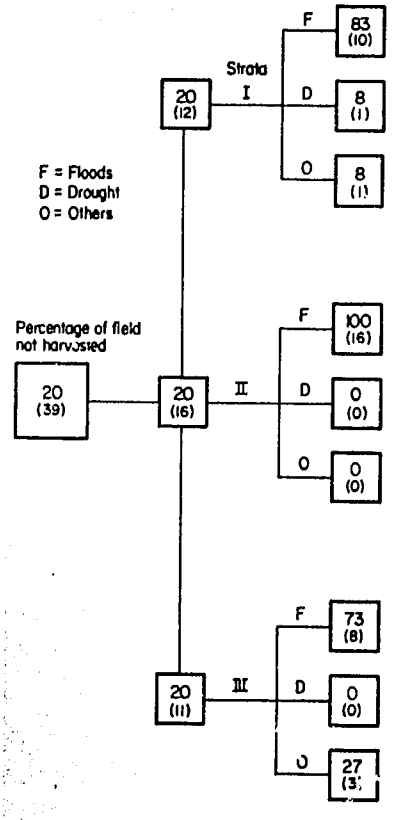
Among the eight cultivars evaluated, IR46 performed more uniformly and yielded as much as or more than other cultivars tested. Stability coefficients of IR46 and IR36 were both less than 1.0, but deviations from the regression were significant for IR36 (Fig. 7). An analysis suggested that within locations, unidentified factors affected IR36 but not IR46 and other cultivars. In the Cagayan environment, IR36, which performs admirably in drought-prone and favorable environments, was

7. Comparisons of cultivars in a drought- and submergence-prone environment indicated that IR46 was moderately well adapted. IR36, regarded as well adapted to favorable rainfed locations, yielded lower and was influenced by factors that contributed to significant deviations from the general trend.





8. Data from 4 yr in a drought- and submergence-prone environment showed that the frequency with which a farmer could expect to puddle soils for transplanting 20- to 30-d-old seedlings of modern cultivars after establishing a dry seedbed on 12 August was 30%. Figures in boxes are estimated percentages of success in land preparation for transplanting seedlings.



9. Regardless of stratum in which MVs were tested in cropping patterns in a drought- and submergence-prone environment, flooding during early reproductive stage was the major cause of crop failure. Numbers in parentheses are number of observations in each class. Severe herbicide, water buffalo, and rat damage also caused failure.

inferior to cultivars that possess other attributes. The IR46 attributes that confer higher yielding ability and stability in this adverse environment are not fully understood.

Photoperiod-sensitive rice in Solana. Research in Solana showed that farmers rely on photoperiod-sensitive traditional cultivars for reasons other than to avoid flood damage. The average age of seedlings transplanted by farmers was 92 d in 1980 and 63 d in 1981. Over those 2 yr, the range was 30 to 125 d.

Earlier studies had shown that tall rices with a photoperiod-induced flowering date later than the most hazardous flood period increased the chance of flood avoidance. Analysis of field data collected in 1980-84 from 48 fields in 3 land strata with different water regimes showed that even in the wettest stratum, farmers could seldom plant seedlings younger than 30 d old, even after at least 3 d with soil wet enough to puddle. The success rate was only 30% across the 3 strata (Fig. 8).

Yields from 4 transplantings of 40- to 120-d-old seedlings of a traditional cultivar were low (2.6-2.9 t/ha) but stable. Because the cultivar was photoperiod sensitive, harvest date was only slightly influenced by seedling age. Yields of MVs averaged only 1.4 t/ha. Analysis of cropping pattern data showed that regardless of stratum on which they were planted, 20% of all rice crops were not harvested, mostly because of flash flooding (Fig. 9). Most failures from floods were caused by a few days of crop submergence in the early, postheading stage.

Given both the hazard of postheading submergence and an inability to schedule puddling operations to coincide with optimum ages of photoperiod-insensitive modern rice seedlings, it appears rational for farmers to plant photoperiod-sensitive cultivars in Solana and other regions with similar physical environments.

Blast in a drought- and submergence-prone environment. In 1983, IR52 had severe Bl infection at the Solana cropping systems site, a shallow rainfed area prone to drought and

submergence. From this observation, we concluded that rice varieties without BI resistance should not be recommended for Solana. IR36 appeared to be BI resistant at the site, but is not tolerant of submergence.

We evaluated benomyl for reducing grain discoloration, BI, and ShB. Grain discoloration and BI incidence were significantly reduced by benomyl spray, but ShB incidence was unaffected. Benomyl application for disease control proved economical.

COMPONENT TECHNOLOGY

Selection and testing of cultivars

We test component crops and varieties for rice-based cropping systems in collaboration with the Philippine Institute of Plant Breeding (IPB), national programs that participate in the ARFSN, and with AVRDC, CIMMYT, ICRISAT, and IITA. IPB does hybridization and selection and the genetic materials come from national, regional, and international breeding programs.

In 1983, IPB added to its collections 1,474 soybean varieties from AVRDC, INTSOY, Indonesia, and Thailand; 2,682 mungbean from AVRDC, Indonesia, Thailand, and Sri Lanka; and 1,022 peanut from ICRISAT and North Carolina State University. IPB screened 2,143 mungbean, 813 soybean, and 813 peanut varieties after rice, and made 50 soybean, 62 mungbean, and 52 peanut crosses.

In March 1983, IRRI and IITA signed a memorandum of understanding to identify cowpea and soybean varieties for rice-based farming systems, and a staff member of IITA was assigned to work at IRRI. Through that project, we are evaluating 40 early-maturing cowpea varieties and elite breeding lines for early maturity, 64 for excessive moisture and drought tolerance, 20 for vegetable cowpea, and 68 for intercropping potential. All those materials are from IITA and have been selected for yield performance and insect and disease resistance.

The most promising varieties chosen from that program have seed multiplied at IRRI and are distributed in the ARFSN. In 1983 we increased seed of 6 soybean varieties from IPB, 7 mungbean from IPB, 8 maize from CIMMYT and IPB, 4 sorghum from IPB, 10 cowpea varieties from IITA, and 1 peanut from Burma. Those varieties will be evaluated in the network in 1984-85.

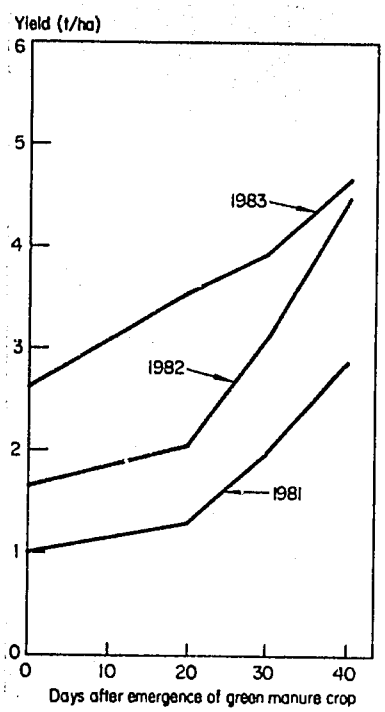
In 1983 we distributed 50 trials before rice (16 mungbean, 8 cowpea, 4 bush sitao, 7 soybean, 8 peanut, 2 sorghum, and 5 maize) and 159 trials after rice (27 mungbean, 18 cowpea,

17 bush sitao, 25 soybean, 20 peanut, 20 sorghum, and 32 maize) to Nepal; Burma; Bangladesh; Thailand; Vietnam; China; Taiwan, China; Indonesia; Malaysia; Sri Lanka; and the Philippines.

Green manures increase rice yield

In 1981, we initiated a study at IRRI to determine how much N could be accumulated in a short-duration green manure crop planted before a transplanted WS rice crop. For the study we selected mungbean *Vigna radiata*, a legume which develops rapidly and nodulates easily. Because mungbean does not tolerate excess moisture, it was planted early to avoid heavy early rains. For 3 yr, rice yield response to incorporated 40-d-old mungbean has exceeded 2 t/ha (Fig. 10).

In 1983, we compared the effect on rice yields of incorporated cowpea *Vigna unguiculata* and sesbania, *Sesbania aculeata*, both of which tolerate saturated root zones better than mungbean. We planted the crops later, when farmers would most likely plant a green manure crop. As WS progressed, the green manure crops periodically had saturated root zones. Green manure was incorporated 24, 36, or 48 DAS. As age before incorporation increased, response to sesbania increased (Fig. 11).



