RESEARCH HIGHLIGHTS FOR 1982

1983
INTERNATIONAL RICE RESEARCH INSTITUTE
LOS BAÑOS, LAGUNA, PHILIPPINES
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The International Rice Research Institute (IRRI) was established in 1962 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:

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ONE STEP AHEAD

Growth with production stability is a major aim of IRRI's research strategy for the 80s. We will accomplish this only through close alliance with rice scientists in national programs. Within the International Rice Testing Program, we work with approximately 800 researchers in more than 70 countries through a worldwide grid of cooperative experiments.

The experiences of farmers are also important to our efforts. When an old rice farmer in a production brigade in the Hanzhou Province of China was complimented for his excellent hybrid rice crop, he said that we must not diminish our attention to maintaining plant and soil health. He was emphasizing that a productive, stable agriculture needs ceaseless vigilance.

Much of IRRI's work illustrates the wisdom of vigilance in the never-ending battle to stay one step ahead of pests' ability to counter varietal resistance. One example is our work on breeding for resistance to brown planthopper (BPH), a serious insect pest of rice. During the last few years, the IRRI variety IR36 has become very popular with farmers in Southeast Asia because it matures early and has high yield potential, and insect and disease resistance. More than 10 million hectares of IR36 were grown in 1982.

However, reports have come from Mindanao in the southern Philippines and North Sumatra in Indonesia that IR36 is being damaged by BPH, indicating a new shift in the biotype population (Fig. 1). A biotype shift is to be expected when resistance of a

1. Differential reactions of rice varieties TN1, IR36, and IR56 to brown planthoppers collected from Mindanao, Philippines. IR56 showed no feeding damage 12 days after infestation.

2. In areas where the soil has an adequate amount of phosphorus, the water fern azolla has the potential to help reduce the need for purchased nitrogen fertilizer. Blue-green algae associated with the fern actually do the nitrogen fixing.

3. Disease and insect resistance and superior agronomic characteristics are the core of IRRI's Genetic Evaluation and Utilization (GEU) program. Plant breeders and problem area scientists work to incorporate into a desired plant type the genetic ability to withstand other production constraints, without sacrificing its desired agronomic characteristics. IRRI works closely with scientists in national programs to focus breeding strategies on rice varieties for less favored environments.

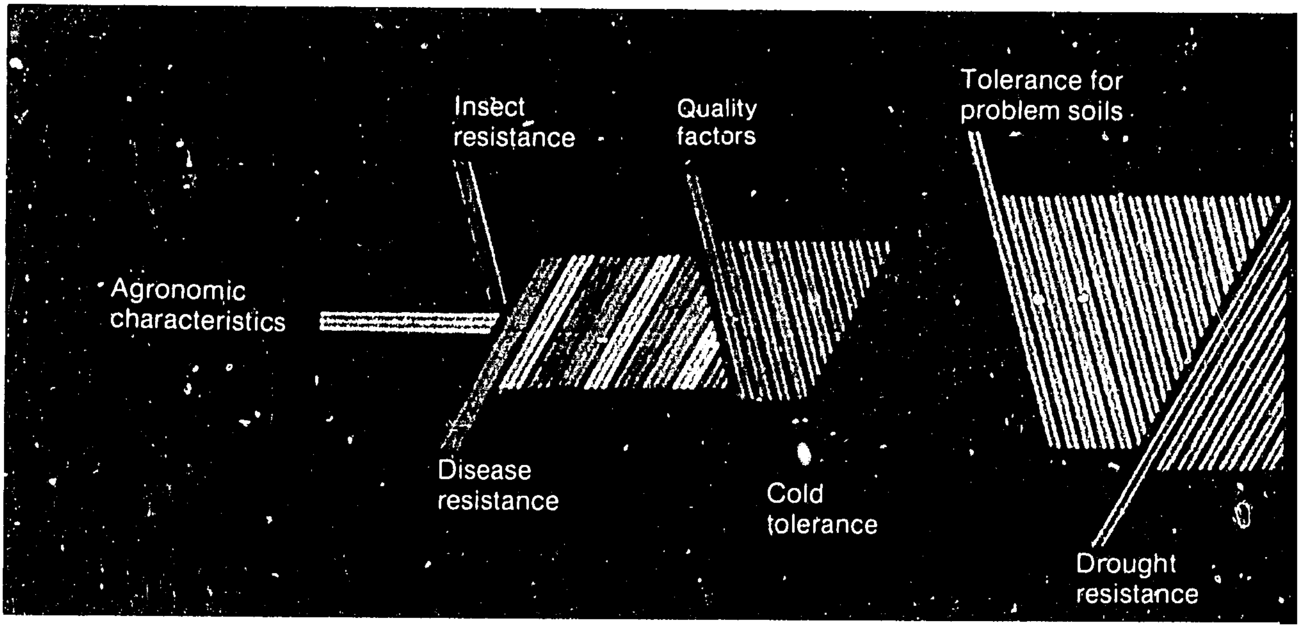
widely grown variety is specific to particular biotypes, and so our plant breeders had varieties ready that are resistant to this new biotype population. IR56, named by the Philippine Seed Board in 1982, is one such variety.

Several tons of IR56 seed were sent to areas in Mindanao where the new BPH biotype was attacking IR36. About 150 farmers each were given 1.5 kg of IR56 seed to multiply.

Indonesian scientists also found that IR56 is resistant to the new biotype occurring in North Sumatra. In response to an urgent call, we airlifted more than 20 tons of IR56 seed for distribution and multiplication to the stricken areas of North Sumatra.

BPH is not the only enemy of rice that we must stay one step ahead of. That was made poignantly clear when a new strain of grassy stunt virus tentatively called RGSV 2 appeared in 1982. BPH is the vector for that virus. We are now searching for genes that will provide RGSV 2 resistance.

To reduce occurrence of such shifts of insect biotypes and virus strains, varietal diversification must be encouraged. In October 1982, we jointly conducted a Technology Transfer Workshop with the Philippine Ministry of Agriculture to recommend varieties with general as well as specific adaptation to various rice environments. Steps were taken to intensify regional testing of varieties and for prerelease multiplication of the most promising strains on the plant breeders' assembly line.

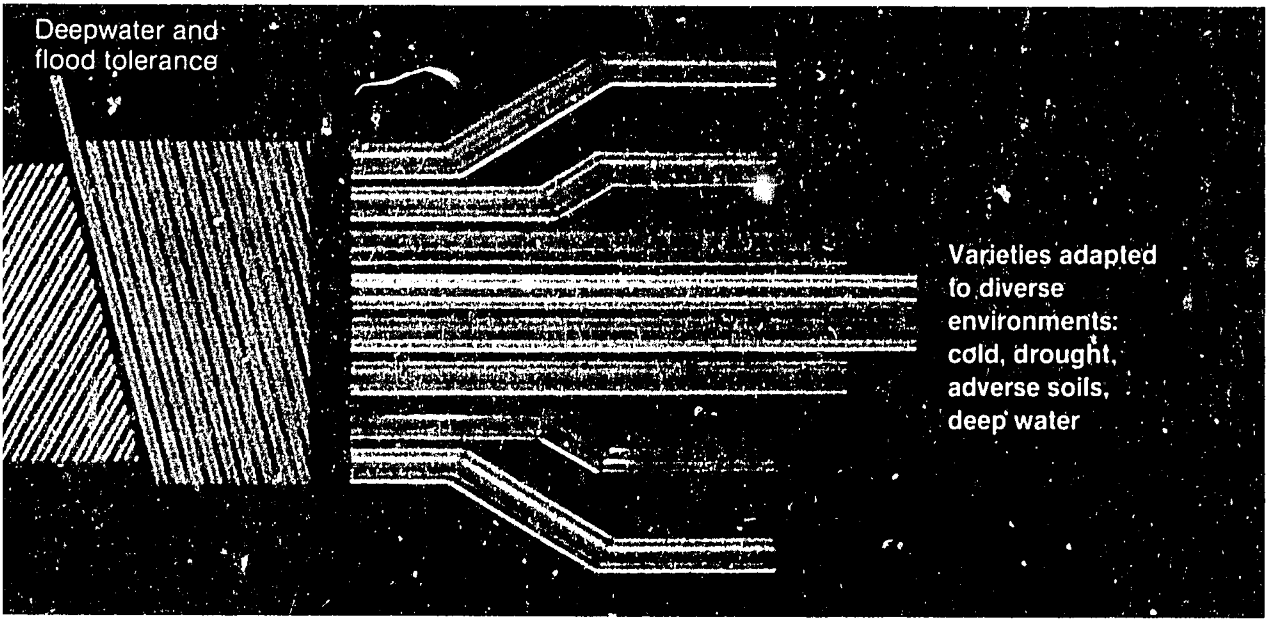


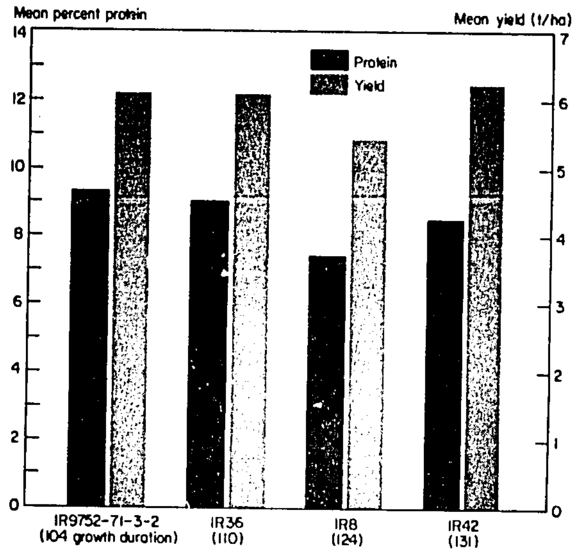
The Chinese farmer in Hanzhou Province wisely advised greater attention to soil health. IRRI is strengthening soil management work, particularly in the area of biological nitrogen fixation.

We know that nitrogen fixed by blue-green algae in conjunction with the water fern azolla can help reduce the need for purchased nitrogen fertilizer (Fig. 2). We have discovered, however, that azolla grows poorly in phosphate-deficient soils. Soils containing more than 25 μg available phosphorus per gram of soil could support good azolla growth without fertilizer. In 1982, trials to determine the extent that azolla can replace nitrogen fertilizer and improve soil fertility were conducted at 15 sites in 10 countries. In areas with sufficient phosphorus, we are working to help popularize azolla use by farmers and to determine optimum procedures for distribution, use, and maintenance of the beneficial water fern.

GEU program is 10 years old

The anticipatory research of our Genetic Evaluation and Utilization (GEU) program has enabled us to stay one step ahead on several fronts. The GEU program, IRRI's largest endeavor, is now in its 11th year. It has enabled us to develop multi-insect and disease resistant varieties. The inputs of our soil chemists, entomologists, plant pathologists, plant physiologists, agronomists, and plant breeders on the GEU team have also produced rices





4. IR36 has about a one percentage point higher protein content than IR varieties of longer growth duration. One promising line, IR9752-71-3-2, which has a yield similar to IR36, matures about 1 week earlier and has a protein content that is as high as, and at times higher than, that of IR36. Replicated trials, 1978-82 dry seasons.

with tolerance to adverse soils, salinity, drought, cold, and submergence (Fig. 3).

In a somewhat unexpected development, we have found that our new early-maturing varieties that combine multiple resistance to insects and diseases also have a high protein content. Since 1978, replicated yield trials have shown that we can maintain yield potential and the characteristic of higher protein content associated with short duration varieties such as IR36 (Fig. 4). Early-maturing varieties also help farmers produce two or more crops in irrigated areas.

Dryland rice research

In 1982 a detailed strategy for dryland rice research was developed during an international workshop at Bouaké, Ivory Coast. Before the workshop IRRI scientists joined other researchers from Latin America, Asia, and Africa in a monitoring tour to review dryland rice improvement efforts in Nigeria and Ivory Coast (Fig. 5).

In his World Food Day convocation address at IRRI on 16 October, President Ferdinand E. Marcos announced that the Philippine Government would make available 100 hectares of land at Bamban in Tarlac (Fig. 6) to help IRRI intensify dryland and rainfed rice research.

5. Rice scientists from Latin America, Africa, and Asia review dryland breeding material at the International Institute of Tropical Agriculture substation at Onne, Nigeria.

6. Plans are being made to utilize the new Rainfed Rice Research Station site at Bamban, Tarlac.

IRRI's third decade

The "Plan for IRRI's Third Decade" was completed during 1982. It is based on priorities suggested by the Board of Trustees and the Second Quinquennial Review team which reported on IRRI's progress to the Consultative Group for International Agricultural Research (CGIAR). The advice of the Technical Advisory Committee to CGIAR was very helpful in finalizing the research strategies. The Plan describes how IRRI will intensify and expand its collaboration with national programs in their rice improvement activities during the next 10 years.

The Articles of Incorporation and By-laws of IRRI were amended in October 1982 to make them compatible with IRRI's position as an international agricultural research center supported by CGIAR.

Awards

The first King Baudouin International Agricultural Research Award was presented to IRRI in November during the CGIAR meeting in Washington, D.C. (Fig. 7). The award recognized the continuing vitality and recent advances of IRRI's breeding programs as illustrated by the development of IR36.

The Third World Foundation for Social and Economic Studies announced that IRRI had been named the 1982 recipient of the Third World Prize for its outstanding contributions to the Third World. The citation reads, in part: "Over the last two decades when so much else faltered in the struggle against hunger and poverty, IRRI's quiet, persistent, highly professional and wholly dedicated work touched the lives of millions in the Third World, improving the human condition in truly practical and lasting ways. That such a contribution should have been the result of fruitful cooperation between scientists and food technology experts from developed and developing countries alike is in itself a cause of satisfaction and encouragement."

7. Dr. Guy Camus, chairman of the Technical Advisory Committee (TAC) of the CGIAR, presents Dr. M. S. Swaminathan, IRRI director general, with the 1982 King Baudouin International Agricultural Research Award.

GENETIC EVALUATION AND UTILIZATION

CONSERVING AND USING THE RICE GERMPLASM

Rice workers in many countries continue to send collected seeds to IRRI. During 1982, we received 3,481 diverse samples from Bangladesh, Bhutan, China, India, Kenya, Malaysia, Nepal, the Philippines, Sierra Leone, Sri Lanka, Thailand, and Vietnam.

To study the specific problems of drought stress at the meiotic stage, spikelets are dissected from developing panicles of rice plants that have been subjected to drought stress.

Although workers in national programs collected the bulk of the samples, teams from developed countries with the financial help of International Board for Plant Genetic Resources (IBPGR) of the Food and Agriculture Organization led several field expeditions. IBPGR funds channeled through IRRI were used to assist rice workers in Indonesia, Nepal, and Thailand in their field collection activities. Anthropologists and missionaries made additional collections. The cooperation of so many indicates the worldwide concern for the dwindling resources of rice germplasm.

Acquisitions pass 60,000 mark

The donations, along with 1,560 other acquisitions, have further enriched our base collection. In 1982 the number of registered cultivars in our germplasm bank passed 60,000. In addition, about 4,560 new samples are yet to be planted and registered. There were slightly more than 4,000 accessions of African rices and wild species.

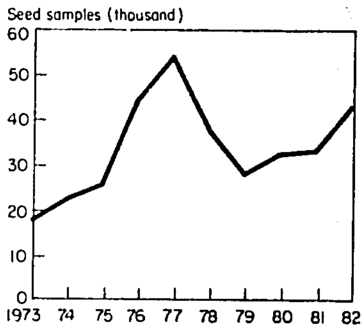
IRRI and IBPGR jointly plan to launch during 1983 a second 5-year plan to complete the germplasm collection, which is estimated to be half done.

Added insurance against germplasm loss

The National Institute of Agricultural Sciences (NIAS) of Japan, the U.S. Department of Agriculture, and IRRI continue to collaborate in the storage of duplicate seed stocks and consolidation of rice collections. While an IRRI accession is processed for canning, we set aside a duplicate amount of seed for the U.S. National Seed Storage Laboratory, Fort Collins, Colorado. NIAS and IRRI have been comparing their accession lists and exchanging seeds. We have provided NIAS with Japanese varieties coming from sources outside Japan, and NIAS is supplying us with varieties not yet in our bank. These multilocation preservation sites provide insurance against loss of the irreplaceable germplasm.

Expanding germplasm use

Rice researchers throughout the world continued to show avid interest in evaluating and using diverse rice germplasm. During 1982, we supplied 11,075 seed samples of *O. sativa* cultivars and 378 samples of other species in response to 174 foreign requests. IRRI researchers requested seeds on about 300 occasions and obtained 33,975 cultivars and 378 accessions of other species. The



1. Rice seed samples provided by the Genetic Resources Program to rice researchers at IRRI and elsewhere, 1973-82.

present volume of requests indicates a sustained demand for new genetic materials since the trend showed a sharp rise in 1976 (Fig. 1).

AGRONOMIC CHARACTERISTICS

Productivity of early-maturing rices

To increase rice productivity in rice-based cropping systems, we tested several rices which mature earlier than IR8, IR42, and even IR36. Early-maturing IR9729-67-3 matured between 87 and 89 days after transplanting and produced up to 7.0 t/ha in the dry season. Its productivity was 81 kg/ha per day, 18 kg/ha per day higher than IR36.

For the first time, we tested IR25588-32-2 during the dry season. This line is similar to IR36 in maturity but has yielded significantly higher, producing 12 kg/ha per day more rice. IR25588-32-2 appears to have higher lodging resistance than IR36 and other early-maturing rices tested during the 1982 crop seasons.

GRAIN QUALITY

An important key to the utilization of the modern rice varieties is their eating quality. The screening of IRRI lines for quality is continuing.

With the help of rice workers in national programs, anthropologists, missionaries, and the International Board for Plant Genetic Resources (IBPGR), registered cultivars in the IRRI germplasm bank passed 60,000 in 1982.

Nature of rice aroma

Aromatic rices have a price premium in tropical Asia. The chemical nature of the aroma principles still needs clarification. In late 1981, we began a cooperative study with the USDA Western Regional Research Center to characterize aroma principles and develop an objective gas chromatographic screening method applicable to the IRRI rice breeding program.

USDA scientists identified the characteristic odor in steam volatile oils of cooked aromatic rice as 2-acetyl-1-pyrroline. This aromatic compound ranged from 0.04 to 0.09 ppm cooked rice basis in eight aromatic milled rices, but was much lower in two nonaromatic check rices (Table 1). Judges ranked the rices in terms of the characteristic aroma in order of the compound concentration. We hope this compound concentration procedure will lead to a new screening method which will be rapid, reproducible, and more reliable than using a taste panel.

Gel consistency as an eating quality factor

Gel consistency is a screening method that we developed in 1973 to differentiate among high-amylose rices by the hardening rates of cooked rice as it cooled.

During the 1982 dry season, we found gel consistency to be a sensitive index of cooked rice texture and Amylograph consis-

Table 1. Concentration of 2-acetyl-1-pyrroline in cooked rice of eight aromatic and two nonaromatic varieties and ranking of cooked milled rice samples based on decreasing aroma, USDA Western Regional Research Center and IRRI, 1982.

Variety or line	Concentration of 2-acetyl-1-pyrroline (ppm dry basis)		Ranking by judges of cooked milled rice for characteristic aroma[a]
	Milled rice	Brown rice	
Malagkit Sungsong	0.09	0.2	1
Milagrosa	0.07		2
Khao Dawk Mali 105	0.07	0.2	3
IR841-76-1	0.07	0.2	4
Basmati 370	0.06	0.17	5
Seratus Malam	0.06		6
Azucena	0.04	0.16	7
Hieri	0.04	0.1	8
Labelle (check)	0.008		10
Calrose (check)	0.006		9

[a]Groups of two or three cooked rice samples were presented to 21-23 judges. Common samples were used so that comparisons could be overlapped and the whole set could be ranked.

tency of 12% milled rice pastes among 21 elite lines with 21-23% amylose. In screening for eating quality for this group of rices, gel consistency was as important as amylose content and alkali spreading value.

DISEASE RESISTANCE

The wide adoption of IRRI varieties has narrowed the genetic diversity of the world's cultivated rice. So it is important to ensure that rice varieties made available to farmers still contain a broad spectrum of genes for disease resistance.

In 1982 177,780 entries were tested for their reaction to 8 fungal, 1 bacterial, and 3 viral diseases. We identified a new strain of a major rice disease and a number of rice genes conveying resistance to disease races.

A new grassy stunt strain

We designated a new grassy stunt strain in the Philippines as rice grassy stunt virus 2 (RGSV 2); the ordinary type strain is RGSV 1. RGSV 2-infected plants show stunting and yellowing of leaves. Plants infected at the seedling stage show profuse tillering similar to that in RGSV 1, but plants infected at later stages develop symptoms indistinguishable from those of rice tungro virus (Fig. 2).

2. Rice plants infected with RGSV 2 show tungro-like symptoms.

Like RGSV 1, RGSV 2 is transmitted by the brown planthopper in a persistent manner. Serological tests using an antiserum to RGSV in Japan showed that RGSV 2 is closely related to RGSV 1.

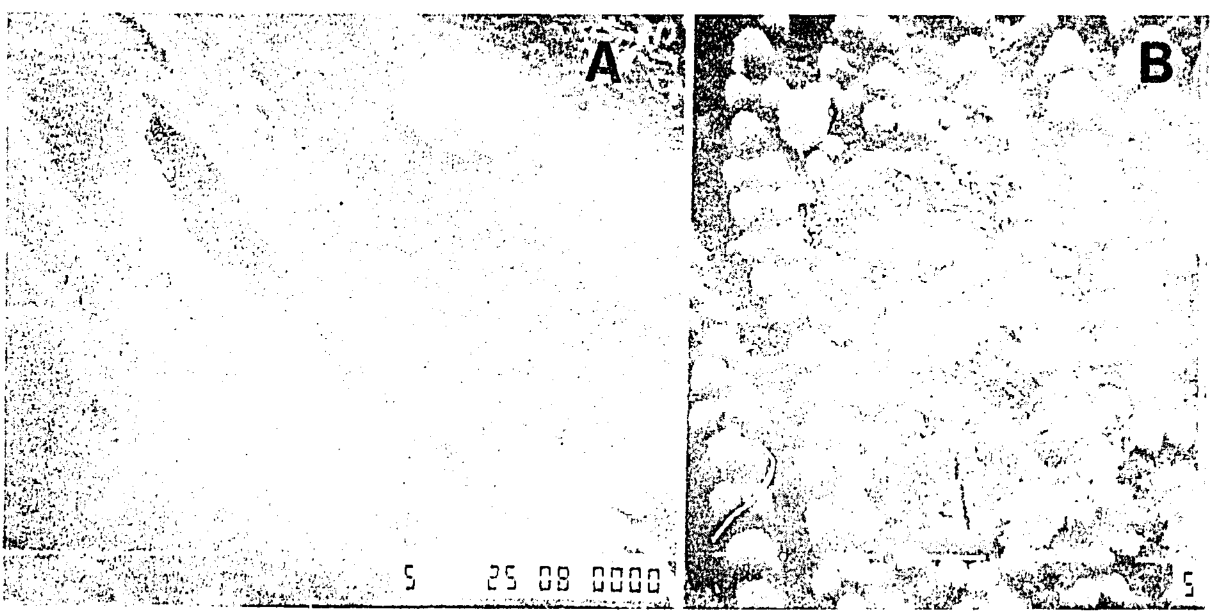
Aside from causing tungro-like symptoms in the field, RGSV 2 differs from RGSV 1 in pathogenicity to rice varieties. *Oryza nivara* is highly resistant to RGSV 1 but susceptible to RGSV 2. Consequently, IR varieties with *O. nivara* genes for resistance to RGSV 1 tested in the greenhouse were all susceptible to RGSV 2. We are searching for sources of RGSV resistance.