10. Incorporation of 40-d-old mungbean before transplanting rice increased rice grain yield by an average 2 t/ha. The 40-d green manure crops were planted 15 April each year.

Evaluating upland varieties at IRRI

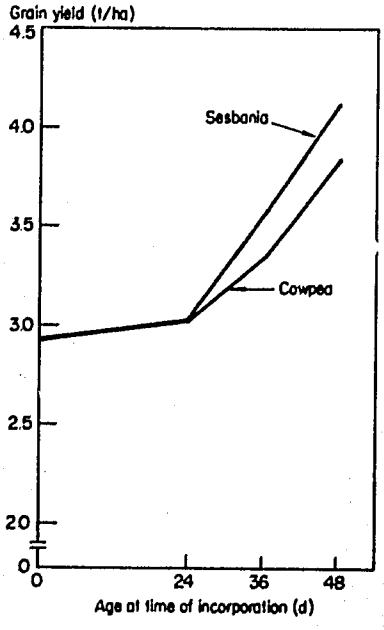
WS rainfall in Los Baños is insufficient to produce consistently high yielding upland rice crops. We explored the possibility of exploiting the normally low rainfall intensity (no month with mean rainfall greater than 275 mm) but long WS (8 months with mean rainfall exceeding 150 mm) to create a range of crop environments in which to compare upland rice cultivars.

Six upland rice cultivars were planted in each of three water regimes maintained using a line source sprinkler on six planting dates between 26 May and 27 August. The line source sprinkler system was used when a simple water balance model indicated there was less than 60% available water in the surface 40 cm of the wettest regime. Results for three contrasting cultivars are shown in Figure 12.

This experiment tested the yield performance and stability of five promising cultivars and a traditional one in anticipation of moving the study in 1984 to on-farm cropping systems research. The method of creating many rainfall patterns in one year has merit for other WS upland rice management studies.

Improved rolling injection planter

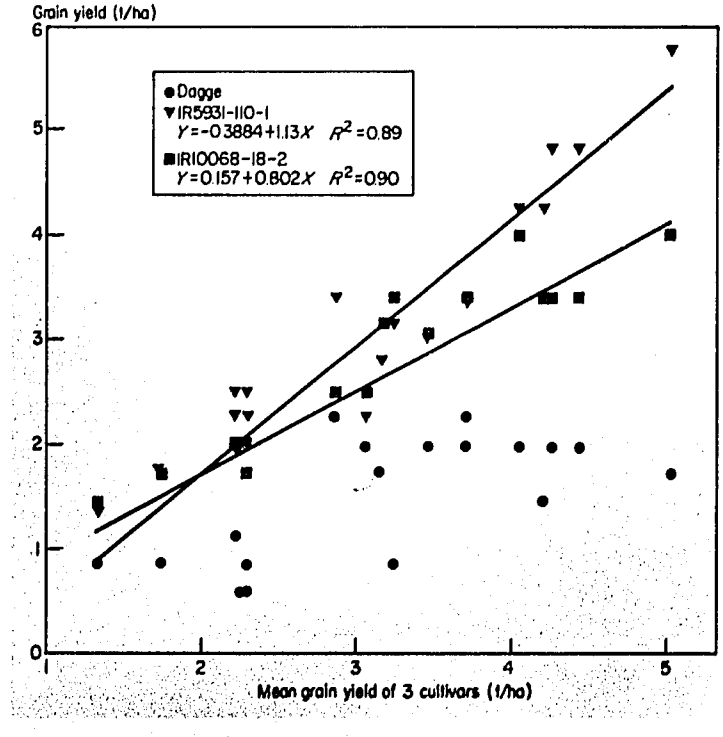
To improve the usually low emergence percentage of sorghum seeds sown with a rolling injection planter after puddled



11. Effect of cowpea and sesbania, both more tolerant of flooding than mungbean, on rice yields.

12. During 1983 WS we created 18 rainfall regimes by superimposing 2 additional rainfall levels on natural rainfall over 6 cropping periods. Under the driest environment cultivars yielded similarly. IR5931-110-1 responded best under favorable conditions.

lowland rice, agricultural engineers added a small covering disk to improve seed-soil contact. We tested the planter with and without the covering disk in tilled and untilled soils. Both tillage and the covering disk increased plant density (Fig. 13). On tilled soil, the covering disk decreased the number of days for a planting operation to produce sorghum plant densities of 150,000/ha, which is necessary for high yields.

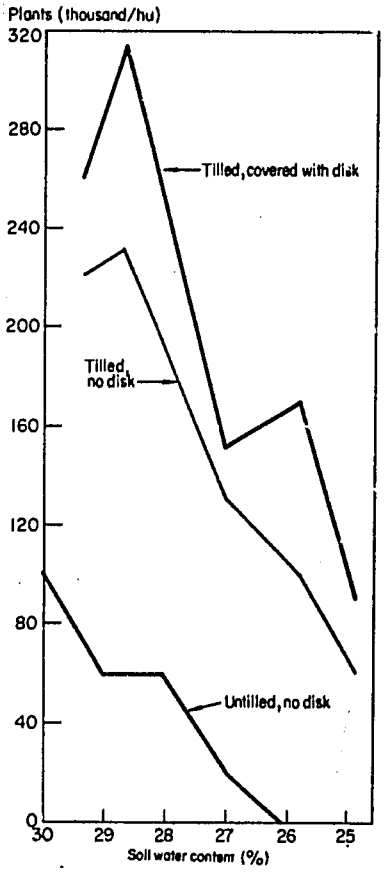


AGRONOMIC MANAGEMENT IN RICE-BASED CROPPING SYSTEMS

Simulation of rice yield responses

The rice phase of a rice-based cropping sequence has many agronomic management options, including type of soil cultivation, rice variety, transplanting date, seedling age, and population density. Those choices determine not only rice yield but also the timing and management of the preceding and/or succeeding nonrice crops. Using a model evolved earlier at IRRI, we developed computer simulations for IR36. Records of actual Los Baños weather were used to predict the outcomes of some of the possible options.

In one set of simulations using 1980 weather, we predicted that IR36 would have yielded more grain had it had slightly more erect leaves that would permit more light penetration. Our



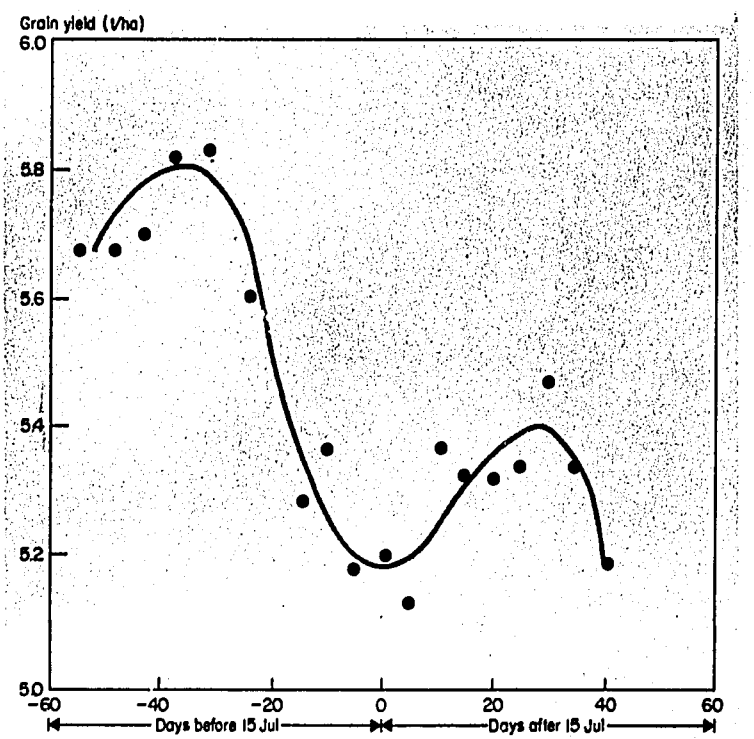
13. Soil tillage and a covering disk attached to a rolling injection planter improved emergence from soils after puddled lowland rice. Numbers in parentheses are days after floodwater was drained from harvested fields. Plants were counted 6 DAS.

simulation also indicated that grain yield was insensitive, over a broad range, to the weight of seedlings transplanted per unit ground area. A second set of simulations used the weather records for each of the years 1959 to 1978 to explore the effect of the interaction of soil physical properties and the crop water balance on rainfed IR36 rice yield. In wetter years, such as 1966, the water balance would suggest that at Los Baños a farmer could transplant WS rice earlier than the conventional 15 July.