Disease resistance evaluation

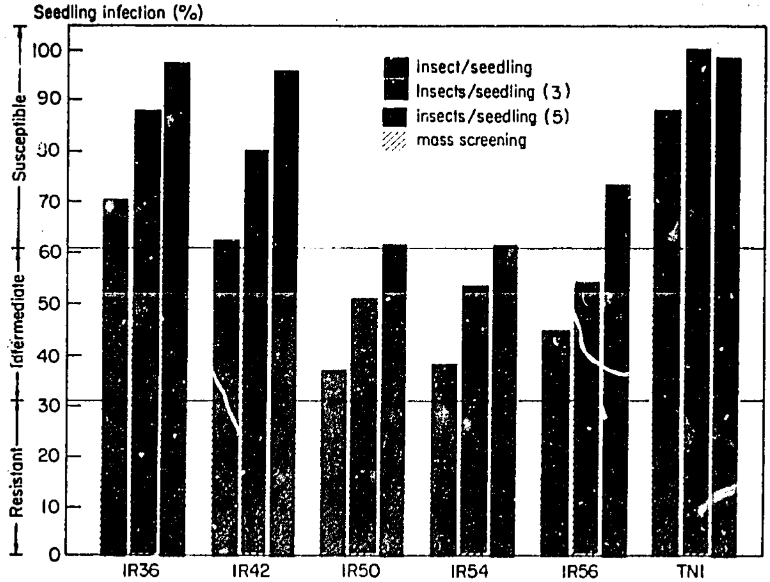
Bacterial blight. Cells of avirulent strain PXO 86 of the bacterial pathogen did not increase in number on water pores of the leaf surface of Cas 209. However, the virulent strain PXO 61 increased the bacterial cell number within 24 h of spray inoculation of a bacterial suspension on the rice plants. We demonstrated with scanning electron microscopy examination that the bacteria invaded the rice plants via water pores of the hydathode but not the stomata (Fig. 3).

Tungro virus complex in resistant IR varieties. Rice tungro disease is associated with rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV). We determined whether or not the two viruses were present on IR36, IR42, IR50, IR54, and IR56, bred as tungro-resistant varieties. The latex agglutination test used antisera and the virus recovery test used vector insects.

3. Bacterial cells of *Xanthomonas campestris* pv. *oryzae* on the water pores of Cas 209 which is resistant to PXO 86 (A) and susceptible to PXO 61 (B).



4. Seedling infection of some tungro-resistant IR varieties inoculated with different numbers of tungro-viruliferous *N. virescens* per seedling, following the mass screening and test-tube methods of inoculation.



We detected only RTBV in IR50 and IR54 tungro-infected plants tested and either RTBV alone or both RTBV and RTSV in IR42 and IR56 infected plants. IR36, IR42, and IR56 showed a fairly higher percentage of tungro infection than IR50 and IR54 when inoculated by the mass-screening and test-tube methods (Fig. 4). We detected RTBV and RTSV in all TN1 (susceptible check) infected plants. No virus recovery was recorded from plants used as a virus source with RTBV alone. We detected tungro symptoms from plants with both viruses.

This is the first time we found the presence of RTBV alone in infected plants of tungro-resistant varieties. Even infected plants will not serve as a virus source for the spread of the disease.

Effect of varietal mixture on blast

We demonstrated that planting mixed varieties or lines differing in resistance reduced blast disease. The number of susceptible lesions per hill decreased when seeds of IR54, IR1905, and IR442 were mixed before sowing. The blast control effect was better than planting the three rices alternately, or individually. Isogenic lines are desirable in some instances for mixed variety plantings to minimize the rice quality problem.

IR533-PP854-1, Suweon 287, and Iri 353, which have different genes for blast resistance, showed different varietal responses to the blast pathogen. Iri 353 showed stable resistance to blast at two sites during the evaluation period.

Rajeswary Srilingam, scholar from Sri Lanka, prepares to cross blast-resistant and blast-susceptible parents in continuing studies on inheritance of blast resistance.

Blast nursery improvement
We had used a single variety to provide inoculum for blast screening; however, the races were sometimes not adequate to evaluate test materials. In 1982, we found that using mixed-variety inoculum donor plants gave better screening results.

Genetics and inheritance of resistance
Blast. We identified eight genes from Tetep, Carreon, Ta-poo-cho-z, Pankhari 203, and Dawn against three blast races: IA-61, IB-47, and IH-1. The moderate resistance in Dourado Precoce and OS6 to race IH-1 was conveyed by one major gene and some modifiers. There was no linkage relationship between blast resistance to race IB-47 or IH-1 and waxiness chromogen, dripping wet, liguleIessness, brittle culm, glabrousness, long hairiness, and polycaryosis.

Based on the information, we propose using F_1 hybrids and composite varieties as additional strategies for blast resistance breeding.

Bacterial blight. We studied the resistance of breeding line IR1545-339 to representative strains of *Xanthomonas campestris* pv. *oryzae*. We found the recessive gene *xa* 5 conveys the high resistance of that line to races I, II, and III. Its moderate susceptibility response to a strain of race IV characterized by slow lesion development also appeared to be governed by the same gene.

Trisomic analysis revealed that this gene is located on chromosome 2 of Nishimura's designation.

We found a new dominant gene, designated *Xa 10*, that conveys the resistance of Cas 209 to race 2.

INSECT RESISTANCE

Problems associated with the rapid development of new insect biotypes continue unabated. A new biotype of the brown planthopper is attacking IR36 in areas of the southern Philippines and North Sumatra in Indonesia. Realizing the possibility of a shift in the biotype after the widespread planting of IR36, we were ready in 1982 with IR56, a new resistant variety. We have shipped IR56 to locations where the new biotype is ravaging IR36.

In 1982, we began studying rice variety resistance to storage pests. For the first time, we found a brown planthopper population that can survive on a nonrice plant. We have continued to improve our facilities for basic studies of insect pests.

Resistance of IR36 to storage pests

In addition to decreasing grain yields in the field, insects often cause severe grain losses by feeding on stored rice. For the first time, we conducted studies on the resistance of rice varieties to storage pests. Test insects included the important rice grain pests: the maize weevil *Sitophilus zeamais*, lesser grain borer *Rhyzopertha dominica*, and the Angoumois grain moth *Sitotroga cerealella*.

IRRI assistant scientist Rodolfo Aquino (left) and plant breeder G. S. Khush inspect a field of IR56, which is resistant to all known biotypes of the brown planthopper in Southeast Asia, including those that in 1982 attacked IR36 in Mindanao, Philippines, and in North Sumatra, Indonesia.

Varieties with different amylose and gel temperature types were compared for their resistance to the Angoumois grain moth. Based on insect reproduction (moth emergence) and lost weight due to insect feeding, IR24 and IR36 were the most resistant varieties tested. IR36 also has multiple resistance to insects and diseases in the field. There was no apparent relationship between amylose type or gel temperature and level of resistance.

Leersia hexandra as brown planthopper host

The brown planthopper (BPH) had not been shown to complete development and multiply on a host other than cultivated and wild rices. Recently, we observed high BPH populations on the weed *Leersia hexandra* in irrigation canals at two sites on the IRRI farm. BPHs were collected from the *L. hexandra* plants and greenhouse studies conducted to determine the suitability of *L. hexandra* and rice as a host. We compared the biology of the *Leersia* BPH population with greenhouse cultures maintained on rice.

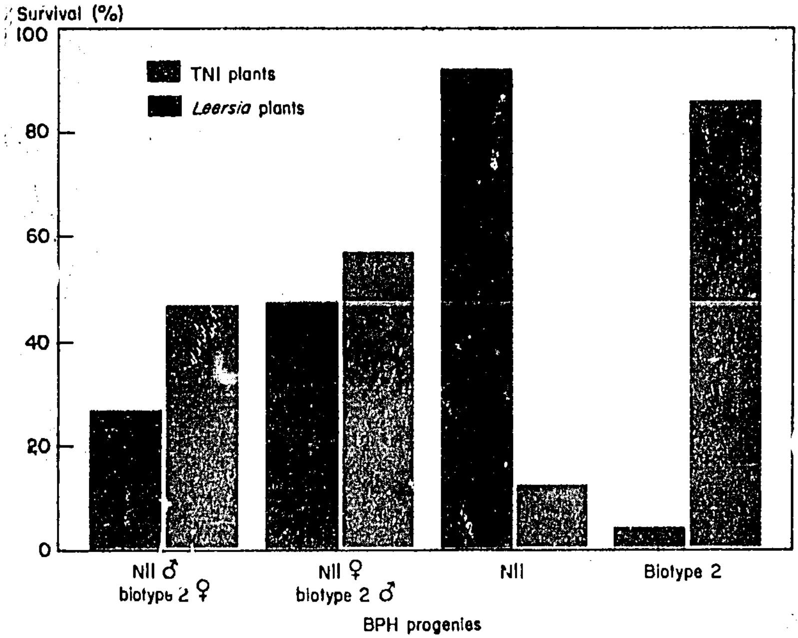
The incubation period of the BPH on *Leersia* plants was 7.8 days; egg hatchability, 81.2%; longevity, 30.0 days; and fecundity, 513 eggs/female. These data compare with those of BPH biotype 1 on susceptible TN1 rice plants. However, when placed on TN1, which is susceptible to the three BPH biotypes at IRRI, and on several resistant varieties, the *Leersia* BPH fed very little and did not survive.

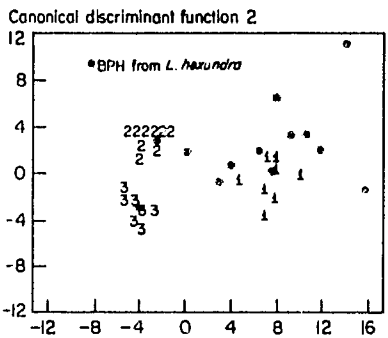
The inability of the *Leersia* BPH to feed on rice plants indicates that this population could not serve as a source of infestation in ricefields. However, it could contribute to the rice-feeding BPH gene pool through interbreeding. We conducted an experiment to determine whether interbreeding between the two populations occurs and to determine the survival of the progeny on *Leersia* and TN1.

Fifth-instar nymphs of *Leersia* BPH were individually placed in test tubes containing *Leersia* cuttings and greenhouse cultures of BPH biotype 2 were individually placed in test tubes containing TN1 seedlings. Crosses between the *Leersia* BPH and rice BPH were made by placing insects in cages containing a closely planted mixture of *Leersia* and TN1 plants. When eggs resulting from the crosses hatched, a survival test was conducted by caging 10 newly emerged nymphs on separate potted *Leersia* or TN1 plants.

Survival of the F_1 progeny of all of the crosses was high on both *Leersia* and TN1 (Fig. 5) although still lower than that of the *Leersia* BPH on *Leersia* plants and rice BPH biotype 2 on TN1.

5. Survival of progenies resulting from various crosses between the *Leersia*-infesting BPH (NII) and BPH biotype 2.





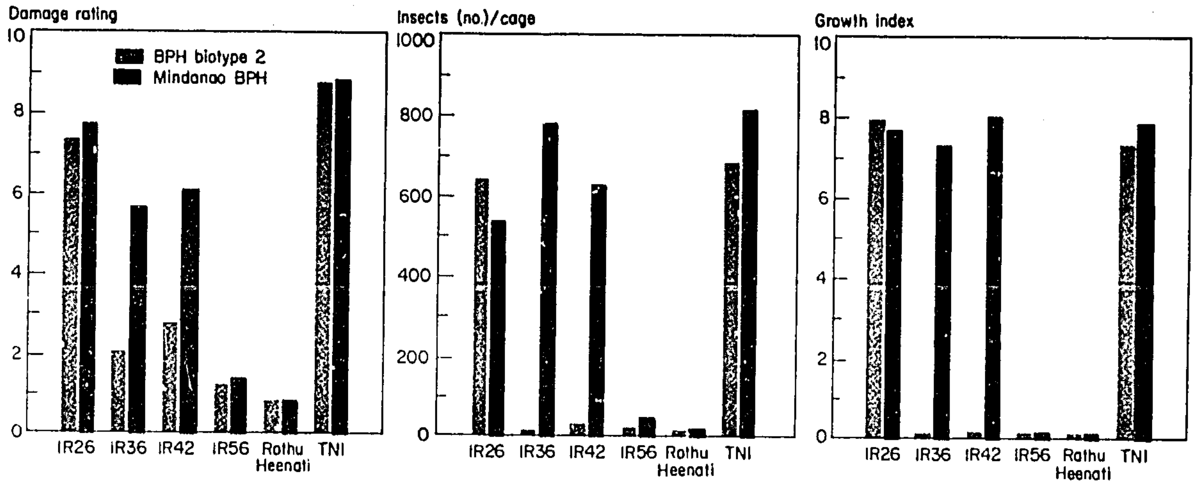
6. Discriminant scores based on rostral, leg, and antennal characters of macropterous females of biotypes of *N. lugens* infesting a grass and rice hosts in the Philippines. The numbers indicate type designation; the orange dot indicates a group centroid.

This indicates that if intermating also occurs in the field, the *Leersia* BPH can contribute to infestations on rice and introduce genetic variability to the BPH population, possibly slowing the biotype selection process on resistant varieties.

Morphological variations. The biological characteristics of *Leersia* BPH clearly differentiate it from the rice-infesting populations of BPH biotypes 1, 2, and 3. The scatter plot diagram based on computed discriminant scores of the rostral, leg, and antennal characters of macropterous females of the *Leersia* population and of macropterous females of biotypes 1, 2, and 3 showed distinct segregation (Fig. 6). However, the diffused cluster character of the *Leersia* population indicated it to be a less homogenous population than either biotype 1, 2, or 3. The *Leersia* BPH population is distinct from the rice-infesting biotypes and represents a primitive, nonvirulent *N. lugens* biotype.

A brown planthopper biotype feeding on IR36

After IR26 with the *Bph 1* gene for BPH resistance was grown for about 2 years in Indonesia, Philippines, and Vietnam, it became susceptible because of a shift in the planthopper population to biotype 2 which could feed on and destroy it. IR36 with the *bph 2* gene conferring resistance to biotype 2 was then planted and has been planted on more than 10 million ha. In some areas, it has been planted for 6 years.



7. Plant damage, insect population, and growth index of Mindanao BPH and BPH biotype 2 on selected varieties. IR26 has the *Bph 1* gene, IR36 and IR42 the *bph 2* gene, and IR56 and Rathu Heenati the *Bph 3* gene for brown planthopper resistance. TN1 has no gene and is susceptible.

In 1982, reports from Mindanao in the southern Philippines indicated that IR36 was being damaged by the BPH. Hoppers collected from IR36 in Mindanao were compared with biotype 2 hoppers cultured in the greenhouse. As expected, biotype 2 was able to damage IR26, but not IR36 and IR42 having the *bph 2* gene or IR56 and Rathu Heenati with *Bph 3* gene for resistance (Fig. 7). The Mindanao biotype, however, was able to feed and multiply on IR26, IR36, and IR42, indicating that the population is probably a new biotype.

Because we expected a shift in the biotype after the planting of IR36, we had identified varieties with new genes for resistance and these have been used for several years as donors in the breeding of resistant varieties. IR56 is one such variety and several tons of seed have been shipped to areas where the new biotype is destroying IR36.

Integration of varietal resistance and biological control

Resistant varieties are effective in decreasing BPH populations. Because the resistant varieties do not require insecticide applications, predators survive and can decrease BPH populations to even lower levels than the action of varietal resistance alone. Field studies at IRRI in 1982 showed that despite low BPH populations on a resistant variety, populations of the predators *Lycosa pseudoannulata*, *Cyrtorhinus lividipennis*, and *Microvelia atrolineata* are relatively high resulting in a low BPH-predator ratio (Table 2). This favors biological control effectiveness. The susceptible variety, on the other hand, had high BPH-predator ratios.

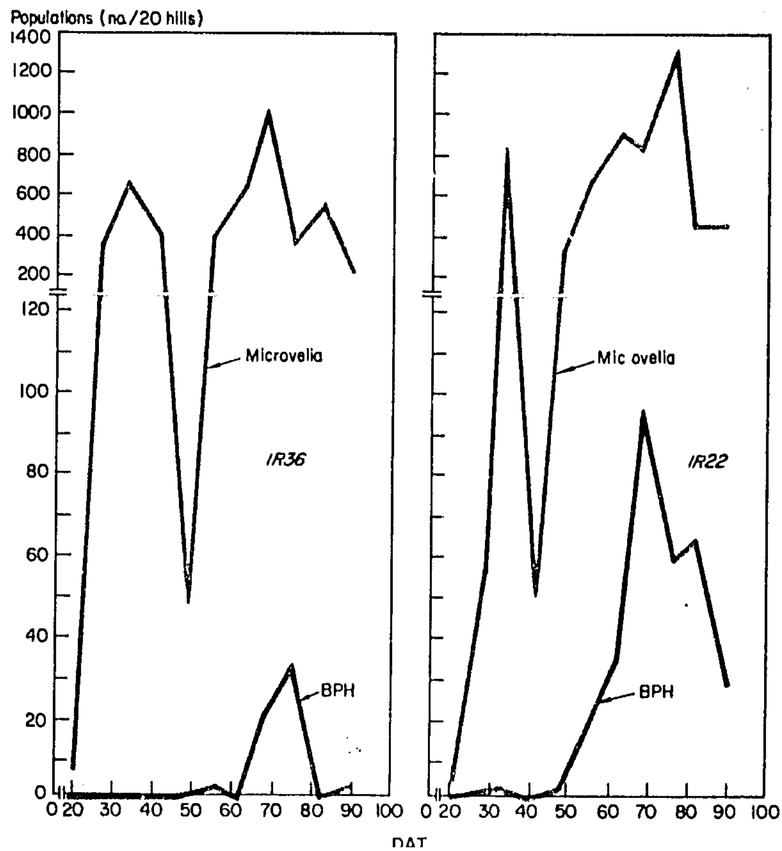
Table 2. BPH-predator ratios in field plots having different levels of BPH resistance.[a] IRRI, 1982.

Variety[b]	BPH: *L. pseudoannulata*	BPH: *C. lividipennis*	BPH: *M. atrolineata*
IR36 (R)	46 bc	41 bc	7 c
Triveni (MR)	125 ab	92 ab	27 abc
IR8 (S)	207 a	120 a	42 a

[a]In a column means followed by a common letter are not significantly different at the 5% level. [b]R = resistant to BPH, MR = moderately resistant, S = susceptible.

In another study on farmers' fields, BPH and predator populations were compared on IR36, a variety having multiple resistance to BPH and other insects and diseases, and IR22, a susceptible variety. BPH populations were lowest on the resistant variety but populations of the predator *M. atrolineata* were equal on both IR36 and IR22 (Fig. 8). This resulted in a more favorable prey-predator ratio on resistant IR36. The combination of the

8. Population of the brown planthopper (BPH) and its predator, *Microvelia atrolineata*, on BPH-resistant (IR36) and BPH-susceptible (IR22) varieties.



resistant variety and the predator works to provide effective control when predator-destroying insecticides are not needed for BPH control.

Tolerance as a mechanism of brown planthopper resistance

Because tolerance exerts no selection pressure, it is being considered as a means of avoiding biotype selection. We have developed methods to screen for tolerant varieties. Tolerant variety Utri Rajapan, supports an insect population but plant damage is low. There is less rice ragged stunt and tungro virus infection and a low recovery of ragged stunt and tungro where insects feed on Utri Rajapan plants. This indicates that disease spread in the field would be limited on Utri Rajapan despite the presence of the BPH and green leafhopper.

Insect rearing facilities

We constantly need rice insects as test subjects for insecticide evaluation, identification of insect-resistant varieties, and other research activities. Leafhoppers and planthoppers can easily be reared on rice plants, but the plant rearing of stem borers and other lepidopterous larvae requires a great deal of space and is not efficient. We developed a rearing facility which provides an artificial diet for lepidopterous larvae. With the assistance of a USDA scientist, we are currently rearing the striped, dark-headed, and pink stem borers; true armyworm; and the ear-cutting caterpillar (Fig. 9) on a modified southwestern corn

9. Ear-cutting caterpillar feeding on an artificial diet.

10. A field worker dispenses first-instar yellow stem borer larvae at the base of rice plants with the Davis inoculator. Artificial inoculation is needed in screening for stem borer resistance as natural field populations are often too low.

borer diet. With this facility, large numbers of insects of uniform size and age can be produced.

Larval inoculation

Field screening to identify rice varieties resistant to the yellow stem borer is often hampered by inadequate borer populations. To supplement natural field populations, newly hatched larvae can be placed on plants with the aid of a camel's hair brush. However, this technique is extremely laborious and time consuming.

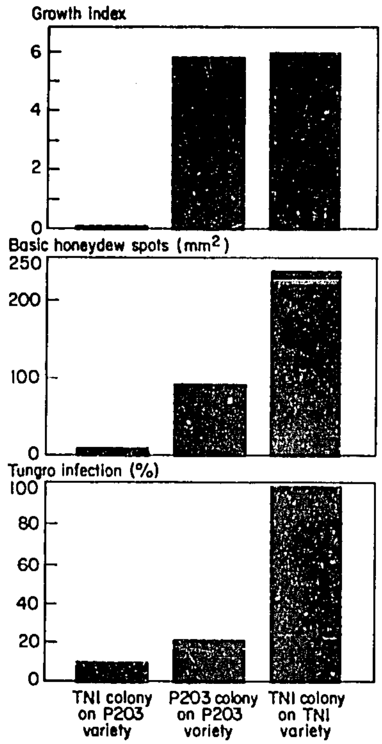
In a search for a more rapid method, we tested the Davis inoculator which is used to dispense larvae in the whorl of maize for resistance studies. We mixed newly hatched stem borer larvae with finely ground rice hulls (about 1 mm) and dispensed them at the plant bases through a plastic tube (Fig. 10). The larvae readily crawled up the plant and bored into the stems.