Using 1966 weather, we predicted the yields (Fig. 14) that could result from transplanting up to 40 d earlier or 40 d later than 15 July. Early transplanting predicted a yield gain due to very high rainfall in May; the July transplanting may have yielded less because of low rainfall in that month; and later transplanting may have benefited from plentiful October rain. From simulations of changes in soil physical properties we found that, except when WS rainfall was both plentiful and evenly distributed, either natural or managed conditions of low soil water diffusivity will result in grain yields lower by 1 to 2 t/ha than the 5 t/ha that is predicted with average diffusivity.

Compacted layers in puddled soils

We surveyed the strength and depth of compacted riceland soil layers at IRRI (Fig. 15) and in five Asian countries. Even when



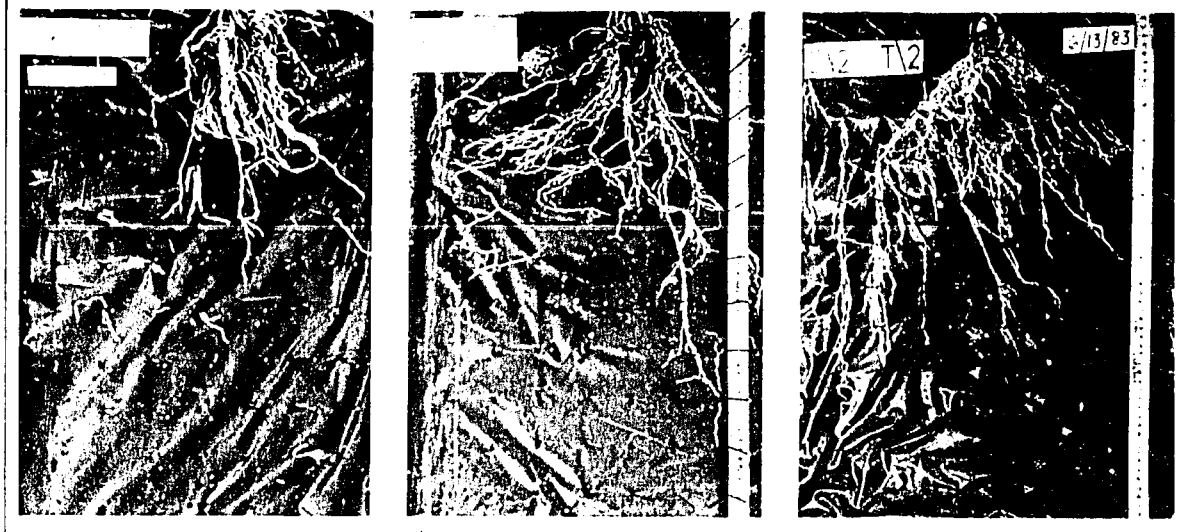
14. Predicted effects on simulated rice yields of transplanting earlier or later than the conventional 15 July, using actual 1966 IRRI weather data.

In a study of the soil physical aspects of tillage of a puddled rice soil in preparation for a following upland crop, a moldboard plow driven by a 10-hp tiller (center) cultivates to 11-cm depth, and subsoiler tines attached to a 4-wheel tractor (right) and to a prototype 10 hp winch-drawn cultivator (left) cultivate soil strips to 35-cm depth at 40 cm interstrip spacing.

moist, many soils had strengths higher than 2 MPa. In laboratory studies we found that strengths of even 1 MPa seriously limit the penetration of rice roots. It is known that strengths of 2 MPa stop root elongation of maize and other upland crops.

On a clay soil with a compacted layer strength of more than 3 MPa extending from 25- to 35-cm depth, cultivation to 35-cm depth by a single subsoiler tine increased soil porosity and encouraged deep rooting of maize (Fig. 16) planted at 6-cm depth within the cultivated strip.

15. S. Maghari, C. Perez, C. Bolacon, and C. Serrano measure the strength of soil at various depths using two different designs of cone penetrometer.



16. Maize roots, as exposed by pinboard sampling, show that roots on a strip-tilled plot (T2) extend widely along the tilled strip and proliferate more at depth than do roots on an untilled (T0) or moldboard-plowed (T1) plot

Maize had high germination rates when seed-soil contact was encouraged either by rolling the tilled strip or by seeding into untilled soil alongside the strip.

We reduced turnaround time to as little as 2 d by using a winch and cable to ensure, even for wet soil, sufficient traction to apply the needed 5 kN draft force. On farms where tractive power is usually supplied by animals, the available draft will be considerably lower than 5 kN. In a collaborative project in Burma, we built a simpler subsoiler that cultivates less deeply and can be pulled by a pair of water buffalo.

PREPRODUCTION TESTING AND TECHNOLOGY TRANSFER

IR58 versus IR36 in rainfed lowland

In May 1983, the Philippine Seed Board released IR9752-71-3-2 as IR58. Because IR58 matures early, we compared it with IR36, the currently recommended variety, on rainfed lowlands in Iloilo, central Philippines. Both varieties were dry-seeded at the beginning of 1983 WS on farmer fields with a wide range of rainfall, landscape, and soil conditions.

Across 29 locations, IR58 yielded an average of 4.6 t/ha, and IR36 yielded 5.9 t/ha. In the north and central locations, where double rice cropping is feasible, 13 of the 17 cooperating farmers preferred IR58 as a second crop because it matured earlier, despite the IR36 yield advantage. On the average, IR58 matured 84 DE, or 15 d earlier than IR36. Preliminary data for the second (WSR) crop indicated that IR58 could be harvested 10-12 d earlier than IR36 (Fig. 17).

In favorable rainfed areas such as Iloilo, there appears to be considerable potential for the spread of very early-maturing

17. A. R. Samiano, research assistant, observing a plot of IR58 surrounded by IR36 planted at the same time. In Iloilo, IR58 matures 10-12 d earlier than IR36.

varieties that can either increase cropping intensity or promote greater stability of existing cropping patterns.

ASIAN RICE FARMING SYSTEMS NETWORK

At the instigation of some national programs collaborating with the farming systems network, we established the Rice Farming Systems Program office at IRRI, and the Asian Cropping Systems working group changed the network name to the Asian Rice Farming Systems Network in April 1983. The general objective of the ARFSN is to identify more productive rice-based farming systems and develop improved technologies that are acceptable to farmers.

In 1983, we had 173 cropping systems sites in 11 Asian countries, which represent a broad range of climatic zones, soil type, soil texture, and socioeconomic conditions. At five sites we are conducting crop-livestock research. Site research emphasized design and testing of cropping patterns for irrigated, partially irrigated, rainfed lowland, upland, and deepwater rice.

Malaysia and Vietnam joined ARFSN in 1983 and are conducting varietal testing. Several national programs implemented the preproduction phase of the cropping systems research methodology. The Philippines conducted multilocation testing in Capiz, Bukidnon, and Agusan and pilot production programs in South Cotabato, Pangasinan, and North Cotabato. Sri Lanka organized multilocation testing in Kurunegala and Bandarawela and pilot production programs in Kurunegala and Anuradhapura. The Bangladesh Rice Research Institute started multilocation testing in Sylhet, Feni, and Jamalpur and a pilot production program in Sylhet. Nepal continued multilocation testing in several districts and implemented a pilot production program at Pumdi Bhumdi, Lele, Chauri Jahari, Khanbhari, Parsa, and Chitwan. Burma, Bangladesh, and Sri Lanka started long-term cropping pattern and fertilizer studies in irrigated and rainfed areas, and Indonesia, IRRI, Korea, and Nepal continued similar studies in 1983.

In 1983 more scientists conducted collaborative research with ARFSN. We are collaborating on cropping pattern testing, varietal testing of upland crops before and after rice, design of farm implements for intensive cropping, long-term cropping pattern and fertilizer studies, insect management, and rice - wheat integrated trials.

In cropping pattern testing we are monitoring the cropping pattern performance and environment at 38 sites in 11 countries. In most comparisons, promising alternative cropping

patterns were more intense and biologically and economically better than dominant farmers' cropping patterns.

We identified several varieties of mungbean, cowpea, maize, sorghum, and soybean that perform better than local checks.

Six countries participated in the collaborative on-farm testing of the rolling injection planter for planting upland crops after rice. The planter performed well for sunflower, soybean, and maize in a newly reaped rice field in Burma and for wheat in Nepal. In Indonesia, seeding with the rolling injection planter was as good as traditional planting for direct-seeded rice, maize, and soybean, and was five times more labor efficient.

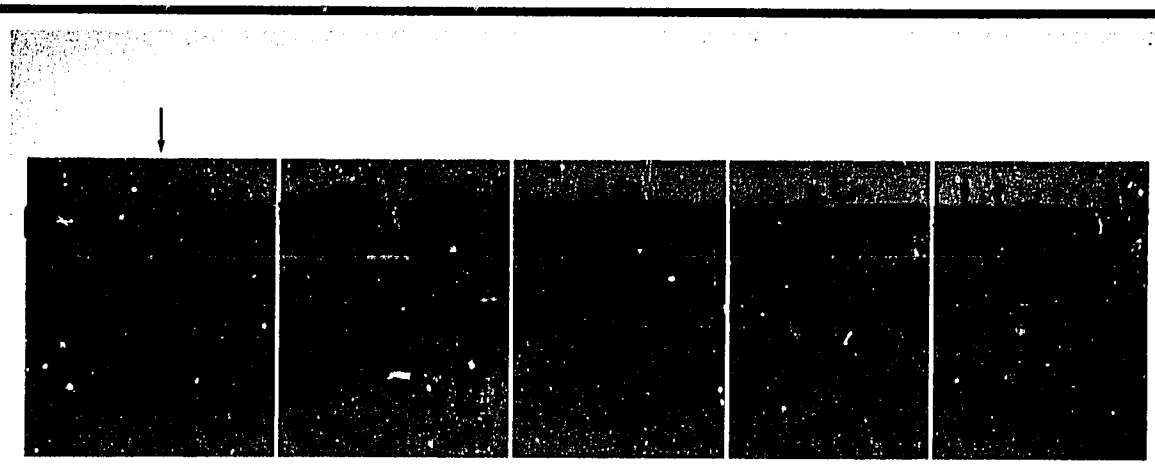
We collaborated with CIMMYT and national programs in rice - wheat integrated trials to identify better wheat and rice varieties for rice - wheat cropping systems. Yields of the first wheat trial from 14 locations were highly related to latitude. Trials in countries at lower than 20°N (Burma, Thailand, Philippines, Sri Lanka) yielded less than 1 t/ha. At latitudes between 20° and 30°N (China, Nepal, and Bangladesh), mean yields ranged from 1 to 4 t/ha. At higher latitudes (Korea) yields reached 5.7 t/ha. The first rice trials with 10 countries were conducted beginning in May 1983. Thirty-six trials were distributed to 12 countries.

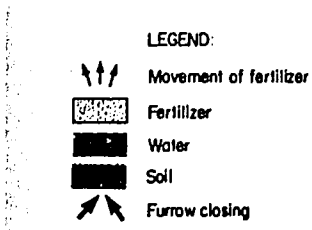
Machinery development and testing

Rising costs of fertilizer and other inputs and the ever-increasing need for more and better quality rice have prompted our agricultural engineers to develop fertilizer applicators, transplanters, pumps, and grain dryers, designed to maximize the efficient use of purchased inputs.

In 1983 we gave top priority to understanding how deep-placed N fertilizer transfers to floodwater during placement and worked to develop applicators that minimize that transfer.

Our industrial extension program now works with programs in eight nations. Farmer need determines the type of machinery that is developed and introduced in each farming area. Because our machines can be fabricated with locally available material in small machine or blacksmith shops, they not only assist the





1. Avenues for fertilizer transfer to floodwater during deep placement.

farmers, but also strengthen the economy of the rural areas, and ensure that maintenance and repair facilities are readily available.

Fertilizer applicators for deep placement

Rice farmers in Asia have not made full use of fertilizer to boost their yields because fertilizer use efficiencies are low. Many fertilizer deep placement applicators have been developed in Japan, China, and at IRRI, but they have performed inconsistently, or have been too costly to be attractive to farmers.

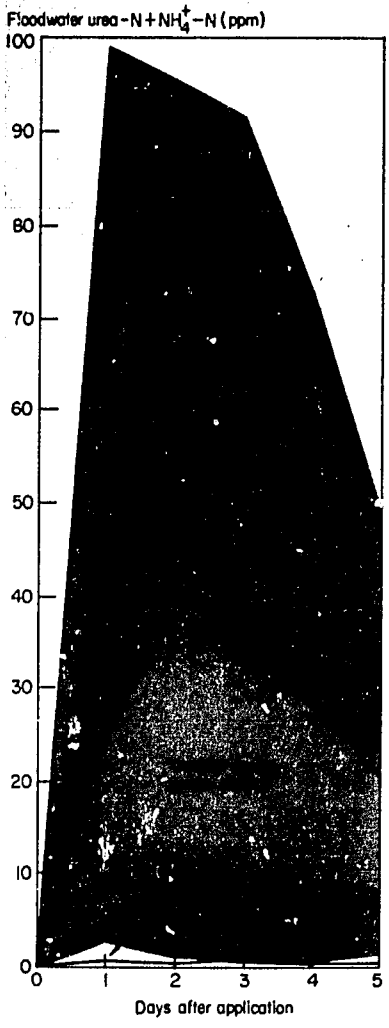
In September 1982 we organized a special engineering team to develop efficient deep placement applicators. Our first step was to review applicator development around the world and establish criteria for technical and commercial acceptability of applicators.

Laboratory experiments helped us understand deep placement phenomena and the failure of earlier applicators. We found that fertilizer placement in flooded furrows, followed by imperfect furrow closing, results in the largest transfer of fertilizer to floodwater, and so least efficiency.

Using those findings, we sought to perfect the designs of three applicator components: metering, conveying, and furrow closing. Of 20 deep placement applicator concepts developed, 6 were selected for intensive design and development efforts. From these came three new applicators: two for PU and one for USG.

Mechanics of N transfer to floodwater. Laboratory experiments helped us identify the various ways of fertilizer transfer to floodwater during placement. There are four fertilizer transfer mechanisms (Fig. 1).

The magnitude of N transfer to floodwater for each avenue during placement of PU in 5-cm furrows is shown in Figure 2.



2. Major avenues for N transfer to floodwater during PU 5-cm deep placement in freshly flooded Maahas clay.

The major ways of fertilizer transfer were

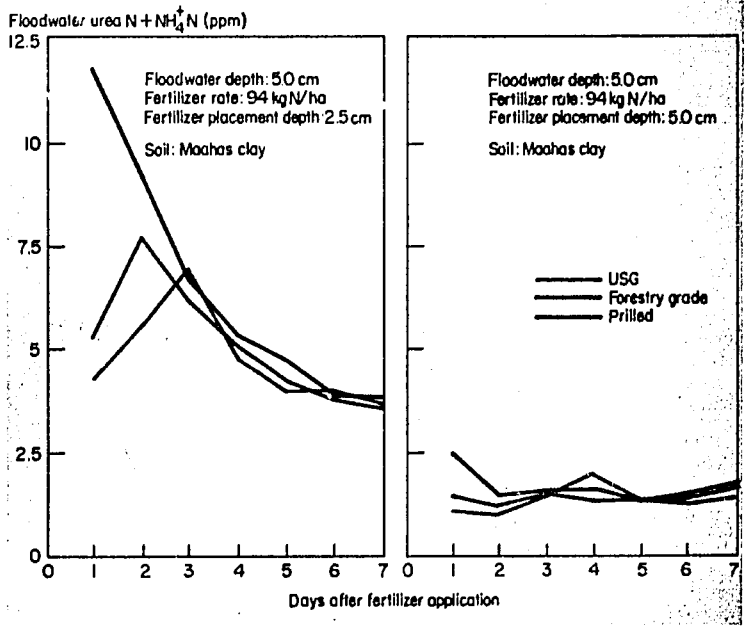
- dissolution of fertilizer during transit from the water surface to the furrow bottom (43-76%), and
- upward movement to the floodwater of fertilizer granules or solution during furrow closing (up to 29%).

If furrows were properly closed, transfer through them was generally less than 10% and transfer due to diffusion through flooded soils was less than 5%.