This technique is also useful in the screenhouse evaluation of varieties and is 10 times faster than the camel's hair brush technique. In a screenhouse study, deadhearts on susceptible variety Rexoro were 71% using the inoculator and 75% using the camel's hair brush. The inoculator will allow more rapid evaluation of the germplasm collection as we search for varieties with resistance to the yellow stem borer.

Green leafhopper biotypes and tungro virus transmission

We selected green leafhopper biotypes in the greenhouse from a population which had been reared on susceptible variety TN1 for several years. The biotypes were caged on resistant varieties where they were forced to feed or die. Survivors were selected and their progeny again placed on resistant plants. This process was continued for 19 generations after which their growth and development were compared on the resistant variety and on TN1. The biotype selected on Pankhari 203, which has the *Glh 3* gene for resistance, is called the Pankhari 203 colony.

Growth of the Pankhari 203 colony on Pankhari 203 was equal to that of the TN1 colony on susceptible TN1 (Fig. 11). Ability to infect plants with virus increased slightly. This was apparently due to a low level adaptation to feeding in the phloem as indicated by the small area of basic honeydew spots produced. The results indicate that, after 19 generations of selection on a resistant variety, insect growth is equal to that on a susceptible variety. However, the amount of phloem feeding (rather than xylem) and subsequent tungro virus infection lagged behind insect growth. Continuing studies should indicate whether phloem feeding and subsequent virus infection will continue to increase, after further selection on Pankhari 203.

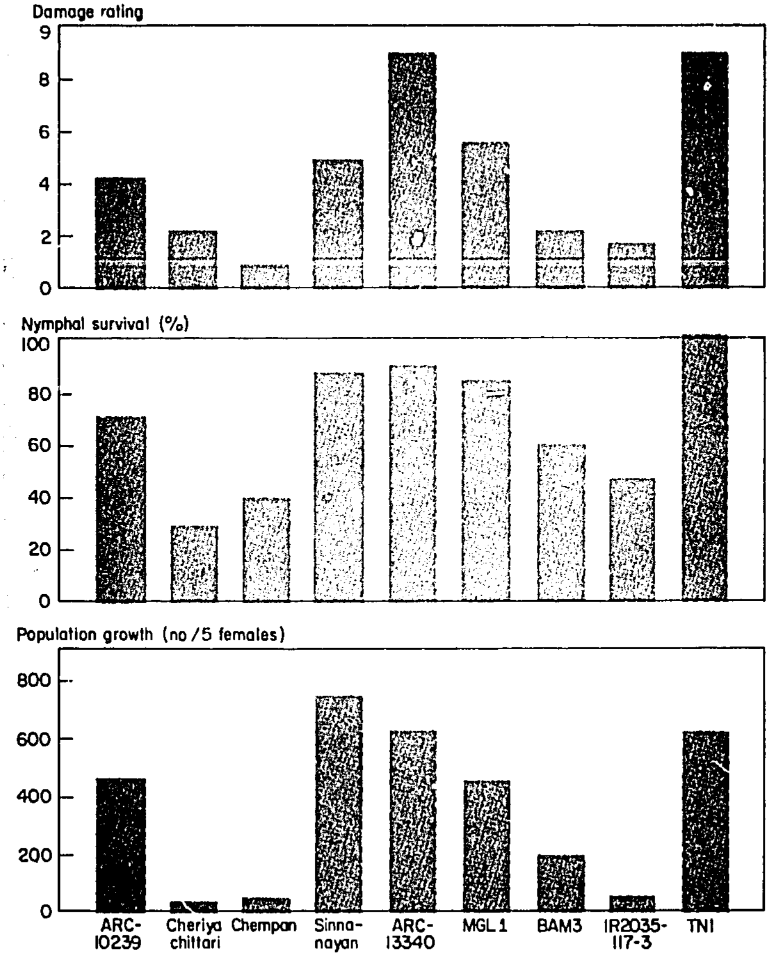


11. Growth index, honeydew excretion, and tungro infection of GLH colonies on P203 and TN1 varieties. Basic honeydew indicates phloem feeding.

Minor genes for whitebacked planthopper resistance

Plant breeders have identified four major genes for resistance to the whitebacked planthopper (WBPH), a pest of increasing importance in Asia. We compared varieties having the *Wbph 2* gene to determine whether all had the same level of WBPH resistance. The various tests indicated distinct differences among varieties based on plant damage ratings in the seedbox screening of seedlings and in the ability of nymphs to survive and reproduce on the varieties (Fig. 12). Results indicate that, in addition to major genes, these varieties have minor genes which play an important role in determining the level of WBPH resistance. We expect that these minor genes will slow the rate of biotype selec-

12. Damage rating, nymphal survival, and population growth of the whitebacked planthopper on varieties with *Wbph 2* for resistance. Damage rating was taken at 9 days after infestation (DI), nymphal survival at 15 DI, and population growth at 30 DI. Damage rating is by the 1980 Standard Evaluation System for Rice.



tion when WBPH-resistant varieties are grown over large areas for several years.

Inheritance of resistance to whitebacked planthopper

We studied inheritance and allelism of genes for resistance to WBPH in 21 resistant rice varieties. One-leaf-stage seedlings were artificially infested in the greenhouse with second- and third-instar WBPH nymphs. Reactions of the seedlings were recorded 7 to 10 days after infestation when the susceptible check TN1 was killed.

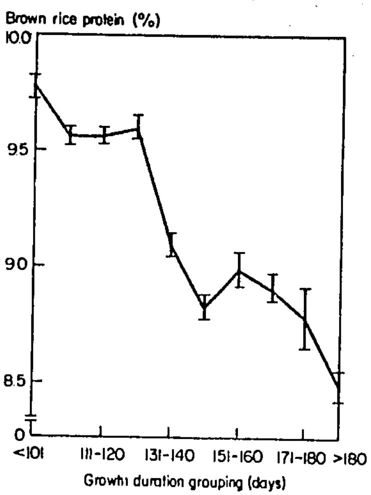
Study of the mode of inheritance from the F_1, F_2, and F_3 populations of test variety crosses with TN1 revealed that single dominant genes confer resistance in S2204, RDS19, Toga 378, JKW141, Gokhue Saier, Dharia, Faram Bajari, Karmuli, Kashi Prasad, Munji 389, Lal Dhan 304 (A), Safed, 357, Lal Dhan 304 (B), Ratua 394, and Nakhi. Two independent dominant genes governed resistance in Early Sutarsar 39, C.I. 6008-1, Son 14, C.I. 6010-1, and JKW S18.

We crossed test varieties with IR13475-7-3-2 and IR30659-2-165, rice lines homozygous for *Wbph 1* and *Wbph 2*, respectively, to determine allelic relationships. Genetic analysis of F_1, F_2, and F_3 populations from these crosses revealed that single dominant genes in RDS19, Toga 378, JKW141, Gokhue Saier, Dharia, Faram Bajari, Karmuli, Kashi Prasad, Munji 389, Lal Dhan 304 (A), Safed, 357, Lal Dhan 304 (B), Ratua 394, and Nakhi are allelic to *Wbph 1*, but the dominant gene of S2204 is independent of and nonallelic to both *Wbph 1* and *Wbph 2*. However, resistance in Early Sutarsar 39, Son 14, C.I. 6010-1, and JKW S18 is governed by *Wbph 1* and another independent dominant gene.

Chemical bases of striped stem borer resistance

The oviposition deterrent, designated compound A, was found to be in low concentration in volatile oils of some rice plants such as IR1820-52-4-1 that are still resistant to the stem borer. Compound A is absent in wild rice samples. The results confirm the presence of insecticidal principles other than compound A in these resistant rice samples.

NUTRITIONAL VALUE



13. Relationship between brown rice protein content and growth duration of 13,224 varieties from the IRRI germplasm bank.

Protein content of early-maturing rices

Rice scientists at IRRI and elsewhere have observed that as growth duration decreases, protein content increases among traditional rice varieties (Fig. 13). This favorable relationship was initially considered to be due to the low yield of early-maturing rices and was not expected to persist in high yielding rices with short growth duration.

However in the replicated yield trials of the IRRI breeding program to produce early-maturing rices with high grain yields the negative relationship between grain yield and protein content has fallen dramatically since 1979, and that between protein content and growth duration has remained strong (Table 3).

IR36, a high yielding variety with short growth duration, has about a one percentage point higher protein content than IR varieties of longer growth duration, such as IR8 and IR42 (Table 4). A more recent promising line, IR9752-71-3-2, which has a yield similar to that of IR36, but matures about 1 week earlier, has

Table 3. Weighted simple linear correlation coefficient between protein content and grain yield, and protein content and growth duration, of advanced breeding lines tested in replicated yield trials. 1979-82 dry seasons.

Year	Lines tested (no.)	Correlation coefficient[a] (*r*) between protein content and	
		Grain yield	Growth duration
1979	598	−0.95	−0.54
1980	598	−0.83	−0.96
1982	375	−0.31	−0.96

[a]All coefficients are significant at 1% level.

Table 4. Grain yield and brown rice protein content of four rices varying in growth duration, from replicated yield trials, 1978-82 dry seasons.

Variety or line	Growth duration (days)	1978	1979	1980	1982	Mean
		Brown rice protein (%)				
IR42	131	8.2	8.3	8.8	7.8	8.3
IR8	124	7.1	7.3	7.7	7.7	7.4
IR36	110	8.6	8.5	10.2	8.8	9.0
IR9752-71-3-2	104	8.8	8.6	10.2	9.2	9.2
		Grain yield (t/ha)				
IR42	131	6.5	6.6	6.4	6.7	6.5
IR8	124	3.4	7.2	3.4	5.4	4.9
IR36	110	6.0	6.9	5.5	6.3	6.2
IR9752-71-3-2	104	5.8	6.9	5.7	6.3	6.2

a protein content that is as high as, and at times higher than, that of IR36. In these yield trials, IR36 and IR9752-71-3-2 approached IR42 in grain yield.

Soil fertility trials with elite breeding lines showed that the early-maturing lines retained high protein content without losing yield advantage over longer duration varieties (Table 5). IR9729-67-3 had higher yield than IR42 although it matured 23 days earlier. Development of high yielding early-maturing rice varieties appears to be an effective means of improving the protein content of rice.

Energy and protein utilization of milling fractions

We repeated the cooperative nitrogen (N) balance study in preschool children involving brown and milled rice with milk instead of casein (2:1 N contribution) at 100 kcal/kg body weight. Powdered cow's milk is more commonly used than casein in weaning foods. Brown rice was again not significantly inferior to milled

Table 5. Effect of rate and method of nitrogen application on mean field duration, productivity, and brown rice protein content of three varieties and two early-maturing IR rices. The rices were arranged in the order of decreasing field duration. IRRI, 1980-82 dry seasons.

Variety	Mean field duration (days)	No nitrogen		87 or 108[a]	
		Grain yield (t/ha)	Brown rice protein (%)	Grain yield (t/ha)	Brown rice protein (%)
IR8	105	2.8	8.8	4.4	9.2
IR42	107	4.4	8.7	6.2	9.8
IR36	88	3.6	8.1	5.7	9.9
IR9729-67-3	84	4.7	8.2	7.1	9.5
IR9752-71-3-2	82	3.4	8.4	6.3	10.1

[a]Deep placed as urea supergranule. Nitrogen rate was 108 kg N/ha in 1980 and 87 kg N/ha in 1981 and 1982.

rice in apparent N absorption and retention by the children. Energy utilization was slightly inferior for brown rice-casein diet than for milled rice-casein at 250 mg N/kg body weight. Thus, the nutritional advantage of brown rice over milled rice remains its higher vitamin B complex level.

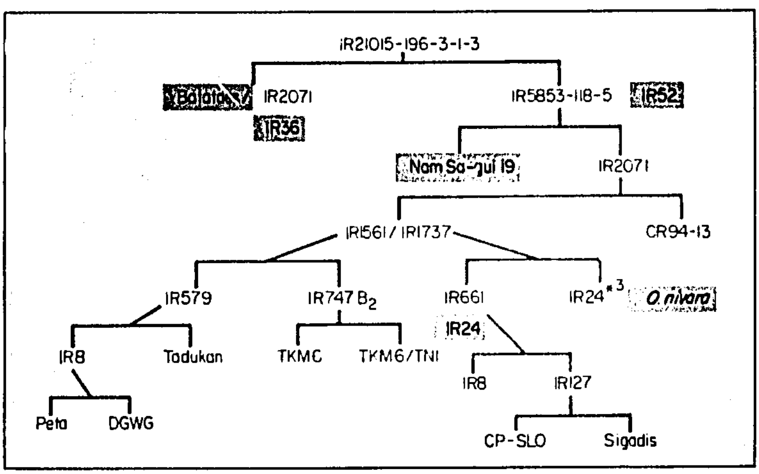
In a cooperative study with the National Institute of Animal Science in Copenhagen, protein of two yellow milled rices resulting from "stack burning" of unthreshed panicles plus straw were shown to be less digested by growing rats with resultant lower net protein utilization than that of raw white milled rice. Digestible energy was not affected, but lysine content of yellow rice tended to be slightly lower than that of raw white milled rice.

Dr. B.O. Eggum, biochemist at the National Institute of Animal Science, Copenhagen, Denmark, inspects rat cages used in collaborative work with IRRI involving nitrogen and energy balance assays.

The experimental breeding line IR21015-196-3-1-3 showed outstanding drought tolerance in field screening in the 1982 dry season. IR36, IR52, Nam Sagui 19, Oryza nivara, *Batataes, and others may have contributed to its drought tolerance (see Fig. 14).*

DROUGHT TOLERANCE

Since 1975 we have screened 58,021 rices, both traditional and improved breeding lines, and have selected about 3,500 for outstanding drought tolerance. We evaluated them for other traits and used some in IRTP multilocation trials. Others served as donor parents. Experimental breeding line, IR21015-196-3-1-3, showed outstanding drought tolerance during the 1982 dry season field screening (Fig. 14).



14. Parentage of IR21015-196-3-1-3 tested during 1982 field screening. The line showed outstanding drought tolerance.

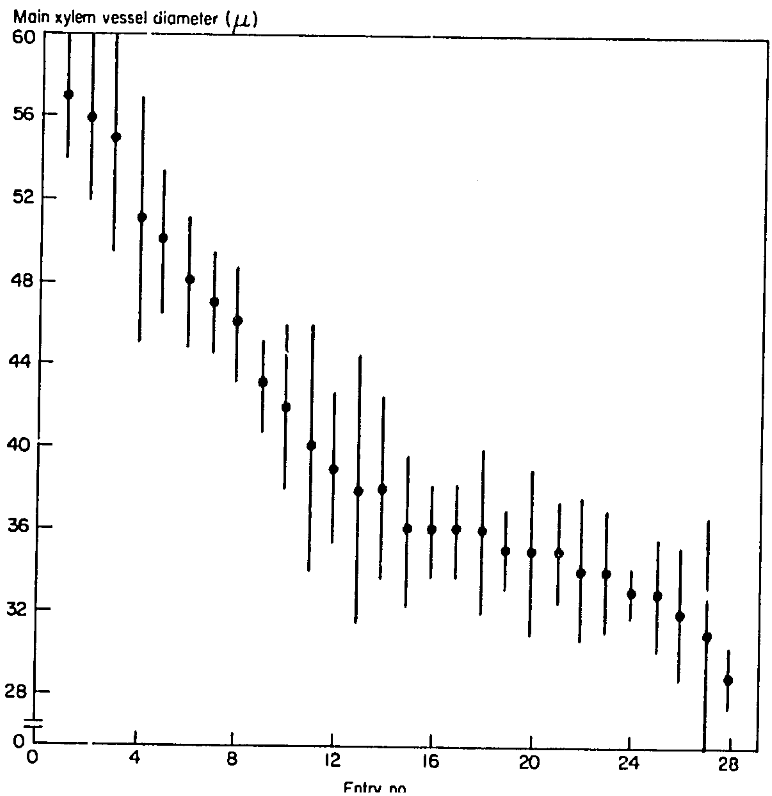
In 1982 we continued to search for better ways to screen rices for drought tolerance. We tested several methods at the flowering stage and looked at the xylem diameter of seminal roots.

Xylem diameter and water movement

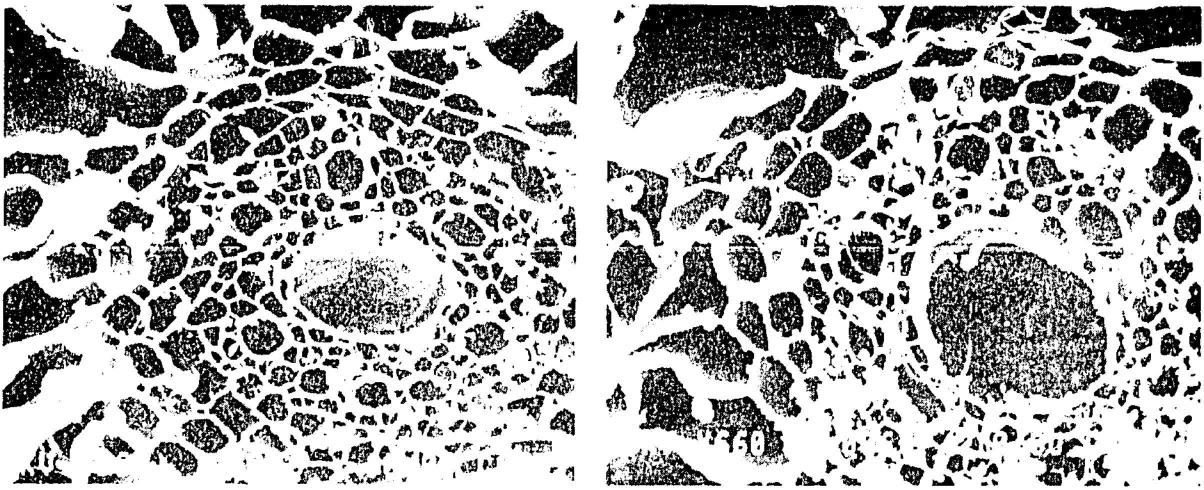
We have found xylem diameter in the seminal roots to be another characteristic with genotypic variation linked to drought tolerance in rice.

Deep rooting is a significant drought tolerance mechanism that allows an adapted cultivar access to unused soil water. Deep rooting should be accompanied by decreased axial or internal resistance to water flow in the root and shoot-conducting tissues to prevent development of detrimental water deficits in the shoot.

In a survey of 28 cultivars with very different hydrological origins, we found a substantial difference in the diameter of the xylem (main water-conducting tissue) in the seminal roots of seedlings (Fig. 15). Scanning electron micrographs (Fig. 16) show the vessels of IR36 and the West African variety Moroberekan.



15. Genotypic variation in diameter of the main xylem vessels of seminal roots is obvious in these 28 rice varieties from Asia, Africa, and South America. Large vessel diameter is associated with less resistance in water movement to the shoot.

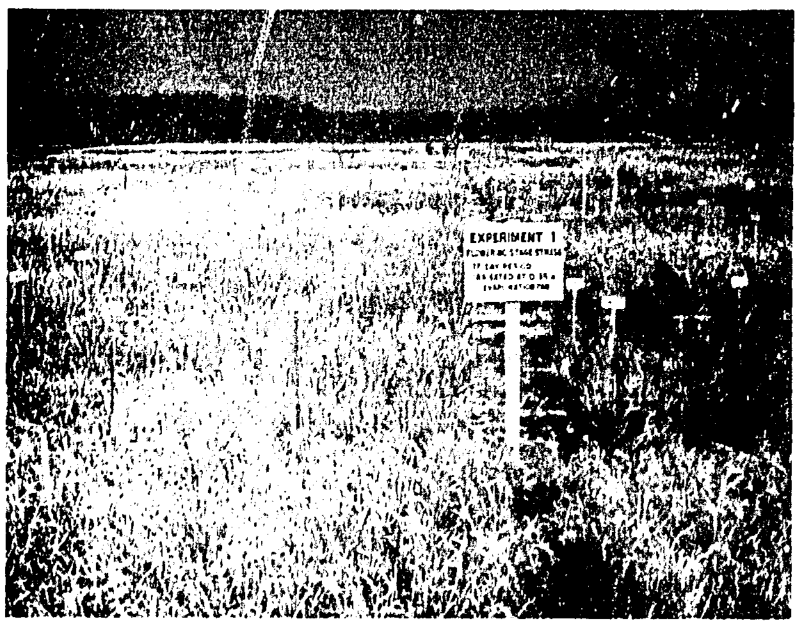


16. Scanning electron micrographs (660X) illustrate the varietal diameter difference of the main xylem vessel in the seminal roots of IR36 (left) and Moroberekan. Note the characteristic large-diameter vessels in the drought-tolerant West African variety.

Screening for drought tolerance at flowering stage

Drought stress during flowering will have a detrimental effect on rice yield. We tested several screening methods and criteria for this growth stage during the 1982 dry season.

We compared the measured yield, relative yield, and estimated fertility of control and stress treatments. Staggered planting dates provided comparable growth stage and stress development interactions. We used regression techniques to improve evaluation among entries not flowering at precisely the same time.



1982 field trials for drought tolerance at the flowering stage showed some promising genotypes.

Table 6. Genotype ranks based on numerical index rank, 1982 dry season.

Genotype	Index rank: Yield	Index rank: Relative yield	Index rank: % fertility	Sum of rank by index	Mean	Overall rank
IR8234-174-3	1	5	2	8	2.7	1
IR9575 Sel.	6	1	1	8	2.7	1
IR52 #1	3	2	4	9	3.0	3
IR9782-111-2-1-2	2	4	9	15	5.0	4
UPL-Ri-5	4	6	10	20	6.7	5

Table 6 shows the top five genotypes in the 1982 field trials.

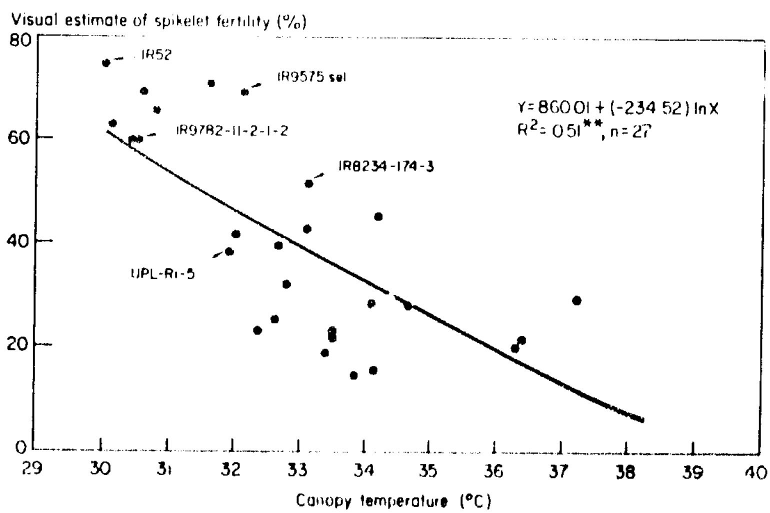
When screening varieties for drought stress at flowering, canopy temperature may provide a rapid means of evaluating varietal response. We found that high canopy temperatures at flowering can have a detrimental effect on spikelet fertility (Fig. 17) and grain yield (Fig. 18).