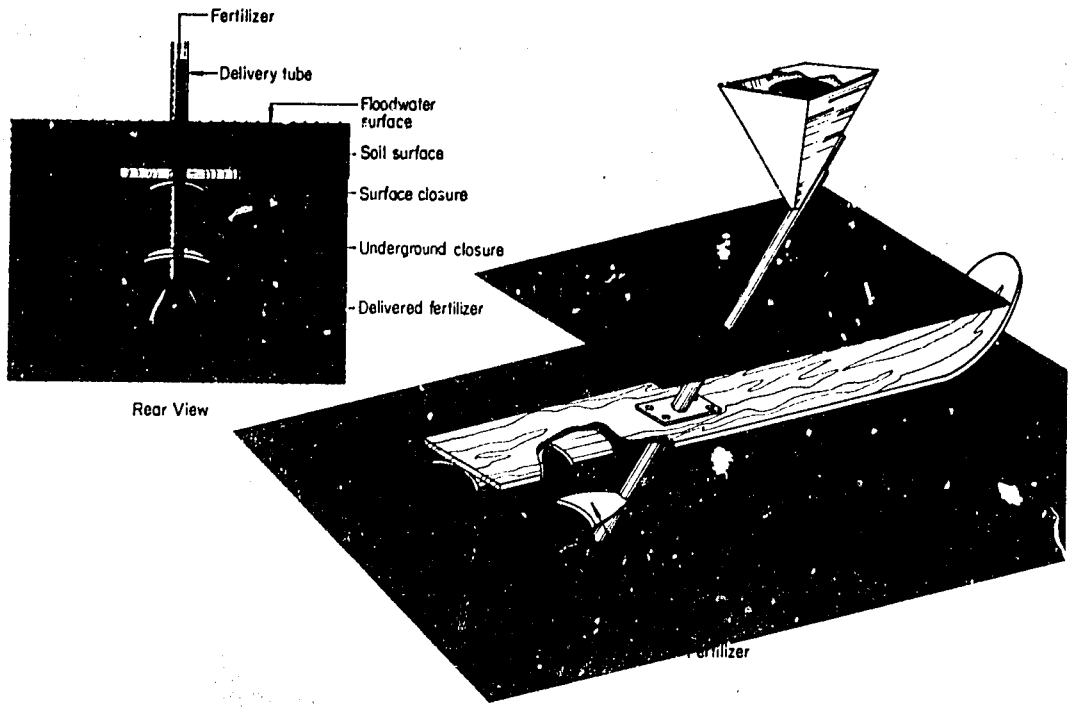
Experiments that embedded prilled, forestry grade, and supergranule urea (Fig. 3) indicated that 4-5 cm placement depth is adequate to minimize fertilizer transfer.

Minimizing fertilizer-water contact during transit, placement, and covering, and maintenance of an adequate soil barrier between floodwater and deposited fertilizer were the most critical features of deep placement applicators. We developed a basic applicator concept (Fig. 4) in which fertilizer would be injected 3-5 cm into the soil through a narrow tube, without coming in contact with floodwater.

When we are developing a machine, it undergoes repeated design improvements and evaluation. Performance evaluation in yield experiments is slow, requiring 5 to 6 mo. Because floodwater concentrations of urea and ammonium N after fertilizer application are generally related to volatilization losses, we used floodwater N level to approximate machine placement efficiency in our early work. This technique helped us to quickly evaluate applicator improvements and led to the development



3. N transfer to floodwater when urea is embedded at 2.5 and 5.0 cm in freshly puddled Maahas clay.



4. Underground and surface closure to minimize N transfer to floodwater during deep placement.

of the spring auger (Fig. 5) and oscillating plunger applicators (Fig. 6) for PU, and the press-wedge applicator for USG (Fig. 7).

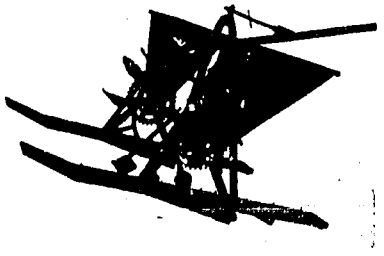
Comparative performance of applicators. During 1983 DS, we compared in yield trials the previously developed deep plunger applicator for USG and USG hand placement with the three new applicators. The new machines performed well. All produced N levels in floodwater below the acceptable level agreed upon by IRRI scientists.

The straight auger and the oscillating plunger gave lower N transfer to floodwater than USG hand placement, long considered the most efficient deep placement method. Because the inclined press-wedge had a higher N transfer value, we redesigned the wedge and opener for a narrower profile that seals furrows better.

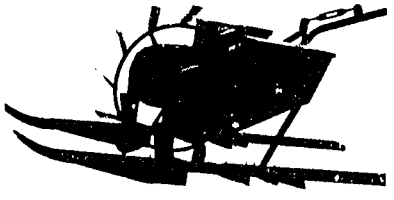
We tested these machines in yield trials in 1983 WS in cooperation with nine progressive farmers in the Philippines. A single fertilizer application by any of the machines produced a higher grain yield per kilogram of urea used than the farmers' traditional practice of split surface broadcast. Average increase in fertilizer use efficiencies for the machines on clayey soils at the farms was

- spring auger applicator 48.8%

5. Spring auger applicator for PU.



6. Oscillating plunger applicator for PU.



7. Press-wedge applicator for USG.

The spring auger fertilizer applicator in the field. All three new applicators have similar basic profile, weight, and operation procedure.

- oscillating plunger applicator 44.5%
- press-wedge applicator 51.3%.

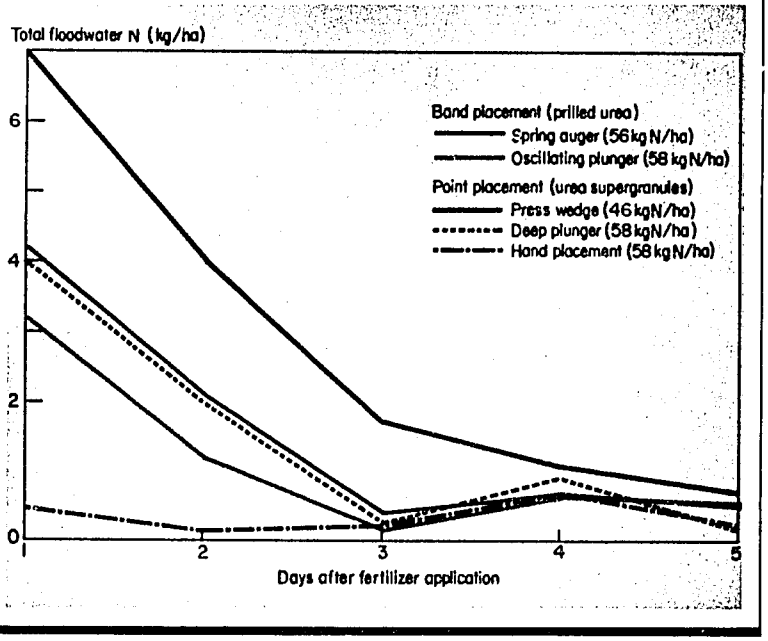
Comparison of the applicators with hand deep point-placement of USG using the oscillating plunger or spring auger produced 5.1 and 4.7 t/ha, similar to 4.6 t/ha with hand point-placed USG. The press-wedge produced less than other application methods because it transferred more nitrogen to floodwater during placement (Fig. 8).

The deep plunger took longer to apply fertilizer (39 h/ha) than the other applicators (17-22 h/ha). Hand point-placement was most labor intensive (47 h/ha). We estimate that farmers could save 30 to 35% on fertilizer by using these machines.

Transplanter redesigned

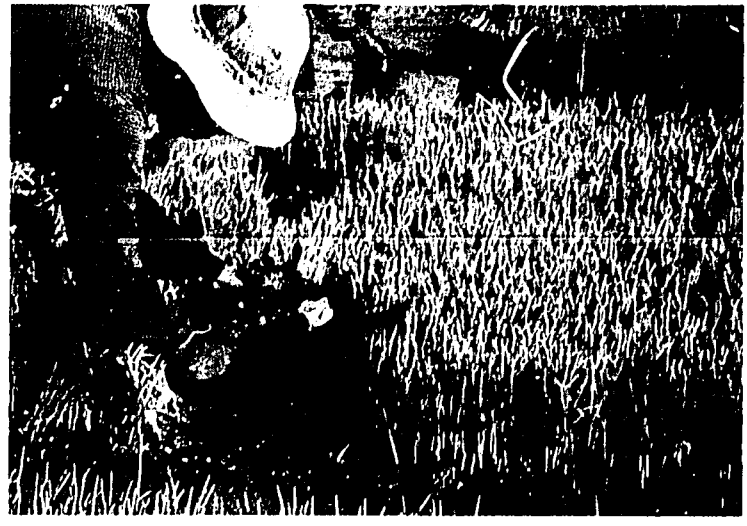
Feedback from farmer cooperators who have used the IRRI 5-row transplanter indicated that improvements were needed to make it more acceptable to small farmers. Using that response, we developed a new 6-row transplanter (Fig. 9). The new model transplants 0.37 ha/d compared with 0.20 ha with the 5-row machine. It weighs 18 kg — 7 less than the 5-row — and 2 long, narrow skids have reduced the pulling force necessary to operate it. Rubber grips on the handle protect the operator's hands.

We also reduced the number of machine parts, used a standard bicycle free wheel as the tray indexing mechanism, and straightened the curved seedling tray to simplify fabrication.



8. Among the 4 most promising fertilizer applicators, the press-wedge transferred highest N levels to floodwater. Hand point-placed USG produced little floodwater N.

9. The new 6-row IRRI transplanter



10. Modified wet-bed seedling preparation for the 6-row transplanter.

The 6-row transplanter requires no adjustment during operation, can be carried by one person, and seedling tray displacement per stroke can be varied to give different seedling density.

We also modified the wet-bed method of seedling preparation (Fig. 10) to eliminate the expensive wooden frames and to allow the use of a long, sharp-edged bolo to cut the seedling mat. The new transplanter is being introduced in areas of the Philippines where labor shortage is acute at transplanting time.

Grain dryers

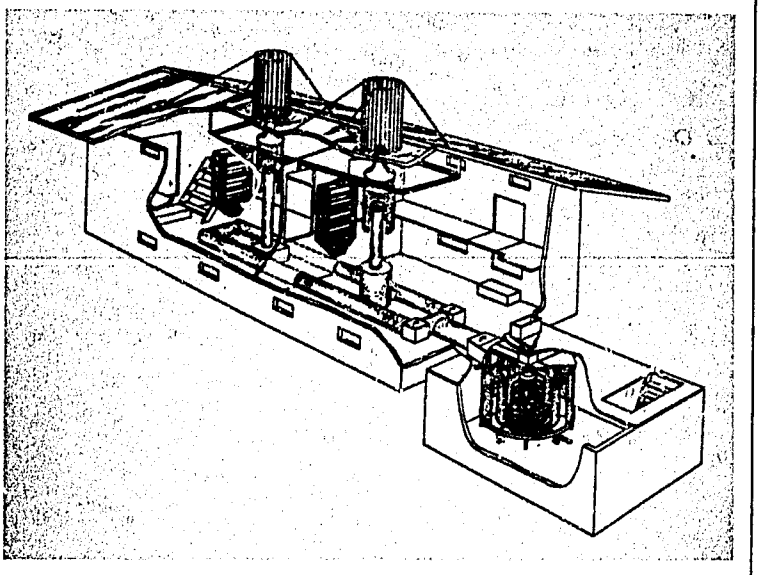
We continued to study and improve grain dryers in 1983, concentrating our efforts on the heated floor dryer and the warehouse grain dryer, both of which are appropriate for village or cooperative level operation.

Heated floor dryer. In the Philippines, rice is traditionally sun-dried, which is inexpensive. However, more rice is harvested in WS when sun-drying often is delayed by clouds and rain. We have designed, developed, and tested a heated floor dryer (HFD) to complement sun-drying. HFDs are located near conventional sun-drying floors so rice can be conveniently pushed to the HFD when clouds appear.

A HFD uses a furnace which burns rice straw or hulls to heat water to 93-95°C, a pump to circulate water from the boiler to the drying floor, a metal dryer floor heated by the circulating hot water, and a roof to protect the floor from rain.

The dryer floor is heated to about 90°C by the internally circulated hot water and the layer of rice on the floor is raked as it is in traditional sun-drying (Fig. 11). On the floor, rice is dried to about 18% moisture content, after which it may be stored

11. Drying rice in a HFD dryer



12. The warehouse dryer is indirectly fired, which produces better quality products.

safely until weather permits sun-drying to 14% moisture. In tests, we find that

- head rice recovery is substantially higher for grain dried with the HFD than it is for traditional drying,
- no parboiling effect occurs in rice dried by the HFD, and
- rice dries satisfactorily even under high relative humidity (66-99%).

Warehouse dryer. We are continuing to improve a warehouse drying system that uses an intermediate, nonconventional drying and storing technology. The dryer is fabricated with insulating bricks made of soil and straw and utilizes a soil brick furnace that burns agricultural residue. A vortex wind machine moves air through the warehouse (Fig. 12).

We found the dryer effective and economical for drying rice, maize, coconut, and fish. Cost of drying rice from 23 to 14% moisture in 8 h or less was below $1/t. Milling yield of warehouse dried rice was superior to that of sun-dried rice.

We are developing for the dryer standard low-technology operating procedures adapted to local conditions and capacity requirements.

Industrial extension program

Our machinery development program now extends to India, Burma, Thailand, Indonesia, and the Philippines, and we cooperate with machinery development programs in Sri Lanka, Pakistan, and Egypt.

Thresher manufacture is increasing in Indonesia. In 1983, 14 manufacturers fabricated 450 threshers in West Sumatra.

Competition has developed and prices have declined.

The improved buffalo plow, developed in 1982, is being distributed to farmers in northeast Thailand. Two firms have manufactured 70 plows and 3 other firms have started production.

The India project has been established at Tamil Nadu University in Coimbatore, with facilities to be completed in 1984.

In the Philippines, the industrial extension program collaborated with the Ministry of Agriculture to strengthen the national capability to develop and extend the use of small farm equipment. Program staff at the Ministry developed an animal-drawn seed and fertilizer applicator (SFA) that can be used to plant maize, sorghum, legumes, and upland rice (Fig. 13). In a single pass it opens a furrow, applies fertilizer, plants seeds, and covers them with soil. Fertilizer is placed below and to the side of the seeds. The SFA can be fabricated inexpensively using tools and materials that are available in rural areas. It is to be introduced to farmers in 1984.

The Philippine program has expanded substantially in 1983 and now includes more than 180 cooperating members, ranging from small blacksmith shops to relatively large firms, located throughout the major rice-producing areas of the country.

Finances

Summary of financial support to IRRI core and special projects received in 1983[a]

	CORE			
	Unrestricted	Restricted	Special Projects	Total
U.S. Agency for International Development	$ 5,520,278.00	$ —	$1,891,133.69	$ 7,411,411.69
Japanese Government	—	3,331,292.10	300,511.51	3,631,803.61
Canadian International Development Agency	1,242,722.50	—	1,756,492.82	2,999,215.32
United Nations Development Programme	—	1,490,700.00	289,143.00	1,779,843.00
International Fund for Agricultural Development	—	1,700,000.00	—	1,700,000.00
Overseas Development Administration, UK	975,810.00	—	—	975,810.00
Australian Government	635,448.00	—	—	635,448.00
Federal Republic of Germany	533,728.59	—	7,528.00	541,256.59
International Bank for Reconstruction & Development	420,000.00	—	—	420,000.00
Government of Sweden	370,605.82	—	—	370,605.82
Asian Development Bank	—	—	326,500.00	326,500.00
Government of Saudi Arabia	300,000.00	—	—	300,000.00
International Development Research Centre	—	186,400.00[b]	110,385.36	296,785.36
International Centre of Insect Physiology & Ecology	—	61,906.00[b]	205,707.66	267,613.66
Ford Foundation	150,000.00	—	70,800.00	220,800.00
Government of Belgium	142,558.45	—	—	142,558.45
Government of Denmark	129,282.48	—	—	129,282.48
Government of India	122,748.00	—	—	122,748.00
Swiss Federal Council	—	120,510.97[b]	—	120,510.97
Government of the Philippines	105,396.63	—	—	105,396.63
Rockefeller Foundation	100,000.00	—	—	100,000.00
Government of the Netherlands	—	75,000.00	—	75,000.00
International Food Policy Research Institute	—	—	68,733.19	68,733.19
International Fertilizer Development Center	—	—	65,201.19	65,201.19
Government of Spain	25,000.00	—	—	25,000.00
Government of New Zealand	16,387.50	—	—	16,387.50
Others	—	—	—	305,590.87[c]
Total	$10,789,965.97	$6,965,809.07	$5,092,136.42	$23,153,502.33

[a]Receipts are accounted for on a cash basis. [b]Transferred Projects starting 1983. [c]Other donors were the Third World Foundation, 1982 Third World Prize to IRRI, $100,000.00; Office of Rural Development, Korea, $70,000.00; International Board for Plant Genetic Resources, $55,418.20; National Food and Agriculture Council, $23,204.23; Philippine Council for Agriculture and Resources Research and Development, $11,591.64; United Nations Environment Programme, $8,876.80; International Potash Institute and Potash and Phosphate Institute, $8,000.00; Ciba-Geigy, $5,000.00; Monsanto, $3,500.00; Stauffer Chemical Company, $3,000.00; SKTrostberg Aktiengesellschaft, $3,000.00; FMC International, $3,000.00; American Cyanamid Overseas Corporation, $2,000.00; Walt Disney Production, Scholarship Fund, $2,000.00; KenoGard, $1,000.00. IRRI also received the following donations in kind. IBM Philippines provided IRRI the exclusive use of an IBM 4331 computer system for 4 yr beginning 1983. USAID donated excess property of an indeterminable value. Honda Philippines, Inc. donated 8 Honda engines and Marsson Industrial Corp. donated 5 Briggs and Stratton engines.