In 1983 several hundred varieties and lines will undergo systematic testing. The methods will continue to change and develop as we learn more about the consequences of drought stress at flowering.

Drought stress and sterility in rice

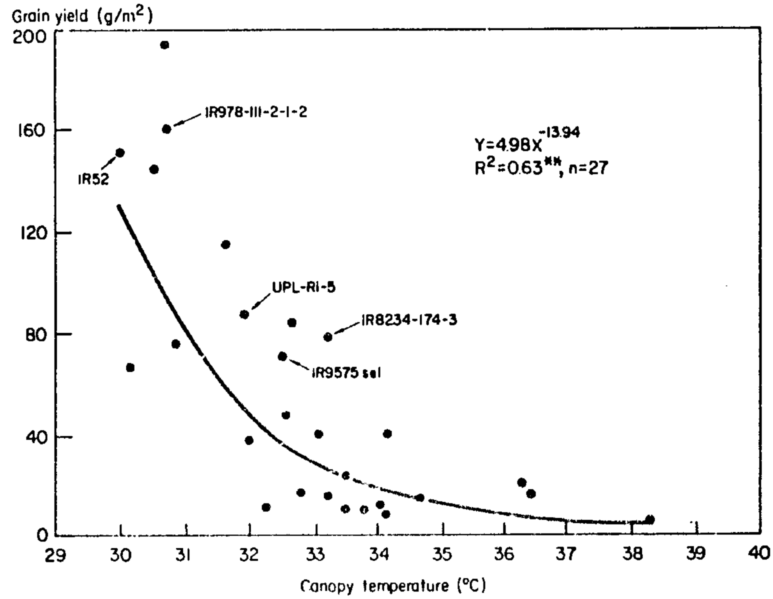
Although drought stress has a drastic effect on spikelet fertility at or near flowering, we do not know its effect during earlier stages or reproductive development.

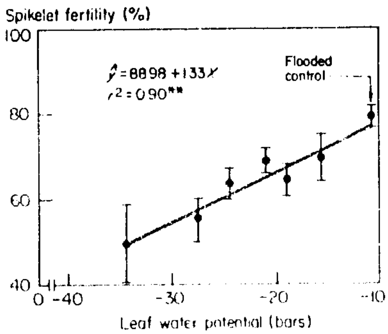
We reduced spikelet fertility (Fig. 19) by stressing IR36 at pollen development, specifically during meiosis, the reduction



17. Relationship between spikelet fertility and canopy temperature at flowering of 27 rice cultivars during screening for drought resistance, 1982 dry season.

18. Relationship between grain yield and canopy temperature at flowering for 27 cultivars or lines of rice during screening for drought resistance, 1982 dry season.

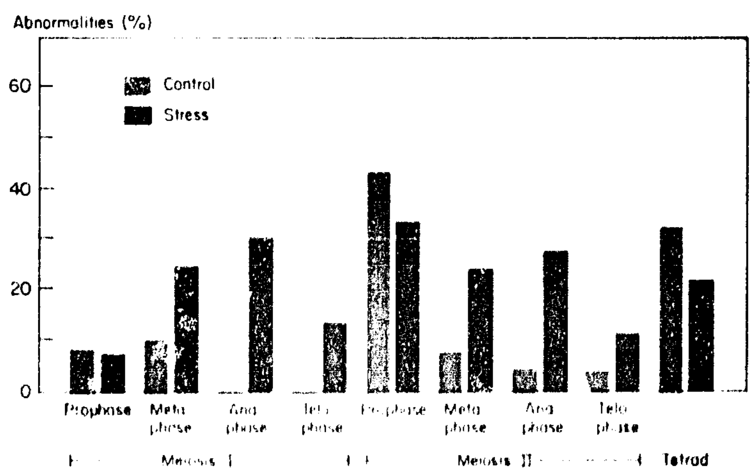




19. Spikelet fertility (av % ± S.E.) of IR36 stressed during pollen development.

division step in pollen development. Drought stress enhanced meiotic abnormalities in most cases (Fig. 20).

Although each of the meiotic stages appeared to have one or two characteristic irregularities, such as abnormal pairing and movement of chromosomes, there were no indications that the abnormalities are related to spikelet sterility. Latent effects such as lack of anther dehiscence or pollen viability may be more of the direct cause of drought stress-induced sterility in rice plants during pollen development.



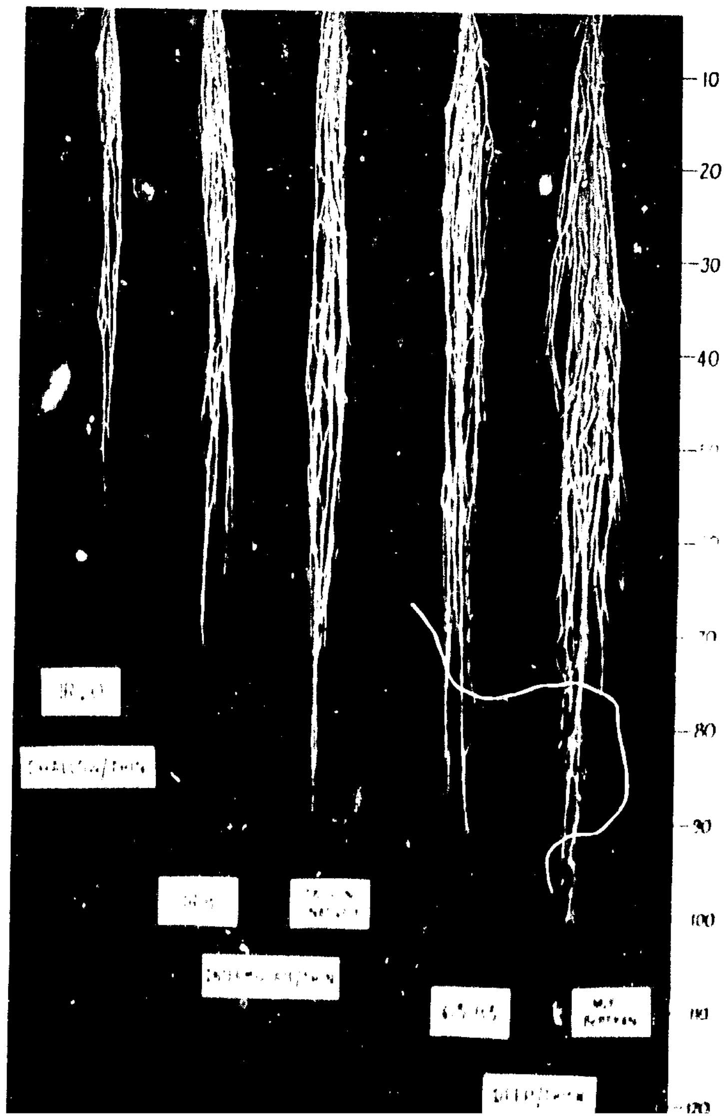
20. Drought stress often intensified meiotic abnormalities during pollen development in IR36.

Aeroponic culture system

To perfect a systematic and rapid method of screening rice germplasm for root characteristics, we tested 27 rice varieties 3 times in aeroponic culture. The relative patterns of principal root characters were similar to those obtained in the field, root boxes, or mylar tubes.

Root diameter appeared to be the most stable varietal feature. It was least affected by the environment and its coefficient of variation ranged from 7.54 to 8.68%. Root number, root dry weight, and root-shoot ratio showed larger variations from one planting to another.

Because the ratio of the test variety value to the check variety (specifically thin and shallow-rooted) is more meaningful than the absolute value in comparative studies, thin-shallow rooted and thick-deep rooted check varieties (Fig. 21) should be planted in every drum when using the aeroponic system.



21. Check varieties with shallow and thin root systems (IR20) and deep and thick roots (Moroberekan) should be planted in every drum when using the aeroponic system.

In densely populated South and Southeast Asia alone, as much as 100 million ha suited to rice production are uncultivated mostly because of soil problems such as salinity, alkalinity, strong acidity, or excess organic matter. In addition, about 50 million ha of cultivated land have deficiencies in zinc, phosphorus, iron, or excess of iron and aluminum that limit rice yields. The goal of our adverse soils tolerance research is to identify rice varieties that will give farmers a reasonable yield on adverse soils without expensive amendments.

In 1982 we screened more than 15,000 rices, about 2,000 from international tests, and found about 2,800 rices tolerant to one or more of nine adverse soil conditions (Table 7).

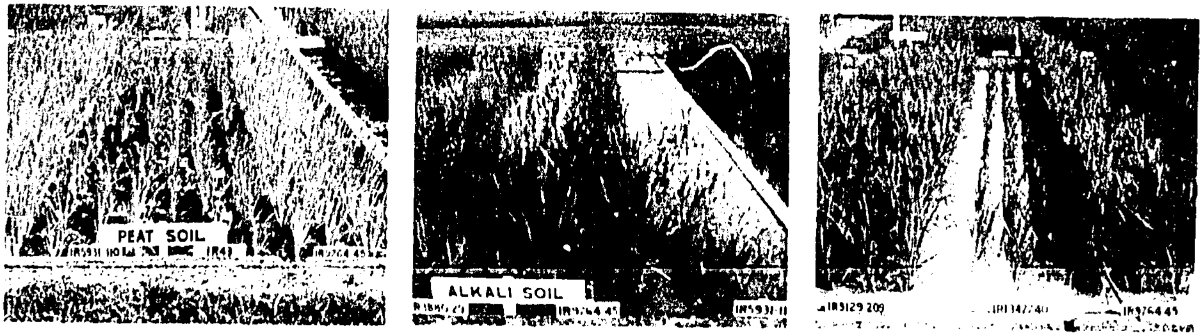
Multiple stress tolerance

We have developed outstanding disease- and insect-resistant varieties and lines suited to adverse soils. IR36, because of its tolerance for salinity, alkalinity, acid sulfate soils, and upland soils, continues to show its wide range of tolerance except for phosphorus deficiency. IR46 has tolerance for salinity, alkalinity, and acid sulfate soils.

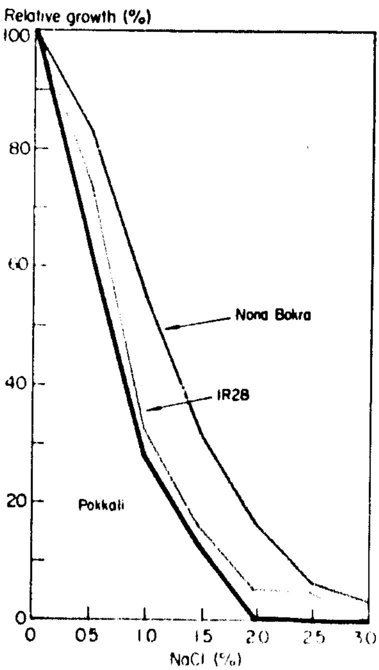
A new promising line is IR9764-45. It has tolerance for salinity, alkalinity, peat soils, phosphorus deficiency, zinc deficiency, and boron toxicity (Fig. 22). It is also tolerant of most other problems.

Table 7. Screening for adverse soils tolerance in 1982 covered nine soil conditions and more than 15,000 entries.

Soil condition	Screened rices (no.)	Tolerant rices (no.)
Salinity	11,912	2,445
Alkalinity	1,009	38
Acid sulfate soil	188	100
Peat soil	155	98
Zn deficiency	656	47
P deficiency	616	31
Boron toxicity	94	22
Iron toxicity	340	14
Aerobic soil		
Mn and Al toxicities	63	13
Iron deficiency	16	3
Total	16,049	2,811



22. IR9764-45 is a promising line with a wide range of adverse soils tolerance. It performed very well on peat soils (left), alkali soils (center), and phosphorus-deficient soils (right).



23. Effect of sodium chloride (NaCl) on the growth of callus cultures derived from three rice varieties.

Varietal difference in salt tolerance at the cellular level

To establish a rational approach to breeding salt-tolerant rice varieties, we must understand the physiological mechanisms. At present we know of two mechanisms for salt tolerance in nonhalophytes: tissue tolerance and low accumulation.

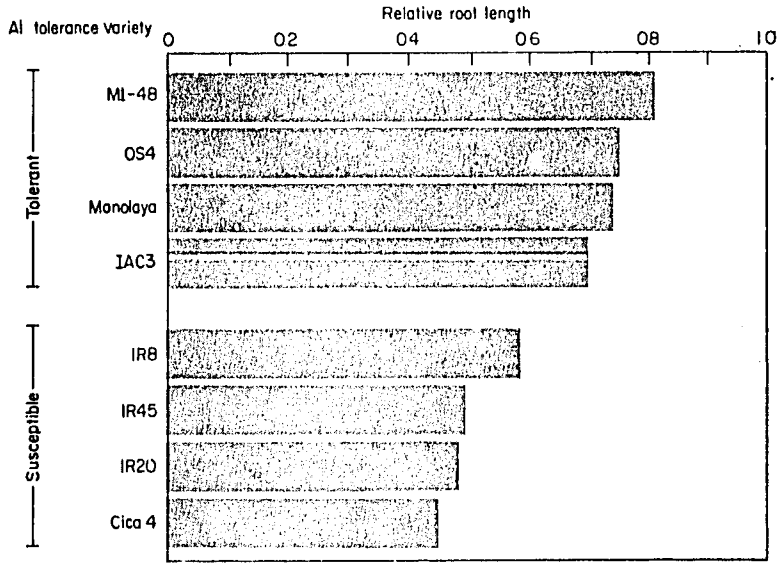
To determine if rice tolerance for salinity relates to tissue tolerance or low salt accumulation, we compared the salt tolerance of calluses derived from Pokkali and Nona Bokra, salt-tolerant varieties, and IR28, a susceptible variety. At the callus level, salt tolerance of Nona Bokra is much greater than that of Pokkali and IR28 (Fig. 23). We were surprised to find the salt tolerance of Pokkali to be as low as that of IR28 at the cellular level. In a separate experiment with the same varieties, we found that Pokkali is a slow sodium accumulator. Nona Bokra appeared to tolerate high salinity by regulating the rate of salt uptake and by high tissue tolerance. It is evident that both tolerance mechanisms operate in rice.

Varietal difference in aluminum toxicity tolerance

We have usually screened rice cultivars for aluminum (Al) toxicity tolerance by solution culture using 30 ppm Al. In soil solution, 5 ppm Al or even lower concentrations can be toxic to rice. So the solution culture technique has been criticized for using an unrealistically high Al concentration.

To see if screening could be done at lower levels, we examined the Al toxicity tolerance of 19 varieties at 5 and 30 ppm Al. At 5 ppm, salt concentration was maintained at one-tenth the standard solution to simulate the soil solution of acid dryland soils. Tolerant varieties as identified at 30 ppm Al are also tolerant at 5 ppm Al (Fig. 24). The relative root length value of tolerant varieties ranged from 0.70 to 0.81 while that of susceptible varieties ranged from 0.41 to 0.59. The correlation coefficient between 5 and 30 ppm Al was high ($r = 0.82$). This shows that we can use

24. Varietal difference in aluminum toxicity tolerance at 5 ppm Al and low salt concentration simulating acid soil solution.



either 5 ppm Al combined with a low salt concentration or 30 ppm Al in the standard culture solution to screen rice cultivars for aluminum toxicity tolerance.

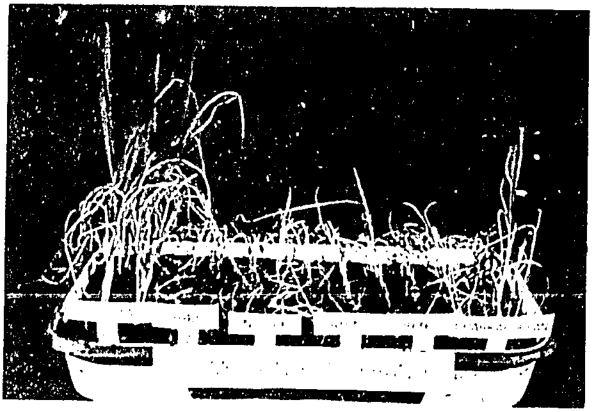
DEEPWATER RICE

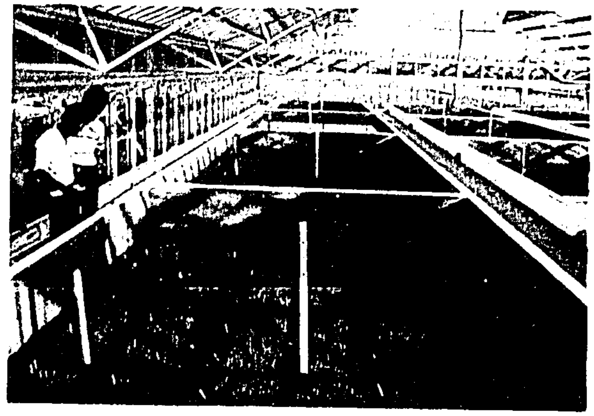
We have expanded work on deepwater rice at IRRI by making more crosses and evaluating them for the different plant characters needed for deepwater areas, and in Thailand by initiating work on screening for insect and disease resistance.

In Thailand, SPR7270-18 and SPR7233-32-1-6-1 are being evaluated as possible alternatives to RD19. Both are crosses of C4-63, a high quality rice, with the floating rice varieties Khao Nahng Nuey and Leb Mue Nahng, respectively.

Production from early lines harvested before flooding

On the Central Plain of Thailand, rain usually starts in April, but in some parts floodwater does not begin to rise until mid-August. In areas without irrigation water, it may be possible to produce a crop from very early rice varieties, and still establish the deepwater rice crop. Twelve promising materials were dry-seeded on 26 April. Rainfall was well distributed. The field was flat and bunded so there was no surface runoff. Several lines matured within 97 days of emergence, and yields were as high as 3 t/ha for IR15429-268-1-2-1; four other IRRI lines yielded from 2.5 to 2.9





A germplasm bank entry, Urarkaruppan, had good submergence tolerance compared with check variety FR13A. Urarkaruppan also displayed good continuous dark tolerance. At right, Moo Sang Lim, postdoctoral fellow from Korea, and Sherwin S. Lopez, IRRI research aide, check the progress of rice plants in the new facilities made available for submergence tolerance screening of breeding lines and the germplasm bank entries.

t/ha. RD25 gave 2.4 t/ha. IR36 and IR52, with 110- and 118-day maturity, were too late, but yielded 1.99 and 1.45 t/ha.

Crop cuts in deepwater rice

Average yields of deepwater rice are low. We are studying potential production and the yield variation between locations. We sampled 30 farmers' fields in a transect across the southern Central Plain of Thailand. Soil type greatly influenced production: yields were as high as 3.6 t/ha in the west, but down to an average of 1.0 t/ha on acid soils of the Eastern Plain where ragged stunt was severe. There were marked varietal differences and several farmers' varieties were collected for testing.

Screening for submergence tolerance

In Thailand after continuous exposure of 40-day-old seedlings to darkness for 10 days, the submergence-tolerant FR13A survived while susceptible Khao Dawk Mali 105 died. The findings have implications for future screening for submergence tolerance.

COLD TOLERANCE

Several entries from the International Rice Cold Tolerance Nursery (IRCTN) have been named as new varieties or are being tested in farmers' fields in different countries participating in the IRTP:

- Nepal. Two varieties selected from the 1977 IRCTN have been released. Kanchan is from IR3941-4-PLPB and Himali from IR2298-PLPB-3-2-1-1B. Another IRCTN entry, K39-96-1-1-1-2, is being tried in farmers' fields.
- Cameroon. Seeds of IR1846-296-3, HPU741, and Kulu have been distributed to farmers for trial.

Table 8. High yielding entries in the 1982 observational yield trial at Chuncheon, Korea.

Entry	Grain yield (t/ha)
IR8455-K2	8.4
Suweon 287	7.8
IR5716-18-1	7.5
IR9129-136-2-2-1-2	7.1
IR8608-298-3-1-1-2	7.1
IR9758-K2	7.1
IR9224-K1	6.9
IR9202-6-1-1	6.9
IR7167-33-2-3-3-1	6.7
SR5204-39-2-1	6.7
IR13155-60-3-1-2-1	6.7
SR4131-19-3-1	6.6
Hokuriku 109	6.5
IR7167-33	6.5
SR5204-39-5-3	6.5

- Upper Volta. Calrose 76 and Fujisaka 5 selected from IRCTN lines are now recommended varieties.
- Larnoo, India. Several lines from the cross K312 (Kuch/IR1846-308-1) were outstanding. IR1846-308-1 is an IRCTN entry from 1975 to 1979. Several crosses with the native varieties were made using this IR1846 line as one of the parents. An outstanding selection from K312 will most likely be named as a variety.
- Himachal Pradesh, India. Two IRCTN entries HPU734 and HPU71 were named Himalaya 1 and Himalaya 2.
- Kashmir, India. K39-96, a cross of China 1039 with IR580, will be released as a variety.

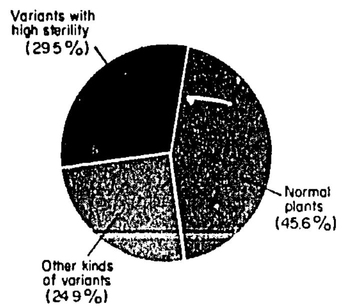
Observational yield trials

The observational yield trial in Korea showed high yields for several IR lines indicating our progress in breeding for cold tolerance (Table 8).

In Banaue, Philippines, we had yields up to 8.5 t/ha. The higher yielders are mostly IR lines of medium growth duration, semidwarf stature, and low spikelet sterility. These improved lines more than doubled the yield of the local check variety.

INNOVATIVE BREEDING METHODS

We continue to apply tissue culture techniques to accelerate breeding procedures, especially in the area of screening for salt tolerance. Our work with hybrid rice took a major step forward with the development of some stable cytoplasmic male sterile lines.



25. We found variants in R2 plants of Taichung 65 through seed callus culture. Other kinds of variants include those with brown leaf spot, chlorophyll mutation, dwarfness, late maturity, and morphological variations.

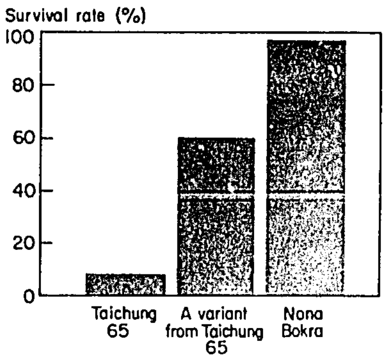
Somaclonal variation in visible traits

The tissue culture cycle itself generates a wide range of variability in various traits of rice. When variation for visible traits (spikelet sterility, chlorophyll mutation, brown leaf spot, plant stature, maturity, and other morphological variations) was examined, we found about 46% to be normal and 54% to be variants (Fig. 25). We found the chlorophyll mutation frequency (8.8/100 R2 lines) to be as high as that obtained with irradiation, but lower than that induced by chemical mutagens. The proportion of variants should increase as more traits are examined. Somaclonal variation observed in visible traits suggests that similar variation occurs in physiological and biochemical traits.

Salt-tolerant calluses

When a callus is cultured on a salt-enriched medium, some cells of the callus may gain salt tolerance. After 24 weeks of such culture in 1982, there was only a slight indication that the callus had gained some degree of salt tolerance. After 52 weeks of continuous subculture on a salt-enriched medium, however, the callus gained a substantial degree of salt tolerance (Fig. 26).

26. We obtained a salt-tolerant callus after 52 weeks of continuous subculture on a salt-enriched medium. We are now regenerating plants from the salt-tolerant callus.



27. A selected salt-tolerant variant of Taichung 65 shows high salt tolerance compared with its parent under high salt stress (0.75% NaCl).

Salt-tolerant variant plants

We can produce salt-tolerant variant plants by using somaclonal variation. The frequency of salt-tolerant variant plants produced increases with the increase in length of the callus culture. A selected variant of Taichung 65 showed a very high survival rate compared with the parent (Taichung 65) in a salinized culture solution (Fig. 27). However, salt tolerance of the variant is still lower than that of the salt-tolerant variety Nona Bokra.

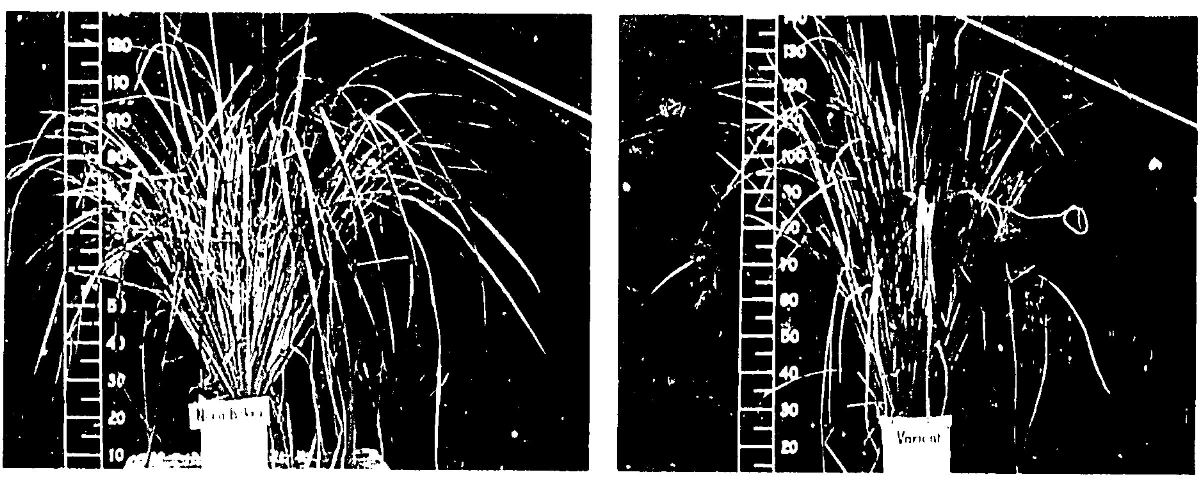
Another way of using tissue culture is to modify morphological traits of salt-tolerant varieties. Nona Bokra is salt tolerant but it has open tillers, which hampers productivity. The tissue culture cycle has produced one Nona Bokra variant with a compact tiller arrangement (Fig. 28).

Aluminum toxicity-tolerant variants

We examined aluminum toxicity tolerance of 3,991 R2 plants from 472 lines regenerated from calluses of Taichung 65 grown without aluminum in a culture medium. By measuring root growth of young seedlings in the presence of 30 ppm Al in culture solution, we found increasing and decreasing tolerance for aluminum (Fig. 29). Some R2 plants were highly tolerant of aluminum; their roots at 30 ppm Al were even longer than those of the parent at 0 ppm Al. Occurrence of aluminum-tolerant variants appears to increase with increasing subcultures. Thus, the tissue culture process itself appears to generate a wide range of variability in tolerance for aluminum toxicity.

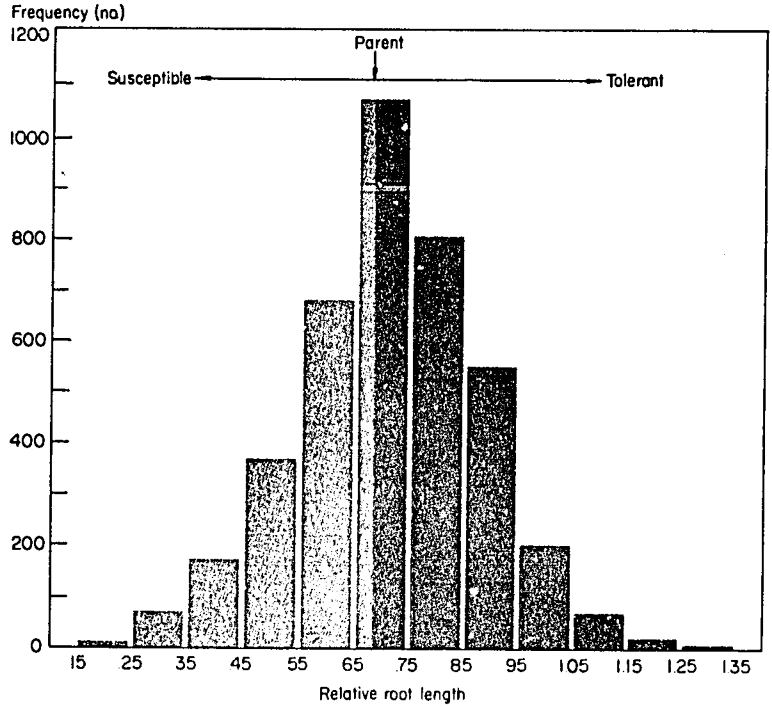
Increasing plant regeneration efficiency

Low efficiency in plant regeneration from long-term cultured calluses and from IR lines and other indicas poses a serious

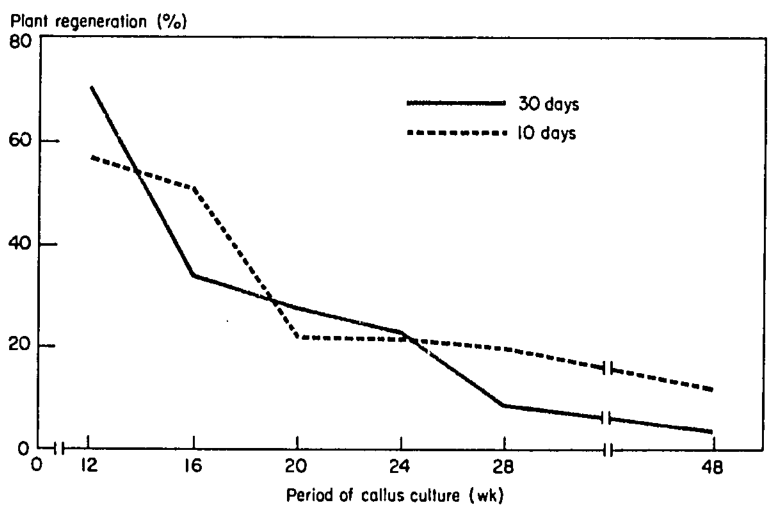


28. The compact tillering variant (right) of Nona Bokra is slightly shorter, earlier in maturity, and 20% higher yielding than the parent (left).

29. Frequency distribution of the relative root length of 3,991 plants from 472 variant lines from Taichung 65 grown in culture solution with 30 ppm Al. Relative root length of the parent is 0.68.



barrier to using tissue culture for rice improvement. Plant regeneration efficiency declines with time and goes down to 0 (most varieties) or to 10% (best variety) after 48 weeks of culture (Fig. 30). For a given variety, choice of explant and composition of



30. Plant regeneration from 12- to 48-week-old calluses derived from seeds taken at 10 and 30 days after anthesis of variety Reiho.

culture medium greatly affect the regeneration efficiency. Using immature seeds increases the regeneration efficiency in japonica varieties but not in IR lines. We are conducting an intensive study to increase plant regeneration efficiency of IR lines and long-term cultured callus by choosing young inflorescence as an explant and by improving culture media.

Anther culture

The anther culture technique in F_1 sexual crosses can help to speed up some aspects of breeding work.

With the floating anther culture method and using J-19 and E-24 media for high callus production, we have produced hundreds of pieces of callus from anthers of F_1 sexual hybrids. We plated selected pieces on the N-19 medium for plant regeneration and regenerated more than 500 green plants from 18 F_1 reciprocal crosses of indica/indica, indica/japonica, japonica/japonica, and japonica/indica rice varieties.

The number of green plants regenerated is 50% of the number of calluses plated or 10% of the number of anthers plated. We germinated and grew seeds from regenerated plants in the field during the 1982 wet season. Plants coming from seeds of individual anther culture-derived plants did not exhibit phenotypic variations, suggesting their homozygous nature.

In general, japonica rices are highly responsive in producing calluses and regenerating plants when their anthers are cultured *in vitro*. In contrast, indica varieties respond poorly or not at all. In some cases where anthers of two indica varieties do not respond well to anther culture, the reciprocal F_1 sexual crosses of the same varieties do exhibit high callus production and green plant regeneration.

The incorporation of cold tolerance at the seedling stage is difficult and the progenies of crosses involving cold-tolerant parents usually show little or no resistance. Anther culture, which increases the possibility of attaining a recessive character or difficult to recover plant characters, shows a promising pathway of obtaining cold-tolerant materials at the seedling stage. In some cases, it is possible to obtain homozygous lines from anther culture of F_1 hybrids which are as cold tolerant as or more than the parents (Table 9).

We studied the meiotic behavior of pollen mother cells of 41 random plants of varieties and F_1 sexual crosses regenerated from anther culture. The regenerated plants showed 66% diploids and 34% haploids. We observed no other ploidy level.

Table 9. Cold tolerance response of anther culture-derived plants.

Plant[a]	Plants (no.)	Seedlings (no.) with cold tolerance score[b] of				
		1	3	5	7	9
Cross with a cold-tolerant parent						
Tatsumi mochi/Suweon 290 (J/I)	16	—	1	8	7	—
Tatsumi mochi/BG90-2 (J/I)	7	—	1	4	2	—
Taipei 309/Tatsumi mochi (J/J)	14	—	—	10	4	—
BG90-2/Taipei 309 (I/J)	13	3	10	—	—	—
Silewah/Taichung 65 (I/J)	1	—	1	—	—	—
Parents						
Tatsumi mochi (J)		—	x	—	—	—
Suweon 290 (I)		—	—	—	x	—
BG90-2 (I)		—	—	—	—	x
Taipei 309 (J)		—	x	—	—	—
Silewah (I)		—	x	—	—	—
Taichung 65 (J)		—	x	—	—	—

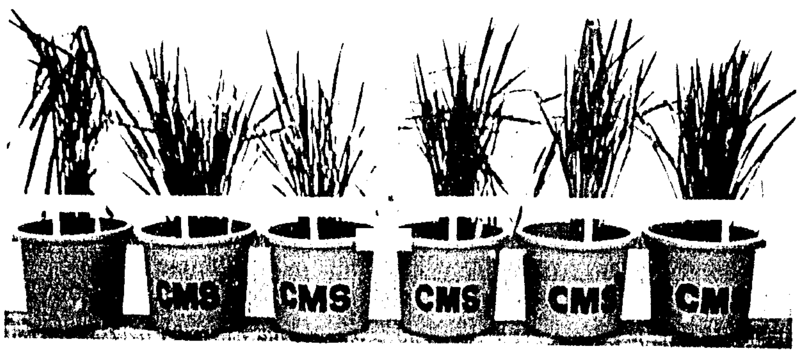
[a]J = japonica, I = indica. [b]1980 Standard Evaluation System for Rice Scale: 1 = seedlings dark green, 9 = seedlings dead.

Hybrid rice

We continue to explore if hybrid rice can help increase the yield potential of tropical rice varieties.

Results show significant yield superiority (up to about 30%) over the check varieties (IR36, IR42, IR54) in selected intervarietal F_1 hybrids. Some experimental hybrids showed up to 20% yield advantage over check varieties IR42 and IR52 in a trial conducted at a shallow rainfed area in Pangasinan Province, Philippines. Hybrid rice also has wider adaptability to the varying water situations of wetland conditions.

The major constraint to developing F_1 rice hybrids for the tropics has been the insect and disease susceptibility of the available stable male sterile lines. During 1982, we developed some stable cytoplasmic male sterile (cms) lines (Fig. 31) which are



31. Compared with Zhan Shan 97A (extreme left) introduced from China, the new cms lines developed at IRRI adapt better to tropical rice growing conditions.

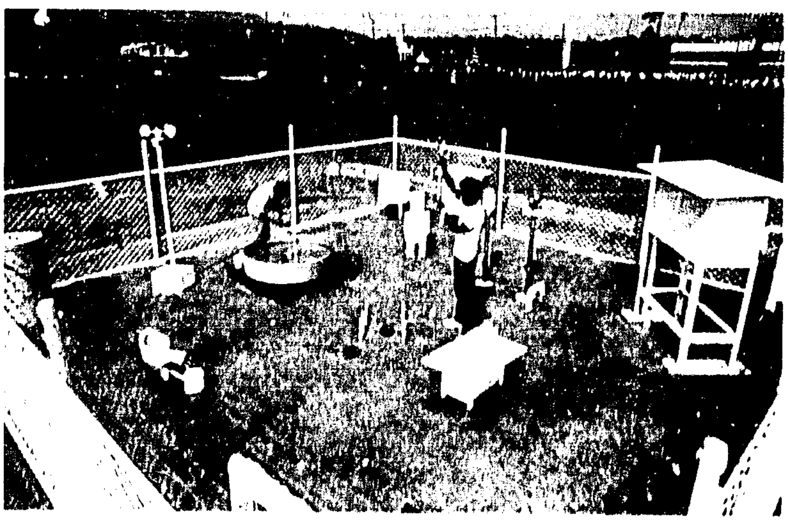
better adapted to tropical conditions than the male sterile lines introduced from China. We are multiplying these cms lines and crossing them with identified elite restorer lines to study their combining ability. If found good for combining ability, these lines should lead to development of F_1 hybrids for the tropics. We hope to develop additional cms lines in different elite genotypes adapted to the tropics.

Alternative sources of cytoplasmic male sterility are necessary to protect F_1 rice hybrids against potential genetic vulnerability to disease and insect epidemics which may be linked to the use of a certain cms system. We have identified four different cytosterility systems among the stable cms lines available at IRRI. *Oryza glaberrima* has also been identified as a source of cytoplasm inducing male sterility in indica rice. The work is in progress to develop elite cms lines, possessing different cytosterility systems for use in the development of F_1 rice hybrids.

We continue to collaborate with Chinese scientists on a number of mutually beneficial hybrid rice projects. During 1982, collaborative research on hybrid rice was initiated with some other rice growing countries in Asia.

INTERNATIONAL RICE TESTING PROGRAM

The IRRI-coordinated International Rice Testing Program (IRTP), which is in its eighth year, has effectively linked national and regional rice improvement programs with the GEU program. The network's strength comes from national rice scientists who collaborate in evaluating elite germplasm, varieties, and advanced breeding lines. In 1982 IRTP continued to strengthen



The irrigated nurseries of the International Rice Testing Program offer a unique opportunity to obtain a better understanding of the behavior of rice varieties under different climates. With World Meteorological Organization support, monitoring stations are being set up at 22 locations in 15 countries. These sites represent a cross-section of the radiation and temperature conditions under which rice is cultivated. IRRI's agromet station is shown at right.

Table 10. More than 150 rices showed good performance at many sites in 1981 IRTP tests. Data from the tests were submitted by scientists at test sites and analyzed and summarized at the IRTP headquarters at IRRI. (Individual nursery reports published by IRRI provide detailed information.)

Nursery	Promising entries
	Nurseries for cultural types
Irrigated — yield	
IRYN-VE (very early)	• BG367-4, IR50, IR9729-67-3, BG276-5, BG367-7
IRYN-E (early)	• Taichung sen yu 285, IR9828-91-2-3, IR36, Chianung sen yu 13, IR13429-196-1
IRYN-M (medium)	• IR13540-56-3-2-1, BR51-282-8, IR54, IR13423-17-1-2-11, Taichung sen 10, IR42
Irrigated — observational	
IRON	• IR14538-48-2-3, Chianung sen yu 13, 32-Xuan-5-C, IR9698-16-3-3-2, C1321-9, C1322-28, IR9830-26-3-3, IR13240-108-2-2, MRC603-303
IRARON (arid regions)	• Several Giza lines, IR9192-209-2, IR9129-3203-3, IR19746-28-2-2, IR8608-298-3, IR19819-31-2-3
Rainfed — yield	
IURYN (upland)	• IR5931-110-1, IR6115-1-1-1, UPL Ri-5, IR43, IET4094, IR52
IRLRYN (lowland)	• IR14632-2-3, IR14753-49-2, BR4, IR13146-45-2-3, BR51-282-8, IR46, IR4819-77-3-2, IR10781-75-3-2
Rainfed — observational	
IURON (upland)	• IR9761-19-1, IR19793-25-2-2, IR9256-29, ITA175, ITA235, UPL Ri-3, IR10004-3-1, IR12979-24-1, IR6023-10-1-1, IR3794-9-2-3, IAC1246, IR10110-23-1, IR5440-1-1-3
IRLRON (lowland — early group	• IR2987-13-1, IR3179-25-4, IR5853-198-1-2, IR13146-13-3-3, IR3880-10, IR8608-82-1-3, IR9698-16-3-3
IRLRON (lowland — medium group)	• IR10781-143-2-3, IR13358-16-3-2, IR13369-86-2-2, IR46, IR14497-15-2, IR14753-86-2, IR4819-77-3-2, IR4829-89-2, IR14875-98-5, IR19083-22-2-2, IR19256-88-1
IRDWON (deepwater)	• BKN76001-36-4-2, GEU77057-1-1, HTA7403-110-1-5, SPR7292-151-2-1
	Nurseries for individual stresses
Temperature	
IRCTN (cold)	• JC99, Shin-ei, Fuzi 102, Jodo, Eiko, China 1039, K39-96-1-1-2, K143-1-2, IR19743-46-2-3, IR19746-26-2-3, IR9224-K1, IR9758-K2, IR9202-5-2-2
Problem soils	
IRSATON (salinity and alkalinity)	• *Salinity* — IR8236-B-B-336 *Alkalinity* — IR4227-28-3-2, IR4432-28-5
Acid sulfate	• IR1632-93-2-2, IR46, IR36
Acid upland	• B2443b-Kn-10, Salumpikit, ITA116, *O. glaberrima* (BG187)
Iron toxicity	• BW100, IR4625-269-4-2, IR4683-54-2-2
Peat soils	• IR34, IR52, IR2071-685-3-5
Diseases	
IRBN (blast)	• Fukunishiki, IR1905-PP11-29-4-61, IRAT104, Tetep, CIAT-ICA5, Camponi SML
IRTN (tungro)	• ARC10342, ARC11353, ARC11554, Utri Merah, Utri Rajapan
IRBBN (bacterial leaf blight)	• RP633-76-1, RP633-519-1, IR4442-46-3-3, IR13423-17-1-2-1, IR9209-48-3-2, IR54, IR20
Brown spot	• IR2360-6-7-1-4, Cica 8, IR54, IR4227-28-3-2, RP1045-60
Cercospora	• IR13149-43-2, IR15318-2-2, IR4568-86-1
Sheath rot	• IR19762-2-3, IR9209-181-3
Leaf scald	• IR8192-200-3, IR5853-18-2
Ragged stunt	• Murungakayan 101
Insects	
IRBPHN (brown planthopper)	• BG367-9, BG379-4, PTB33, PET19, Sinna Sivappu, Suduru Samba, IR15324-117-2-2-3, IR17488-2-3-2, IR19660-46-1-3-2, IR19661-150-2-2-2, IR13427-40-2-3-3
Yellow stem borer	• *Vegetative stage* — CO 18, CO 21, MTU15, W1253, W1263 *Flowering stage* — W1263, IR15795-151-2
Leaffolder	• IR13429-170-3, IR9209-26-2-2, TKM6

international linkages through its nurseries, monitoring tours, and workshops. We also continued work on classifying Asia's major rice environments.

International nurseries

In 1982 we assembled 1,351 nursery sets and sent them to 50 network countries. We analyzed 1981 trial results from more than 600 tests.

From the 1981 trials many new promising entries were identified (Table 10). All these superior entries are freely available to national rice improvement programs. Details of entry performance in different nurseries are given in individual reports published by the IRTP headquarters at IRRI.

The disease and insect nurseries (brown planthopper, gall midge, blast, tungro, bacterial leaf blight) provide significant information on the genetic variation in biotypes and pathotypes.

Fifty-six IRTP entries originating from the breeding programs of 7 countries and from IRRI have been released to date to farmers in 30 countries in Asia, Africa, and Latin America.

Several hundred entries were utilized in hybridization programs in different countries and at IRRI for improvement of specific agronomic traits or for incorporation of resistance to specific agronomic traits or for incorporating resistance to specific stresses.

Monitoring tours

The 1982 monitoring tours focused on three major problem areas: cold tolerance, dryland rice, and rainfed wetland rice.

Cold tolerance breeding materials and international nurseries planted in India (Kashmir and Himachal Pradesh), Nepal, Korea, and the Philippines were reviewed and strategies for international collaboration were formulated. Some entries in IRCTN were released as varieties in India (Himalaya 1, Himalaya 2) and Nepal (Kanchan, Himali). Several utilized in crossing programs resulted in promising lines such as K312 at Larnoo Station in Kashmir.