Board of trustees

DR. FORREST F. HILL
Chairman of the Board Emeritus
701 The Parkway
Ithaca, New York 14860, USA

DR. CLARENCE C. GRAY III
Chairman of the Board
The Rockefeller Foundation
1133 Avenue of the Americas
New York, N.Y. 10036, USA

MIN. ARTURO R. TANCO, JR.
Vice Chairman
c/o Ministry of Agriculture
Diliman, Quezon City, Philippines

MEMBERS

DR. M. S. SWAMINATHAN
Director General
International Rice Research Institute
P.O. Box 933, Manila, Philippines

ATTY. EDGARDO J. ANGARA
President
University of the Philippines System
Diliman, Quezon City, Philippines

DR. NORMAN R. COLLINS
Program Officer-in-Charge
The Ford Foundation
320 East 43rd Street
New York, N.Y. 10017, USA

DR. M. M. ELGABALY
No. 6 Nabatat Street
Garden City, Cairo
Egypt

DR. M. AMIRUL ISLAM
69, Tejkunipara
Tejgaon, Dhaka, Bangladesh

MR. LIN SHIH-CHENG
Plant Breeder
Chinese Academy of Agricultural Sciences
Beijing, China

MR. ALBAN F. GURNETT-SMITH
Honorary Fellow
Center for International Cooperation
CSIRO, P.O. Box 260, Civic Square
ACT 2608, Canberra, Australia

PROF. DR. HANS W. SCHARPENSEEL
Universitat Hamburg
Ordinariat fur Bodenkunde
Von Melle Park 10, D-2000 Hamburg 13
Federal Republic of Germany

DR. IN-HWAN KIM
President, Korean Seed Association
Room 1014, Songnam Building
4-1, Seucho-Dong, Kangnam-Ku
Seoul, Korea

MR. SADIKIN, S. W.
Director General
Agency for Agricultural Research and Development
Jalan Ragunan 29, Pasar Minggu
Jakarta Selatan, Indonesia

DR. ROBERT K. CUNNINGHAM
Overseas Development Administration
Eland House, Stag Place
London, SW1, United Kingdom

DR. JAAP J. HARDON
Directie Landbouwkundig Onderzoek
Bureau of Wageningen
Mansholtlaan 4 Postbus 59
6700 AN Wageningen
The Netherlands

DR. KENZO HEMMI
Professor
Department of Agricultural Economics
University of Tokyo
Bunkyo-ku
Tokyo, Japan

Personnel

Office of the Director General

M. S. SWAMINATHAN, Ph D, director general
MARCOS R. VEGA, Ph D, deputy director general
DENNIS J. GREENLAND, Ph D, deputy director general
MANO D. PATHAK, Ph D, director, research and training
HUGH T. MURPHY, BA, director, administration
FAUSTINO M. SALACUP, BS, CPA, director, protocol and liaison
PAUL A. COOPER, BA, director, budget and accounts

Administrative and Professional Staff

REBECCA C. PASCUAL, MS, manager, food and housing services**
ZOSIMO Q. PIZARRO, LLB, senior administrative associate**
PEDRO G. BANZON, LLB, administrative associate
PURITA M. LEGASPI, BBA, CPA, special assistant to the director general

Liaison Scientists

J. RITCHIE COWAN, Ph D, IRRI liaison scientist, Indonesia and Malaysia*
MANUEL J. ROSERO, Ph D, IRRI liaison scientist, Latin America
WALTER C. TAPPAN, BS, IRRI liaison scientist, Indonesia and Malaysia****
DIOSCORO L. UMALI, Ph D, IRRI liaison scientist, China (consultant)****
KAUNG ZAN, Ph D, liaison scientist, Africa

Senior Scientific Staff

Agricultural Economics

ROBERT W. HERDT, Ph D, agricultural economist*
JOHN C. FLINN, Ph D, agricultural economist
EDWIN C. PRICE, Ph D, agricultural economist
CRISTINA C. DAVID, Ph D, agricultural economist****
MASAO KIKUCHI, D Agr, associate agricultural economist*
LEONARDO A. GONZALES, Ph D, associate agricultural economist
CLARENCE J. MILLER, Ph D, agricultural economist+
MARLIN G. VAN DER VEEN, Ph D, associate agricultural economist****
ALBERT POLAK, Ph D, visiting associate agricultural economist****
ROBERT E. HUKE, Ph D, visiting scientist****
FOSTER CADY, Ph D, visiting scientist***
HAROLD C. CONKLIN, Ph D, honorary visiting research associate****
MARK ROSEGRANT, Ph D, visiting scientist***

Agricultural Engineering

CLARENCE W. BOCKHOP, Ph D, agricultural engineer
MAKOTO ARIYOSHI, MS, agricultural engineer
MARVIN L. NAFZIGER, BS, associate agricultural engineer*
J. BART DUFF, MS, associate agricultural economist
AMIR U. KHAN, Ph D, agricultural engineer
JOHN A. WICKS, Ph D, associate agricultural economist*
MALCOLM M. HAMMOND, Dip. Agr. E., agricultural engineer****+
VENKAT R. REDDY, MS, agricultural engineer+
MARVIN M. PARKER, MS, agricultural engineer*+
RAYMOND C. FISCHER, MBA, associate agricultural engineer*+
BILLY J. COCHRAN, Ph D, agricultural engineer****+
ROBERT E. STICKNEY, Ph D, agricultural engineer+

Agronomy

SURAJIT K. DE DATTA, Ph D, agronomist
KEITH MOODY, Ph D, agronomist
JOHN C. O'TOOLE, Ph D, agronomist
CEZAR P. MAMARIL, Ph D, agronomist
DONALD W. PUCKRIDGE, Ph D, agronomist+
RAY B. DIAMOND, Ph D, visiting scientist*
NEIL C. TURNER, Ph D, visiting scientist*

Cereal Chemistry

BIENVENIDO O. JULIANO, Ph D, chemist**

Entomology

ELVIS A. HEINRICHS, Ph D, entomologist
JAMES A. LITSINGER, Ph D, entomologist
OSAMU MOCHIDA, D Agr, entomologist
RAMESH C. SAXENA, Ph D, associate entomologist
H. DAVID CATLING, Ph D, entomologist+
JOHN PERFECT, MS, visiting scientist
ANTHEA G. COOK, Ph D, visiting scientist

Irrigation Water Management

SADIQUL I. BHUIYAN, Ph D, agricultural engineer
ALAN C. EARLY, Ph D, associate agricultural engineer*

Multiple Cropping

RICHARD A. MORRIS, Ph D, agronomist
LEONARD R. OLDEMAN, Ph D, visiting scientist
JERRY L. MCINTOSH, Ph D, agronomist+
FRANK D. WHISLER, Ph D, visiting scientist*
ROSENDO K. PALIS, Ph D, agronomist+

Plant Breeding

GURDEV S. KHUSH, Ph D, plant breeder
DERK HILLERISLAMBERS, Ph D, plant breeder
SANT S. VIRMANI, Ph D, plant breeder
DAVID MACKILL, Ph D, associate plant breeder
PEDRO B. ESCURO, Ph D, plant breeder+
BEN R. JACKSON, Ph D, plant breeder (Rockefeller Foundation, serving as IRRI representative)†+•
DWIGHT G. KANTER, Ph D, associate plant breeder+
EBRAHIMALI A. SIDDIQ, Ph D, plant breeder****+
GUN SIK CHUNG, Ph D, visiting scientist*
TSUGUFUMI OGAWA, Ph D, visiting scientist
MICHEL A. ARRAUDEAU, MS, visiting scientist****