Scientists from Latin America and Asia joined rice researchers in Africa in a tour to review dryland rice improvement efforts in Nigeria and Ivory Coast. This tour preceded an international workshop on dryland rice held at Bouake, Ivory Coast, in October. Scientists compared the diverse problems in developing better dryland rices on three continents. Plans were made for more attention to germplasm adapted to the more difficult dry-

[illegible] K[illegible] R[illegible] Research Station, K[illegible] India. [illegible] is a promising [illegible] rice, K39

land rice environments, specifically areas with short growing seasons or poor soil or both

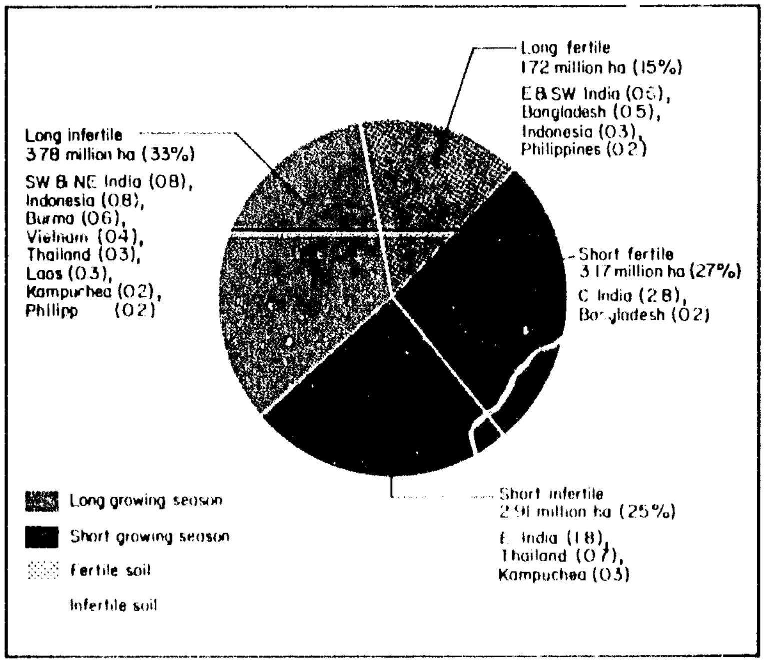
The problems of the vast areas of rainfed wetland rice in northeast Thailand and eastern India were the target of another tour. The need for improved photoperiod-sensitive varieties was highlighted and greater international efforts were outlined in several group discussions.

Asian dryland rice environments

Asian farmers grow dryland rice on 11.5 million ha in widely varying environments. Differences in growing season length and soil constraints will require improved dryland rices with a range of characteristics suited to specific locations. To achieve a broad understanding of their distribution and importance, we are trying to differentiate dryland rice environments.

We divided the region's dryland rice into four tentative major environmental complexes (Fig. 32). The most favorable environments, those with a rainy season of 5 or more months and relatively good quality soils, account for 15% of the total. The largest complex (33%) includes a long rainy season and relatively

32. We classified Asian dryland rice into four major environments according to the length of the rainy season and the soil fertility.



poor soils and is most commonly found in Indonesia and southwestern and northeastern India. Environments with a short rainy season and poor soils are also common (25%) and the most difficult areas for dryland rice improvement.

This classification system serves an accelerated dryland rice improvement effort targeted to each of the major environmental complexes. We are reinforcing the international dryland rice observational and yield nurseries to meet the requirements of the different dryland ecosystems.

INTEGRATED GEU PROGRAM

IRRI rices continue to gain worldwide popularity

IRRI breeding lines are tested worldwide in various growing environments. Many promising varieties are identified on the basis of such tests. By the end of 1982, 117 varieties from the IRRI breeding materials had been released in countries of Asia, Africa, and Latin America. They are now planted in more than 30 million ha of riceland.

During 1982 seven IRRI breeding lines were named varieties by the national programs:

- IR2061-214-3-8-2, an early-maturing selection, with multiple disease and insect resistance, recommended in Cameroons. This is the same line which in 1974 IRRI released as

IR28. It has also been recommended in the Philippines, Indonesia, Burma, Bangladesh, China, India, and Egypt.

- IR2070-199-3-6-6, IR38 sister line with multiple disease and insect resistance, released in Vietnam as NN8A.
- IR2071-586-5-6-3, earlier released as IR42 in the Philippines, Indonesia, Malaysia, Kampuchea, and Nigeria, recommended as NN4B in Vietnam. In addition to its multiple disease and insect resistance, IR42 has multiple tolerance for several problem soils and does well under acid sulfate soil conditions.
- IR3941-4-P1p 2B, a cold-tolerant line recommended as Kanchen for the hill zone of Nepal.
- IR2298-P1p B3-2, another cold-tolerant line recommended as Himali for the hill zone of Nepal.
- IR13429-109-2-2-1, named IR56 by the Philippine Seed Board for countrywide planting, matures 2-3 days earlier than IR36, but has the same yield potential. It has long, slender, and translucent grains with high amylose content and low gelatinization temperature and high milling recovery.

In the Philippines, IR56 is resistant to all the major diseases and insects such as blast, bacterial blight, tungro, grassy stunt, green leafhopper, and three biotypes of brown planthopper (BPH). The main advantage of IR56 over IR36 is its higher level of resistance to tungro and its resistance to three BPH biotypes. It has the *Bph 3* gene for resistance, whereas IR36 has *bph 2*. IR56 should help diversify the genetic base of improved materials grown in Asia.

New promising lines

Several new promising lines were evaluated for adaptation to various growing conditions. The Philippine Seed Board recommended some of them for seed multiplication as possible future varieties.

Irrigated conditions. Seed is being increased for five promising breeding lines with multiple disease and insect resistance:

- IR9752-71-3-2, an early-maturing line with short growth duration and 100-day maturity. It has excellent medium long and slender grains with excellent milling recovery. Its yield potential is high — 4-6 t during wet season and 7-8 t during dry season.
- IR9729-67-3, maturing in 100 days, outyielded all the other early-maturing lines in many trials. It has medium long and slender grains.

Table 11. Cold-tolerant lines from Banaue Observational Yield Trial, Philippines, 1982 dry season.

Designation	Yield (t/ha)	Flowering (days)	Height (cm)	Sterility (%)
IR8866-30-3-1-4-2	8.5	124	78	16.0
IR2061-522-6-9	6.7	125	91	11.7
IR15579-135-3	6.0	124	112	17.5
IR9202-33-4-2-1	6.0	126	105	17.8
IR9202-5-2-2-2	5.8	115	86	14.6
IR5853-118-5	5.7	124	78	16.7
IR3880-17	5.4	127	104	9.9
IR5716-18-1	5.4	127	84	17.0
B2980b-Sr-2-1-1-1	5.0	120	84	6.1
Onoy (local check)	2.7	117	109	23.1

- IR13429-299-2-1-3, a sister line of IR56 and resistant to three BPH biotypes. It matures in 110 days and has excellent long and slender grains with strong grain dormancy.
- IR13525-43-2-3-1-3-2, maturing in 120-125 days with excellent long and slender grains, is resistant to three BPH biotypes.
- IR19672-140-2-3-2-2, maturing in 130 days with long and slender translucent grains, is resistant to three BPH biotypes.

Cold-tolerant lines. We evaluated several early-maturing and cold-tolerant lines in fields at Banaue in the Mountain Province of the Philippines. Some of the promising lines are listed in Table 11.

Dryland lines. Three promising rices are being widely evaluated and one is under seed increase:

- IR3839-1, an early-maturing line with 110-day maturity, resistant to drought and has good recovery ability. It has intermediate amylose content.
- IR12721-24-3-1, maturing in 130 days, with good drought resistance and good recovery ability, has intermediate amylose content.
- IR12979-24-1, maturing in 110 days, has good drought and blast resistance and high amylose content.

Rainfed wetland lines. Several promising lines for rainfed wetland conditions along with their attributes are listed in Table 12. Some have submergence tolerance, drought tolerance, or tolerance for both.

Deepwater lines. We identified several promising lines for deepwater situations. Three lines from IR11288 (IR36/Leb Mue Nahng) have good elongation ability and are resistant to bacterial

Table 12. Promising breeding lines with multiple attributes suitable for rainfed wetland culture. IRRI, 1982.

Designation	Height (cm)	Growth duration (days)	Reaction[a] to Bacterial blight	Brown planthopper biotypes 1	2	3	Green leaf-hopper	Tolerance for stress[b]
IR4819-77-3-2	110	120	R	R	S	R	R	Sub
IR10781-143-2	110	115	R	R	R	R	M	Drt, Sub
IR13146-45-2-3	115	125	R	R	S	R	R	
IR13369-86-2-2	120	100	R	R	R	S	M	Drt
IR13564-95-1	115	120	R	R	R	S	S	Drt, Sub
IR14632-2-3	120	125	R	R	R	R	M	
IR14753-49-2	110	120	R	R	S	R	R	Drt
IR14875-98-5	120	125	R	R	R	R	S	Drt, Sub
IR19083-22-2-2	110	130	R	R	R	S	R	Drt, Sub
IR19431-72-2	110	130	R	R	R	R	M	Drt, Sub
IR21313-39-3-2	120	120	R	R	R	R	R	

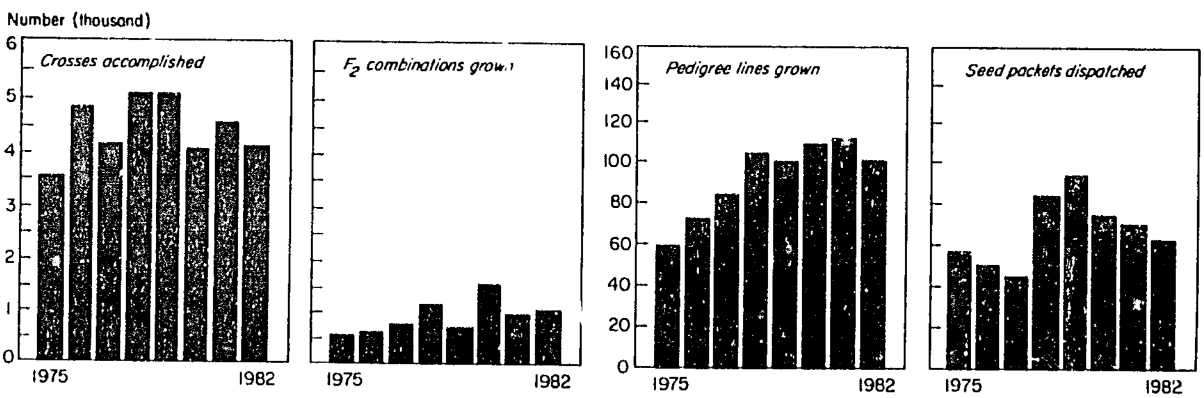
[a]R = resistant, M = moderately resistant, S = susceptible. [b]Reactions reported from IRTP nurseries: Drt = drought tolerance, Sub = submergence tolerance.

blight, green leafhopper, and BPH biotypes 1 and 2. IR11288-B-B-65-1 has vigorous growth and attains a height of 160 cm if planted in regular water depths. Two other promising lines, IR11288-B-B-69-1 and IR11288-B-B-118-1, attain a height of 120 cm in normal water depths. However, all three have the ability to elongate with rising water depth.

Volume of IRRI's breeding program stabilizes

After a rapid growth in the early 1970s, when new plant breeding positions were added, the volume of the plant breeding programs has stabilized at the level shown in Figure 33. During 1982, we made 4,188 crosses, grew 1,003 F_2 populations, planted 102,397 pedigree nursery rows, and sent abroad 61,439 seed packets of IRRI breeding lines and varieties.

33. Growth of the IRRI breeding program, 1975-82.



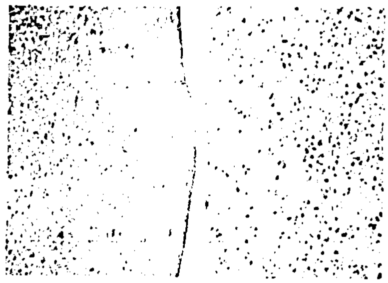
IRRI continues to work on chemical control of diseases, insects, and weeds, particularly where there are no identified sources of varietal resistance. Above, IRRI laborers Nestor Cunanan and Felix Lanbican place armyworm larvae in field cages for insecticide screening tests.

CONTROL AND MANAGEMENT OF RICE PESTS

Because of IRRI's emphasis on combining growth in yield potential with stability of performance, breeding for multiple resistance to pests and diseases continued to be a major research objective. Study of diseases, insects, and weeds specific to rice and pest management work have received high priority. In addition to research on varietal resistance, we continue work on ecology and chemical control of disease, insects, and weeds, particularly where no source of varietal resistance has been identified.

DISEASE CONTROL

The fight against rice diseases is a never-ending battle. Our plant pathologists continue their efforts to characterize the genetics and epidemiology of rice pathogens, to test methods of chemical control, and to assess yield losses for determining economic control methods. We have strengthened collaborative arrangements to study pathogenic variability of rice diseases in different countries.



1. A light micrograph shows the clumping of latex particles indicating the presence of grassy stunt virus in leaf extract (right) and the absence of clumping in virus-free leaf extract (left).

2. The practical application of the latex agglutination test in the field is shown where pieces of rice leaves are homogenized in test tubes to detect rice grassy stunt virus at a roadside in South Cotabato, Mindanao.

Etiology of grassy stunt

Virus-like filamentous particles were purified from grassy stunt-infected rice plants in Japan. Antiserum was obtained at the Institute for Plant Virus Research, Tsukuba, Japan. The filaments were ribonucleoprotein, 1000-1300 nm long, and circular. They were serologically, but not closely related to rice stripe virus, indicating that they are a virus agent of grassy stunt. We conducted serological tests and found that rice grassy stunt viruses 1 and 2 in the Philippines were closely related to rice grassy stunt virus in Japan.

Serological detection of rice viruses

We introduced two serological tests — latex agglutination test and enzyme-linked immunosorbent assay (ELISA) — for diagnosis of virus diseases and epidemiology and resistance studies.

We used the latex agglutination test to detect rice grassy stunt, rice tungro bacilliform, and rice tungro spherical viruses from infected rice leaves. This simple test takes less than 1 h and the results can be judged visually or under a light microscope (Fig. 1). In our disease monitoring, we conducted the latex agglutination test for the diagnosis of grassy stunt (Fig. 2). Plants showing

tungro-like symptoms also gave positive reactions in the latex test. We suspect these plants were infected with rice grassy stunt 2.

ELISA was adapted to detect rice grassy stunt and rice ragged stunt viruses in rice plants and the vector brown planthopper. We found that ELISA was sensitive enough to detect viruses from individual insects. This technique can be used in epidemiological studies of virus diseases.

Phenotypic analysis of *Xanthomonas* sp.

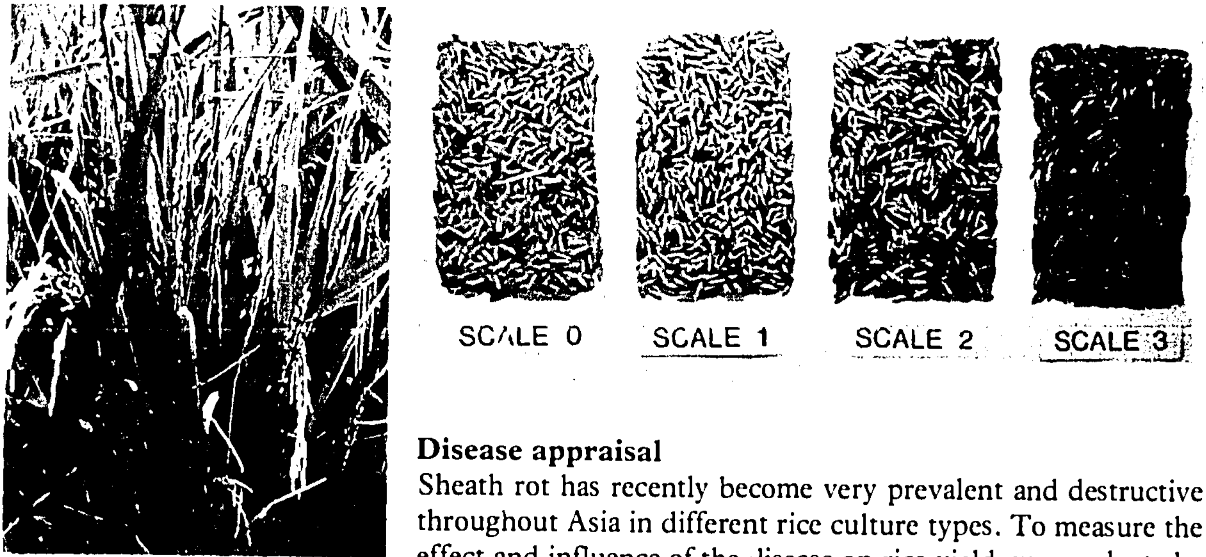
A rice disease named brown blotch, similar to bacterial blight, was reported in Latin America. In a collaborative project with the University of Ghent in Belgium, numerical analysis of the brown blotch, bacterial blight (*Xanthomonas campestris* pv. *oryzae*), and bacterial leaf streak (*Xanthomonas campestris* pv. *oryzicola*) pathogens showed three phenons. Phenon 1 was composed mainly of brown blotch isolates. Phenon 2 was composed of *X. c.* pv. *oryzae* with two strains, NCPPB 1152 and PXO 61, clustering somewhat lower than the other members of the group. Phenon 3 was composed mostly of *X. c.* pv. *oryzicola*. Subphenons A and B in phenon 1 could not be differentiated clearly, whereas subphenons C and D in phenon 3 could be differentiated by two features. Subphenon C could hydrolyze arbutin and grow in the presence of 0.0001% cadmium acetate, but subphenon D could not.

Bacteriocin-like substances produced by *Xanthomonas campestris* pv. *oryzae*

Twenty-two strains of *X. campestris* pv. *oryzae* produced bacteriocin-like substances on solid medium. Most of the 22 strains produced inhibition zones less than 2 mm from the colony margin against *X. c.* pv. *oryzae* indicator strains, but 4 to 6 mm against *X. c.* pv. *vasculorum* strains. Inhibition zones were larger at 20° C than 28° C in nutrient agar amended with 15 g sucrose/liter. The bacteriocin-like substances were heat-stable, sensitive to trypsin and protease, but insensitive to DNAase and RNAase. The bacteriocin-like substances were precipitated by $(NH_4)_2SO_4$.

Ecology and epidemiology

Many bacteria of different colony morphology from ricefields showed strong antagonistic activity against the rice sheath blight pathogen. The bacteria affected the viability of the sclerotia normally serving as primary inoculum of the sheath blight disease. We reduced sheath blight incidence and severity on plants sprayed with the bacteria.



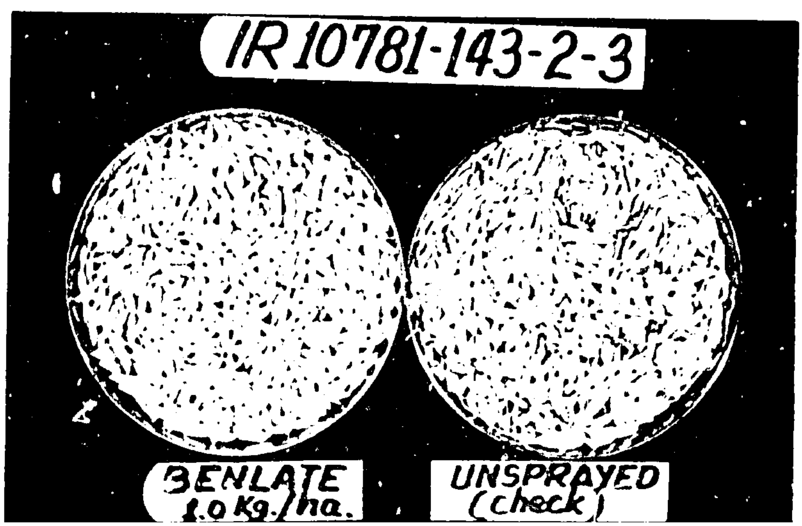
3. A portion of a sheath rot-infected field (left) and the discoloration effect on grains of different degrees of disease severity (right).

Disease appraisal

Sheath rot has recently become very prevalent and destructive throughout Asia in different rice culture types. To measure the effect and influence of the disease on rice yield, we conducted a study on susceptible line IR442-2-58 during the 1982 wet season. Yield loss obtained at different disease levels or intensities demonstrated sheath rot's influence. At a moderate to severe level of infection, the disease reduced yield by 37 to 98%. In addition, the disease also affects grain quality by causing discoloration (Fig. 3).

Chemical control

We applied benomyl 50WP 7 times at the rate of 1.0 kg formulation/ha per application at weekly intervals beginning at early booting stage. This effectively protected the seed from glume and grain discoloration incited by various fungi (Fig. 4). The benomyl sprays also provided ample protection against diseases such as narrow brown leaf spot (*Cercospora oryzae*), sheath rot (*Sarocladium oryzae*), blast (*Pyricularia oryzae*), and sheath blight (*Rhizoctonia solani*). The data suggested that we can apply chemicals to produce *clean seed* for dissemination by IRTP, germplasm, and breeding programs.



4. Clean rice seed (left) produced by chemical application.

CGA49104, a systemic chemical formulation specific to seed treatment for blast disease, was not efficacious on brown spot caused by *Helminthosporium oryzae*. This chemical, therefore, could serve to differentiate the two diseases in varietal screening.

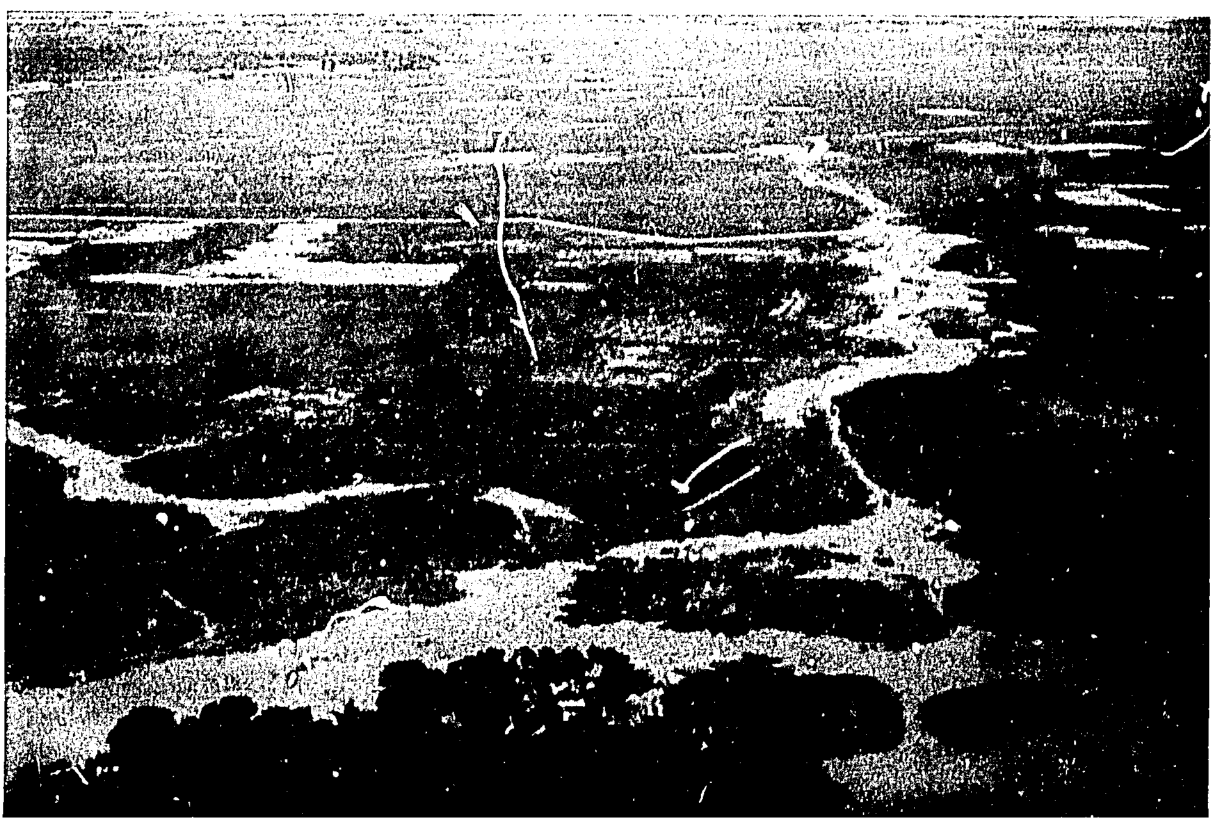
INSECT CONTROL

The search for biological control methods continues, particularly the use of pathogens of insect pests and plant derivatives. Through collaborative arrangements, and the regional deepwater group in Thailand, we are intensively studying pests not present in the Philippines. In 1982, we initiated a project to teach farmers integrated pest management.

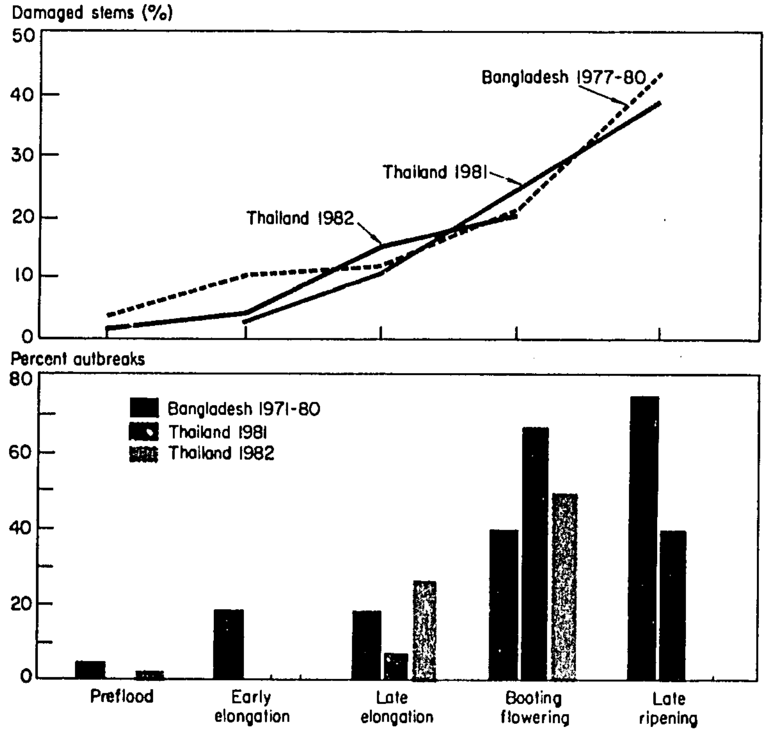
Insect pests of deepwater rice

Although insect pests are usually not considered to be severe on deepwater rice, studies to identify the major pests started in Bangladesh in 1977 with the Bangladesh Rice Research Institute/UK Overseas Development Administration Project and continued in Thailand in collaboration with the Rice Division of the Ministry of Agriculture/IRRI Deepwater Project.

Yellow stem borer. We found that the yellow stem borer can cause significant yield losses in deepwater rice. Unlike in paddy rice, deadhearts and whiteheads, typical yellow stem borer dam-



This is a typical deepwater rice area in Bangladesh where yellow stem borer populations are building up to damaging levels on rice at the mid-elongation stage.



5. Incidence of borer damage (predominantly yellow rice borer) in surveys of deepwater rice in Bangladesh (189 fields) and Thailand (57 fields in 1981, 75 in 1982). Thresholds: preflood — 5% deadhearts, elongation to flowering — 20% damaged stems, ripening — 40% damaged stems.

These deepwater rice stems at harvest are damaged by the feeding of yellow stem borer larvae. Despite the severe damage, typical deadheart and whitehead symptoms are seldom visible in deepwater rice.

age symptoms, are not common in deepwater rice. Of every 10 infested stems, only 1 deadheart or whitehead is visible in deepwater rice. Only 4% of the panicles show typical whitehead symptoms when 40% of the stems are damaged.

Surveys on almost 200 farms in Bangladesh during a 4-year period and on almost 60 farms in Thailand for 2 years showed that the percentage of stems damaged by the yellow stem borer increased steadily from the start of flooding to reach an average of 40% at harvest (Fig. 5).

To determine the extent of the yield losses, we developed special cages to maintain yellow stem borer populations. We compared yields in cages with and without stem borer. We also compared plots sprayed with insecticide using an ultralow-volume, spinning disc-type sprayer with naturally infested untreated plots. Yield losses in the various tests ranged from 19 to 51%.

Rice ragged stunt virus. Ragged stunt virus is primarily a problem in irrigated wetland rice where the brown planthopper (BPH) vector populations are often high. However, severe outbreaks of ragged stunt virus have occurred in the Central Plain of Thailand. We found that plants become infected with BPH prior

Table 1. Possible management tactics for deepwater rice pests.

Pest	Management tactics		
	Varietal resistance	Chemical control	Cultural control
Yellow stem borer	••[a]	•	•••[b]
Brown planthopper and ragged stunt virus	•••	••	–
Green leafhopper and tungro virus	•••	–	–
Ufra nematode	•••	•	•••[c]
Rats	–	•••	–

[a]• = least important, •• = moderately important, ••• = most important. [b]Crop residue treatment. [c]Crop residue destruction.

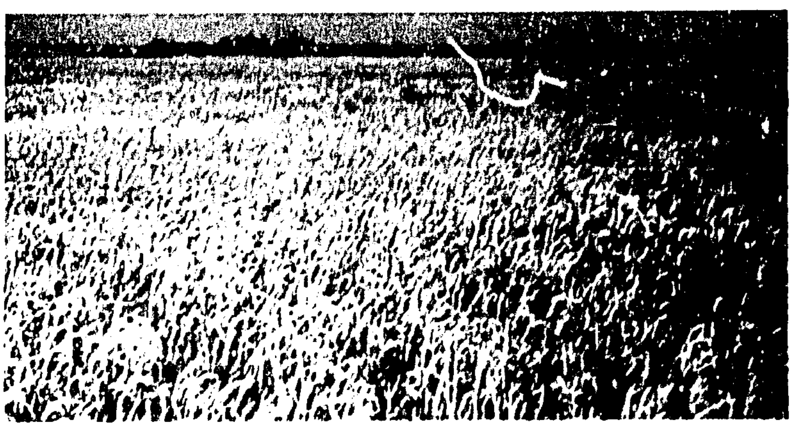
to flooding — during the late seedling stage when the vector populations are highest. We need BPH-resistant varieties to control ragged stunt virus.

Breeders are now incorporating genes for BPH resistance into deepwater rice breeding lines.

Control strategies. Several pests attack deepwater rice (Table 1). We need a pest control strategy based on varietal resistance because insecticide application in deepwater rice is very difficult. Another goal is to develop simple cultural control methods for yellow stem bo and ufra nematode involving cooperation of deepwater rice tarmers.

Black bugs threaten rice in Palawan

The black bug *Scotinophara coarctata* was reported for the first time at Bonobono, Bataraza, South Palawan, in September 1979. We observed heavy infestations around Brooke's Point July and August 1980, in Narra April 1982, in Quezon May 1982, and in seven barrios of Balabac Island September 1982. Yellowing and dwarfing are common, but bugburn (Fig. 6) and whiteheads are



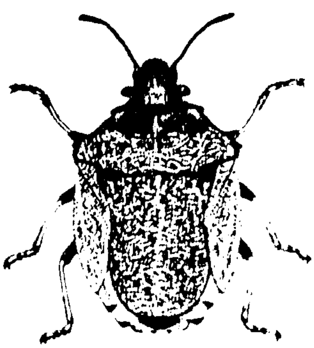
6. This is a ricefield suffering from bugburn at Sukamandi, West Java.

Spraying insecticides on deepwater rice is very difficult.

also frequently found. Adults are attracted to light at night, especially during the full moon (Fig. 7).

We are cooperating with Philippine Government agencies in studying the pest to limit further infestation in Palawan and avoid spread to the rest of the Philippines.

S. coarctata is a rice pest in Indonesia, East and West Malaysia, and Thailand.



7. Large numbers of black bug adults are attracted to light at Brooke's Point in June 1982.

Insecticide	Mortality (%)		Defoliation[a] (grade 0-9)
	24 h	48 h	
Triazophos	100	100	<1
M9918	97	100	<1
Monocrotophos	67	100	<1
Azinphos ethyl	60	100	<1
Control	0-7	0-10	8.0-8.3

Table 2. Laboratory evaluation of insecticides for armyworm control applied as foliar sprays at a rate of 0.75 kg ai/ha.

[a]Grade 0 = no damage, 9 = 100% defoliation 48 h after caging.

8. IRRI research assistant Ruperto Basilio inspects fourth-instar armyworm larvae at the rearing facility. These larvae will be used in field and laboratory screening of insecticides.

Insecticide screening for armyworm control

We developed laboratory and field test methods for evaluating insecticide effectiveness against armyworms using insectary-reared larvae at IRRI (Fig. 8). Triazophos, M9918, monocrotophos, and azinphos ethyl showed 100% mortality 48 h after treatment by foliar sprays (Table 2).

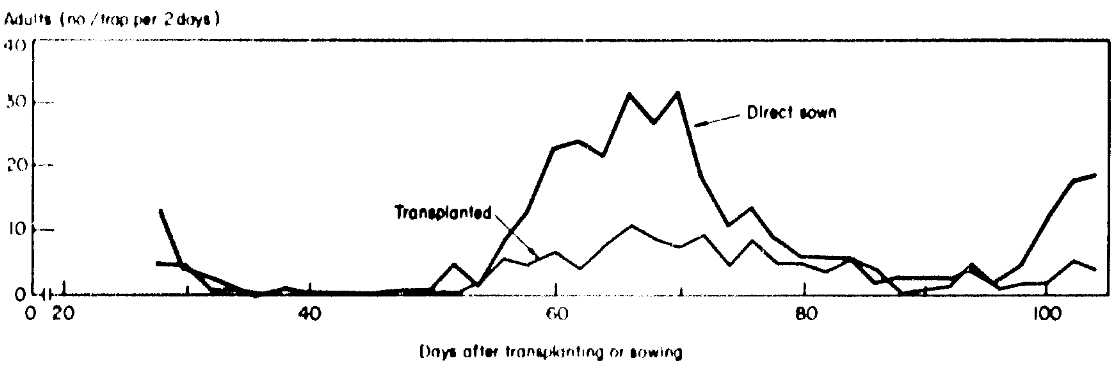
Insect pests on direct-seeded rice

Because direct-seeded rice is becoming popular in the Philippines, we surveyed occurrence of insect pests in direct-seeded and transplanted ricefields. Green leafhopper populations were higher on direct-seeded plots than on transplanted (Fig. 9), whereas BPH and whitebacked planthopper populations were almost the same on both plots. This suggests the possibility of more green leafhopper-transmitted tungro incidence on direct-seeded than on transplanted rice.

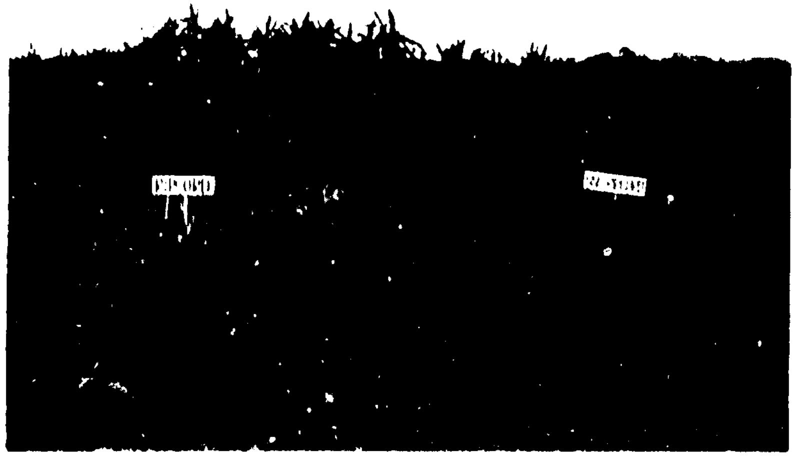
Preventing brown planthopper resurgence

We know some insecticides induce BPH resurgence, causing more hopper populations in treated than in untreated plots. When such insecticides are mixed with buprofezin (NNI-750),

9. *Nephotettix* sp. caught by sticky traps on the direct sown and the transplanted plots at Victoria, Laguna, Philippines, in the 1981-82 dry season.



10. Ripcord (cypermethrin) and Ripcord + NNI-750 were applied on IR22. BPH populations were checked at maturity stage in Calauan on 24 August 1982. We found that hopperburn had started in Ripcord-treated plots.



resurgence disapppears and the hoppers are gradually suppressed (Fig. 10). Buprofezin is effective for hopper nymphs as a molting disturber and is safe to natural enemies, fish, and man.

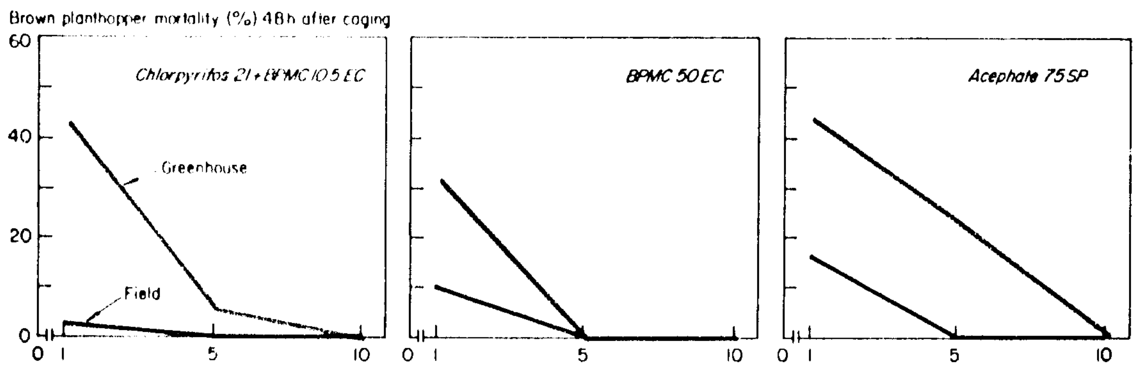
Insecticide-resistant brown planthopper populations

With repeated insecticide applications, the BPH may develop resistance to some insecticides as has happened in Japan and Taiwan, China. We found mortality was much higher on insecticide-free populations than on populations collected from the IRRI farm (Fig. 11). This shows a possibility of some BPH resistance to insecticides in the tropics.

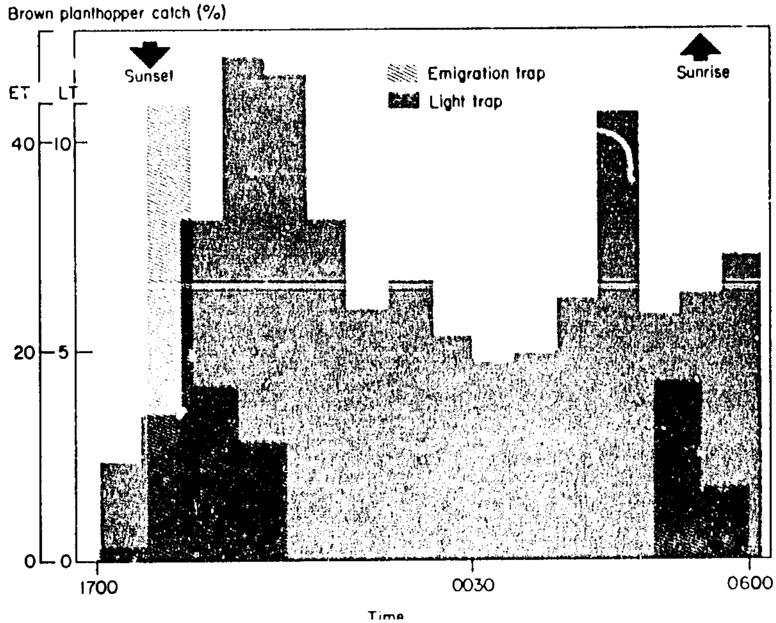
Brown planthopper migration

We continued studies to establish the normal flight range of BPH and investigate movement patterns. Emigration is restricted to the periods around dawn and dusk (Fig. 12). We designed a segregating light trap to determine the time of arrival of hoppers

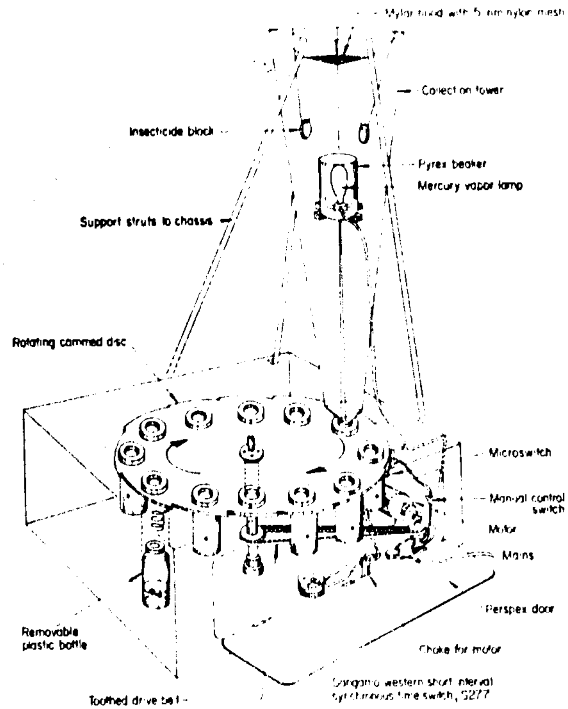
11. Mortality of greenhouse insecticide-free populations and of field populations collected from IRRI farm in April-June 1982 when treated by foliar sprays at 0.75 kg ai/ha.



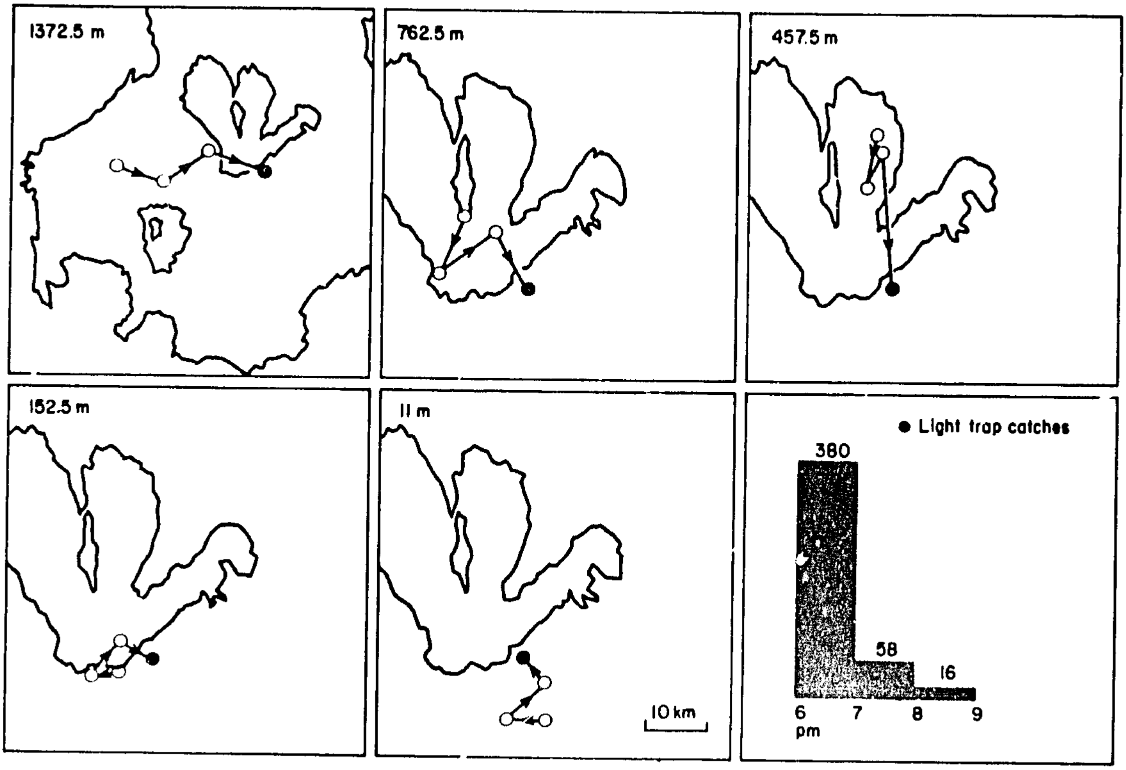
12. Periodicity of catch for BPH in emigration trap (ET) and light trap (LT). The light trap data are pooled over 1 year. Note the tendency for the major peak in light trap catches to occur some 2 hours after peak take-off.



at the trap during the night (Fig. 13). Assuming a dusk take-off, this gives an indication of the time in flight. Because displacement after take-off is largely passive and governed by wind, we



13. Segregating trap designed to investigate periodicity of light trap catches. The motor is switched on at 50-min intervals and rotates the disc to change the sample container. The trap is set at a height of 5 m and the light source directed upwards so that only flying insects are caught.



14. Simulated flight paths for BPH caught at Hanggan, Laguna, (⦿) on 6 September 1982 assuming different flight altitudes. The distance between the open circles represents 1 h flying time. Even at high altitudes, the majority of insects caught in the first hour would have traveled no more than 20 km.