Plant Pathology

TWNG WAH MEW, Ph D, plant pathologist
HIROYUKI H. HIBINO, Ph D, plant pathologist
J. MICHAEL BONMAN, Ph D, associate plant pathologist
TSUYOSHI YAMAMOTO, Ph D, visiting scientist
SEUNG-CHANG LEE, Ph D, visiting scientist****

Plant Physiology

SHOUICHI YOSHIDA, D Agr, plant physiologist
BENITO S. VERGARA, Ph D, plant physiologist
FRANCISCO J. ZAPATA, Ph D, associate plant physiologist

Soil Chemistry/Physics

FELIX N. PONNAMPERUMA, Ph D, principal soil chemist**
HEINZ-ULRICH NEUE, Ph D, associate soil chemist
TERENCE WOODHEAD, Ph D, soil physicist****
IAN R. FILLERY, Ph D, visiting associate soil chemist
GERHILD BOJE-KLEIN, Ph D, visiting associate soil chemist****

Soil Microbiology

IWAO WATANABE, D Agr, soil microbiologist**
JAGDISH K. LADHA, Ph D, associate soil microbiologist
IAN F. GRANT, Ph D, visiting associate soil microbiologist****
PIERRE A. ROGER, D. Pedologie, visiting scientist

Statistics

KWANCHAI A. GOMEZ, Ph D, statistician

International Rice Testing Program

V. SESHU DURVASULA, Ph D, plant breeder**
DENNIS P. GARRITY, Ph D, associate agronomist
JUDITH E. WOOD, BS consultant****

International Rice Germplasm Center

TE-TZU CHANG, Ph D, geneticist

Rice Farming Systems Program

VIRGILIO R. CARANGAL, Ph D, agronomist
RAM K. PANDEY, Ph D, visiting agronomist****

Communication and Publications

THOMAS R. HARGROVE, Ph D, editor
WILLIAM H. SMITH, BS, editor
EDWIN A. TOUT, MA, associate editor
EUGENE P. HETTEL, MA, visiting associate editor*

Training and Technology Transfer

DANNY R. MINNICK, Ph D, training specialist
HOWARD H. HAGERMAN, Ph D, visiting communication specialist*
GLENN L. DENNING, MS, visiting associate field specialist
DENNIS M. WOOD, Ph D, crop production specialist****+
C. THOMAS BRACKNEY, MS, rice production training specialist****+
L. DALE HAWS, Ph D, rice production training specialist****+

Experimental Farm

FEDERICO V. RAMOS, MS, farm superintendent
ORLANDO G. SANTOS, MPS, associate farm superintendent

Library and Documentation Center

LINA M. VERGARA, MS, librarian

Cooperative Research Staff

Africa

KAUNG ZAN, Ph D, IRRI liaison scientist

Bangladesh

FRANK W. SHEPPARD, JR., D Ed, research systems analyst/IRRI representative
C. THOMAS BRACKNEY, MS, rice production specialist
DWIGHT G. KANTER, Ph D, associate plant breeder
CLARENCE J. MILLER, Ph D, agricultural economist

Burma

MALCOLM M. HAMMOND, Dip. Agr. E., agricultural engineer****
ROSENDO K. PALIS, Ph D, agronomist
PEDRO B. ESCURO, Ph D, plant breeder

China

DIOSCORO L. UMALI, Ph D, IRRI liaison scientist (consultant)****

Egypt

MARVIN M. PARKER, MS, agricultural engineer*
EBRAHIMALI A. SIDDIQ, Ph D, plant breeder****
L. DALE HAWS, Ph D, rice production training specialist****

Indonesia

J. RITCHIE COWAN, Ph D, IRRI liaison scientist*
WALTER C. TAPPAN, BS, IRRI liaison scientist****
JERRY L. MCINTOSH, Ph D, agronomist
VENKAT R. REDDY, MS, agricultural engineer

Latin America

MANUEL J. ROSERO, Ph D, IRRI liaison scientist

Philippines

ROBERT E. STICKNEY, Ph D, agricultural engineer
DENNIS M. WOOD, Ph D, crop production specialist****

Thailand

BEN R. JACKSON, Ph D, plant breeder (Rockefeller Foundation, serving as IRRI representative)†*
DONALD W. PUCKRIDGE, Ph D, agronomist
H. DAVID CATLING, Ph D, entomologist
RAYMOND C. FISCHER, MBA, associate agricultural engineer*
BILLY J. COCHRAN, Ph D, agricultural engineer****

---

*Left during the year
**On study leave
***Joined and left during the year
****Joined during the year
†Part time
+Cooperative research staff

Abbreviations and acronyms

Following is a list of abbreviations and acronyms used in *Research Highlights 1983.* Not included in this list, but used, are the standard abbreviations of measurement prescribed by System International.

A

AC = amylose content
ai = active ingredient
AN = ammoniacal nitrogen
ARA = acetylene reduction activity
ARFSN = Asian Rice Farming Systems Network
AS = ammonium sulfate
AVRDC = Asian Vegetable Research Development Center

B

B&I = broadcast and incorporation
BB = bacterial blight
B:C = benefit-cost ratio
BGA = blue-green algae
Bl = blast
BLB = bacterial leaf blight
BLS = bacterial leaf streak
BPH = brown planthopper
BRP = brown-rice protein

C

C:N = carbon-nitrogen ratio
cbar = centibar
CEC = cation exchange capacity
CIMMYT = International Maize and Wheat Improvement Center
cms = cytoplasmic male sterile
cps = centipoise
CV = coefficient of variation
CW = caseworm

D

DAH = days after harvest
DAI = days after inoculation
DAPI = days after panicle initiation
DAS = days after seeding, sowing
DAT = days after treatment
DBE = days before emergence
DBH = days before harvest

DBPI = days before panicle initiation
DBS = days before seeding, sowing
DBT = days before transplanting
DE = days after emergence
DI = days after infection, infestation
DS = dry season
DSR = dry-seeded rice
DT = days after transplanting

E

EC = emulsifiable concentrate
ECe = electrical conductivity of the saturation extract
EE = ethyl ester
ET = evapotranspiration

F

F = foliar
fb = followed by
FGU = forestry-grade urea

G

G = granular
GC = gel consistency
GEU = Genetic Evaluation and Utilization
GLH = green leafhopper
GSV = grassy stunt virus
GT = gelatinization temperature

H

HAI = hours after inoculation
HI = harvest index
HLS = helminthosporium leaf spot
HR = highly resistant
HS = highly susceptible
HT = hours after treatment

I

IBPGR = International Board for Plant Genetic Resources
ICRISAT = International Crops Research Institute for the Semi-arid Tropics
IITA = International Institute of Tropical Agriculture
INSFFER = International Network on Soil Fertility and Fertilizer Evaluation for Rice
INTSOY = International Soybean Program
IPE = isopropyl ester
IPM = integrated pest management
IRAT = Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières
IRCTN = International Rice Cold Tolerance Nursery
IRTIP = International Rice Testing and Improvement Program
IRTP = International Rice Testing Program
IRYN-M = International Rice Yield Nursery-Medium

L
LER = leaf elongation rate
LF = leaffolder
LGB = lesser grain borer
LSD = least significant difference
LWP = leaf water potential

M
MC = moisture content
MR = moderately resistant
MS = moderately susceptible
MV = modern variety

N
NBl = neck blast
NBLS = narrow brown leaf spot
NPU = net protein utilization

O
OM = organic matter

P
PE = preemergence
PI = panicle initiation
PR = phosphate rock
PU = prilled urea
PW = panicle weight

R
R = resistant
RB = rice bug
RCW = rice caseworm
RGA = rapid generation advance
RGS = rice green semilooper
RH = relative humidity
R line = restorer line
R:S = root-shoot ratio
RSV = rice ragged stunt virus
RTBV = rice tungro bacilliform virus
RTSV = rice tungro spherical virus
RTV = rice tungro virus
RWL = rice white leafhopper
RWM = rice whorl maggot

S
S = susceptible
S&P = seepage and percolation
SB = stem borer
SCU = sulfur-coated urea
SES = Standard Evaluation System for Rice
ShB = sheath blight
SMT = soil moisture tension

SR = stem rot
SSB = striped stem borer
SSP = single superphosphate

T
TPR = transplanted rice

U
UPLB = University of the Philippines at Los Baños
USG = urea supergranules

W
WAI = weeks after inoculation
WAS = weeks after seeding, sowing
WBPH = whitebacked planthopper
WP = wettable powder
WS = wet season
WSR = wet-seeded rice
WT = weeks after transplanting
WUE = water utilization efficiency

Y
YD = yellow dwarf
YSB = yellow stem borer