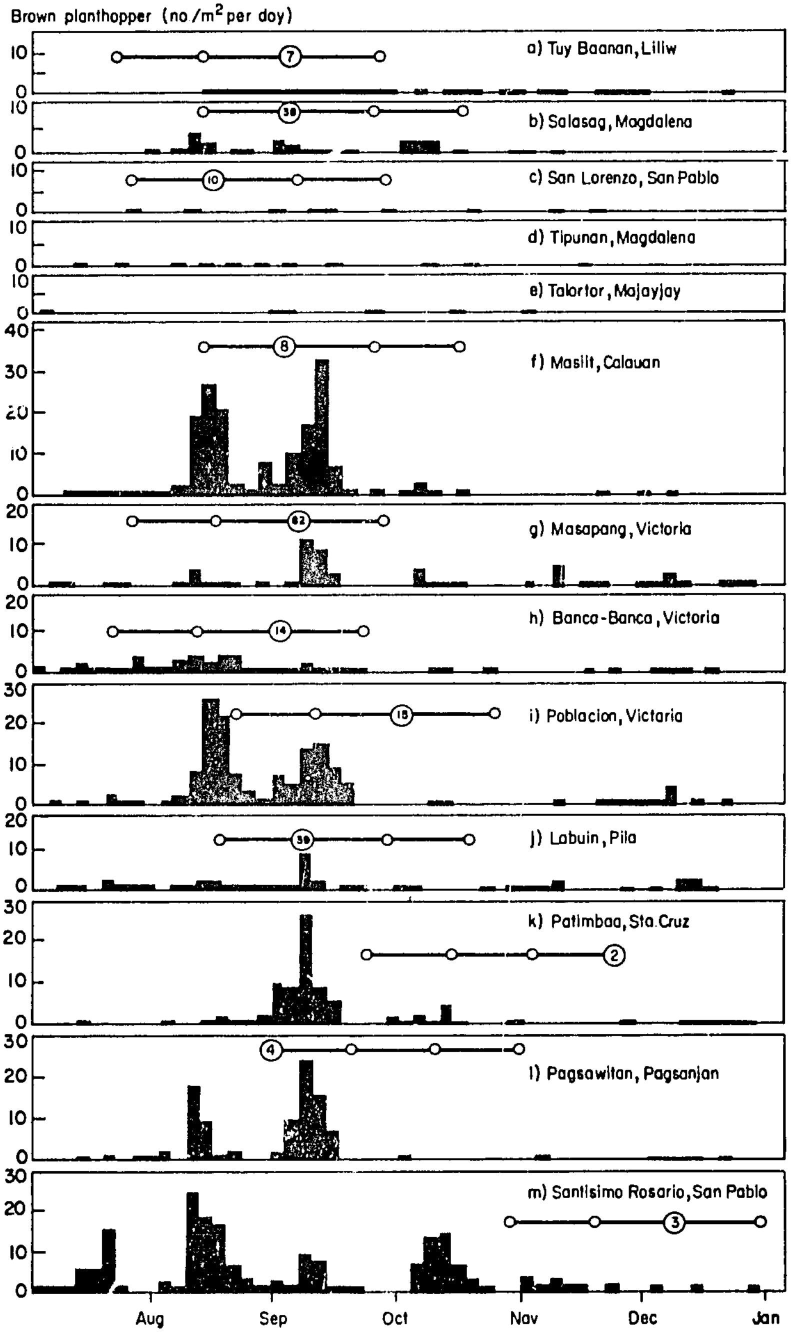
can combine this information with knowledge of meteorological conditions over the same period and simulate flight path trajectories. The periodicity of catch is highly variable from night to night. Peaks can occur at any time, although there is an overall tendency for higher catches in the early evening (Fig. 12). These probably correspond to short distance flights. Direction and distance traveled are profoundly affected by the height at which the insects fly (Fig. 14). We plan radar studies to clarify this.

In temperate countries, the level of initial immigration is the major factor in determining ultimate population size. Studies at a number of sites using yellow pan traps to monitor immigration show little correlation between immigration rate and subsequent population development (Fig. 15), suggesting this is not a useful indicator of potential control needs. Variability in catches between sites indicates highly localized differences in activity.

Mass rearing rice green semilooper

Recent studies show that high yield losses occur in the vegetative stage if several insect pests attack at once. Damage is higher from a multiple infestation with each pest at low population levels than from a single pest infestation. On hopper-resistant varieties, the vegetative stage is attacked by the greatest number of insect pest

15. Yellow pan trap catches (bar graphs) at field sites in Laguna both in the lake basin (wetland sites) and at higher elevations in the tree belt (dryland sites). Lines with circles show cropping period and each circle represents a population sample taken with a D-vac suction machine at 3-week intervals, the first at 30 days after transplanting. The large circle shows the maximum population per hill and its timing at each site. Note the lack of correspondence between immigration (yellow pan trap catches) and population size (D-vac samples).



16. Development of a practical method to mass-rear the rice green semilooper (left) has enabled Pat Pantua, IRRI research assistant (right), to produce a constant supply for insecticide evaluation, rice germplasm screening, host range and damage trials.

species and highest yield losses have been recorded during this early period of plant growth.

In light of this recent finding, the rice green semilooper, formerly considered a minor pest, has been elevated in importance along with other vegetative-stage pests. We know little of its distribution in tropical Asia, but it is widely found in the Philippines. We developed a mass rearing method which places newly emerged moths on potted rice plants in aerated cages and larvae on seedling rice in the greenhouse (Fig. 16). One generation takes 3 weeks.

Insect pathogens

In collaboration with the Boyce Thompson Institute for Plant Research, Ithaca, New York, we are testing pathogens as control agents of rice insect pests. Initially, we concentrated efforts on fungi against the BPH. The first step was to collect and catalog fungal pathogens naturally infecting rice insect pests in Asia. We now have 135 fungal isolates from the Philippines, Malaysia, Indonesia, Thailand, and China which have been cultured and are being bioassayed in the laboratory to determine virulence.

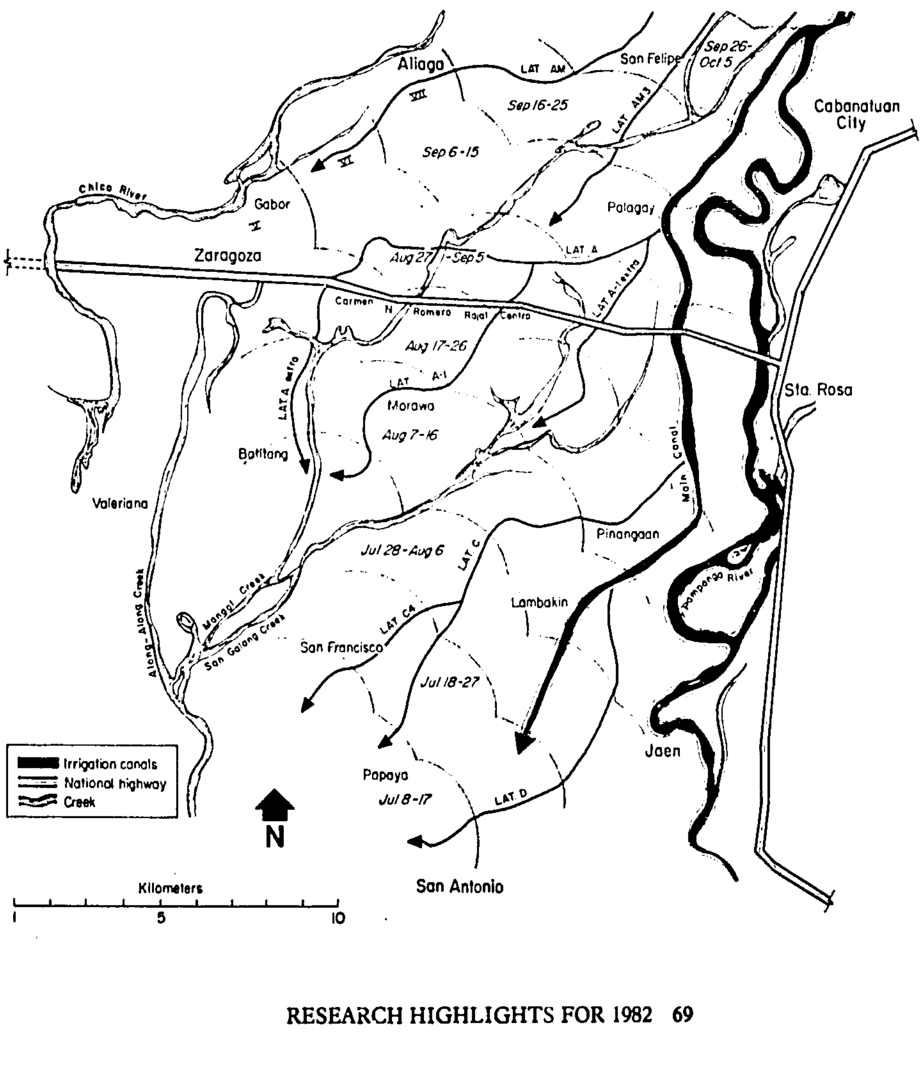
We will test the most virulent pathogens in the field by spraying suspensions of fungal spores on rice plants. We are now testing the effectiveness of fungal pathogens that have been successful in temperate regions. A Boyce Thompson strain RS252 of *Beauveria bassiana* achieved field infection rates of 40-50% against BPH, but controlled only 20% of the population.

Synchronous planting

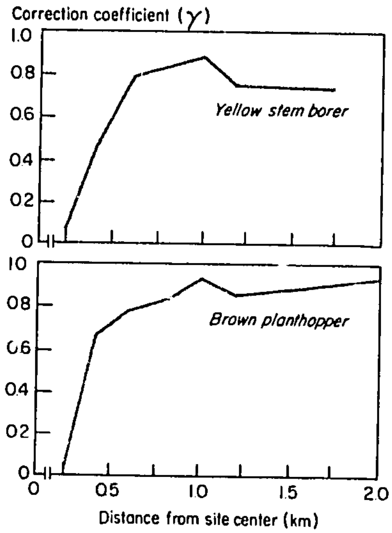
Farmers have learned from experience that to plant a crop out of synchrony with their neighbors leads to high pest damage. Rice-growing areas with the highest incidence of planthoppers and leafhoppers and the diseases they transmit have at least several hundred hectares where, in one spot, one can see ricefields in all stages of growth. The high pest populations in these asynchronous areas can reduce the life of pest resistant-varieties.

It is impractical for many reasons to expect farmers in a large irrigation system to plant together. We suggest that the most efficient means to implement synchronous planting would be to vary planting date gradually from one end to another, possibly relying on a scheme of tail-first irrigation which has been advocated as a more equitable means of distributing water (Fig. 17).

Planting would be done in zones and, within each zone,



17. A zonal schedule of planting dates overcomes the power, labor, water, and credit constraints that would arise from a recommendation of the synchronous planting of 17,000 ha in the Upper Pampanga River Integrated Irrigation System. In this example, planting begins at the tail end of the system in 2.5-km-wide zones successively planted at 10-day intervals.



18. We determined the effective dispersal range of the yellow stem borer and BPH by plotting the correlation coefficients between seasonal light trap totals and the variance of planting dates as a function of the distance within which this variance is calculated. The data represent sites differing in degree of synchrony. The correlation coefficient for yellow stem borer rises to a peak at 1 km and then declines, while that for the brown planthopper is still rising at 2 km.

farmers would need to plant their fields within the time span of one insect pest generation — a maximum of 3 weeks. The minimum size of each zone is related to the effective dispersal range of insect pests which we have found varies from 1 km (stem borers) to more than 2 km (BPH) (Fig. 18).

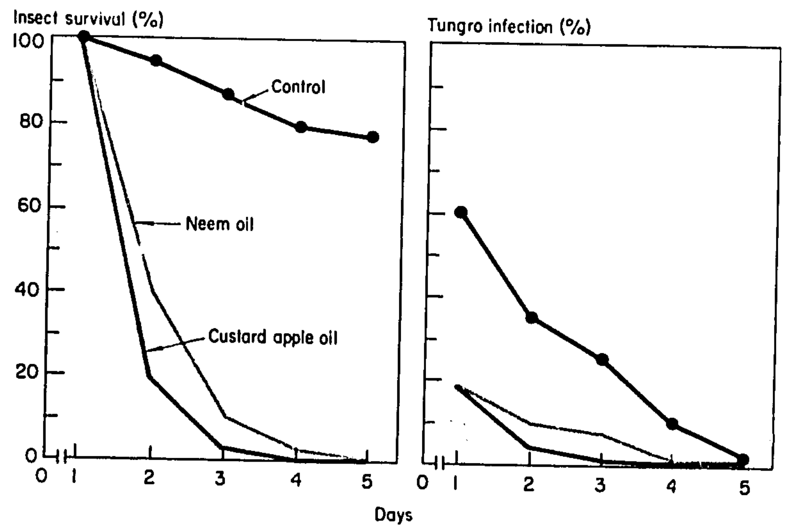
Synchronous planting works on the principle of removing the food from pests. Population suppression would be greater if the rice stubble is plowed down after harvest or allowed to dry for at least a 3-week period between crops.

Plant derivatives for management of rice insect pests

The effects of custard apple oil and neem oil on rice leafhoppers and planthoppers were reported in 1980-81. In 1982, we tested custard apple oil and neem oil for protecting rice seedlings from viruliferous green leafhoppers and rice tungro virus. Insects failed to survive beyond 5 days on oil-sprayed TN1 seedlings (Fig. 19). Insect survival and rice tungro virus transmission became progressively less as oil concentration increased. On the first day of inoculation feeding, rice tungro virus infection in oil-treated seedlings was 18-19%, compared with 60% in the control. Infection was markedly reduced on successive days of inoculation feeding on oil-treated seedlings, but control seedlings were infected even after 5 days of inoculation feeding by viruliferous insects.

Neem oil formulations for brown planthopper control

Because sunlight rapidly degrades the activity of neem oil, sunshields are necessary. We tested crude neem oil formulations



19. Survival of insects and rice tungro virus infection by *N. virescens* exposed for different lengths of time on oil-treated TN1 seedlings. IRRI, 1981-82.

Table 3. Yield in rice fields sprayed with neem oil formulations. IRRI, March-June 1982.[a]

Treatment[b]	Yield[c] (t/ha)
Neem oil + carbon	3.85 a
Neem oil + latex	3.65 ab
Neem oil	3.70 ab
Control (unsprayed)	3.45 b

[a]IR1917-3-17, a brown planthopper-susceptible selection, was planted in 11- × 20-m plots. Each treatment was replicated 4 times. [b]Neem oil formulations were sprayed at 5, 25, 45, 65, and 85 days after transplanting, using an ultra-low volume applicator. [c]Means followed by a common letter are not significantly different at the 5% level.

containing 1% carbon (C-170, Fisher Sci. Co., USA) or 2% liquid latex (supplied by Mr. Richard Wilkins, University of Newcastle-upon-Tyne, UK) for BPH control. Although the pest incidence was low, we recorded a significantly smaller nymphal population in field plots that received five periodic sprays of neem oil-carbon formulation using an ultralow-volume applicator. Neem oil sprays did not affect beneficial insects. Yield was significantly higher in plots sprayed with neem oil-carbon formulation than in the control (Table 3).

Effects of neem oil on rice armyworm

We tested repellency and embryonic inhibitory properties of neem oil against the rice armyworm. Fewer first-instar larvae settled on rice leaf cuts from plants sprayed with neem oil than on leaf cuts sprayed with 1.66% detergent solution (Table 4). Hatchability was progressively reduced when rice armyworm eggs were dipped in increasing concentrations of neem oil (Table 5).

Table 4. Settling response of first-instar rice armyworm larvae allowed a choice between leaf cuts from rice plants sprayed with neem oil and from plants sprayed with detergent solution. IRRI, 1982.[a]

Treatment	Larvae on oil-treated leaf cuts[b] (%)	Difference[c] (T-50%)
Water vs 1.66% detergent	47 a	3 ns
1.56% neem oil vs detergent	22 ab	28 **
3.15% neem oil vs detergent	15 b	35 **
6.25% neem oil vs detergent	28 ab	22 *
12.5% neem oil vs detergent	23 ab	27 **
25.0% neem oil vs detergent	19 b	31 **

[a]Av of 10 replications, 20 larvae/replication. [b]Recorded after 24 h. Means followed by a common letter are not significantly different at the 5% level. [c]ns = not significant; *, ** = significant at 5% and 1% levels.

Table 5. Effect of dip treatments of neem oil on hatchability of rice armyworm eggs. IRRI, 1982.[a]

Treatment	Eggs hatched (%)
1.66% detergent (control)	94 a
1.56% neem oil	51 b
3.12% neem oil	46 b
6.25% neem oil	33 b
12.5% neem oil	12 c
25.0% neem oil	5 c

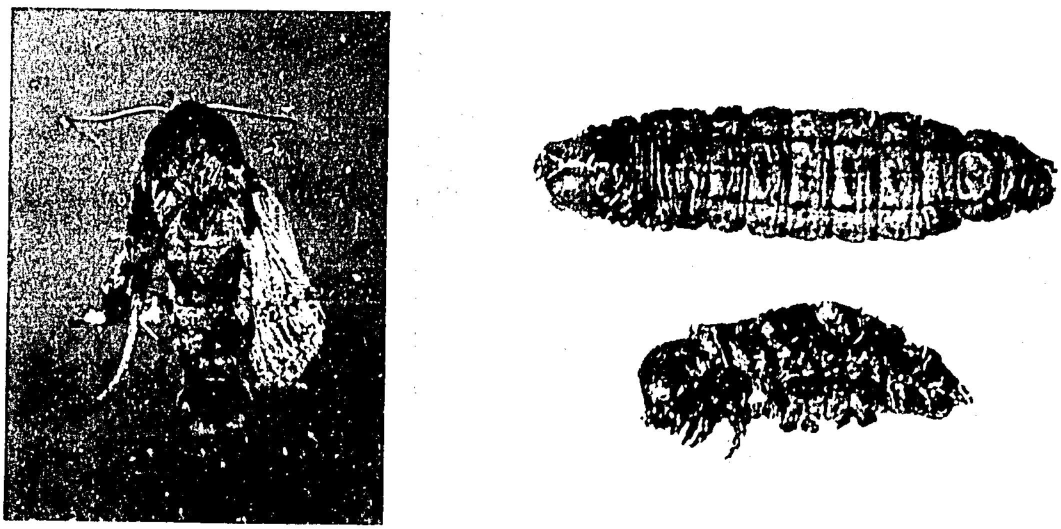
[a]Av of 8 replications, 50-350 eggs/egg mass per replication. Means followed by a common letter are not significantly different at the 5% level.

Morphogenetic effects of fractions and extracts of neem seeds

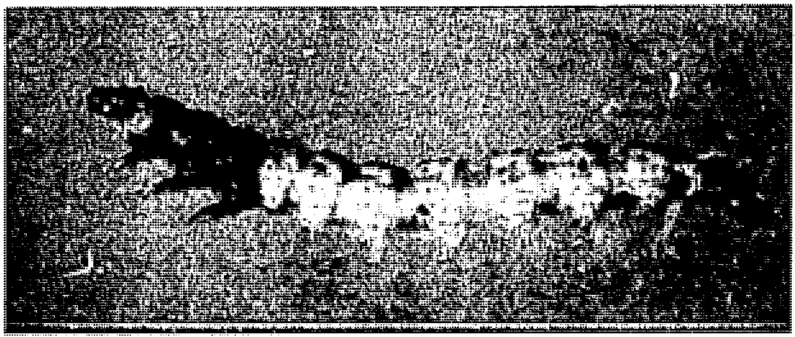
We tested morphogenetic effects of four partially purified fractions of neem seed and two methanolic extracts on the rice ear-cutting caterpillar and the rice leaf folder. Larvae fed for 24 h on rice leaf cuts dipped in different solutions of the partially purified fractions and methanolic extracts exhibited pronounced developmental abnormalities and mortalities in succeeding larval instars and in pupal and adult stages (Fig. 20, 21). A fraction, which did not contain azadirachtin, showed the strongest growth-disrupting effect on young 6th-instar rice ear-cutting caterpillar larvae.

Effect of azadirachtin

Topical application of azadirachtin, a tetracyclic triterpenoid in neem seed, on 5th-instar BPH and green leafhopper caused



20. Larvae of *M. separata* begin to show pronounced body shrinkage (right); an adult shows a reduced and crumpled wing (left). These selected examples of developmental abnormalities resulted from 5th- and 6th-instar larvae confined for 24 h on leaf cuts dipped in different solutions of methanolic neem seed extracts or partially purified fractions.



21. Larva of *C. medinalis* shows blackening of thoracic segments as a result of confinement for 24 h on rice leaf cuts dipped in solution of methanolic neem seed extract.

significant reduction in adult emergence (Table 6) and abnormalities such as retention of nymphal exuviae and distorted wings.

Efficacy of neem cake against brown planthopper

Neem cake, a bulky residue of neem seeds after oil expulsion, is known to possess insect antifeedant properties. Although there was no marked difference in the alighting response, the quantity of food ingested by BPH females was significantly less on plants treated with urea and neem cake than on plants treated with urea alone (Table 7). Antifeedant principles of neem, therefore, persist in neem cake and are translocated in the rice plant. This was further demonstrated by a significant reduction in growth and development of BPH nymphs on neem cake-treated plants.

Purified fraction isolated from the extract of an indigenous plant

In previous years, we reported diverse biological effects of the extract of an indigenous plant on insect pests of rice and other crops. A purified fraction of this extract caused significantly high mortalities of nymphs of BPH, whitebacked planthopper, and

Table 6. Adults emerging from 5th-instar brown planthopper (BPH) and green leafhopper (GLH) nymphs topically treated with azadirachtin. IRRI, 1982.[a]

Dose (μg/insect)	Adult emergence (%)	
	BPH	GLH
0	100 a	100 a
1	47 b	77 a
5	43 b	17 b
10	0 c	20 b
15	0 c	10 b

[a]Av of 3 replications, 10 insects/replication. In a column, means followed by a common letter are not significantly different at the 5% level.

Table 7. Quantity of food ingested by brown planthopper (biotype 1) females and growth and development of nymphs on TN1 plants treated with urea and neem cake. IRRI, 1982.[a]

Treatment	Quantity of food (mg) ingested/female in 24 h[b]	Nymphs becoming adults (%)[c]
Urea	45 a	98 a
Sulfur-coated urea	47 a	88 ab
Urea + 10% neem cake	43 ab	88 ab
Urea + 20% neem cake	44 ab	78 b
Urea + 30% neem cake	33 b	70 b

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]Av of 9 replications, 5 females/replication. [c]Av of 5 replications, 10 first-instar nymphs/replication.

Table 8. Mortality of first-instar nymphs of brown planthopper (BPH), whitebacked planthopper (WBPH), and green leafhopper (GLH) when caged on TN1 seedlings dipped in a solution of a purified fraction of the extract of an indigenous plant. IRRI, 1982-83.[a]

Concentration (mg/kg)	Mortality[b] (%)		
	BPH (biotype 1)	WBPH	GLH
0 (control)	0 d	0 d	0
100	0 d	5 d	12
200	30 c	33 c	30
300	70 b	75 b	45
400	93 a	97 a	57
500	100 a	97 a	80

[a]Av of 6 replications, 10 nymphs/replication. In a column, means followed by a common letter are not significantly different at the 5% level. [b]Mortality recorded at 24 h after infestation.

green leafhopper when caged on rice seedlings that had been dipped in a solution of the purified extract (Table 8). Chemical synthesis and optimization of the fraction are in progress.

Teaching farmers IPM

In an irrigated double rice crop area in Nueva Ecija, we initiated a project to teach farmers integrated pest management (IPM). We held weekly classes in each village during a crop season to teach farmers how to identify insects and quantify their populations so they can base insecticide applications on pest abundance via economic thresholds rather than calendar-based scheduling. We gave classes in seven villages over four crop seasons (Fig. 22).

Preliminary results indicated that farmers were not able to assimilate IPM technology from classes given during one crop

22. Weekly integrated pest management (IPM) classes were given to farmers by Jovito Bandong, IRRI research assistant. The classes combined lectures, classroom demonstrations, question-and-answer periods as well as field practice. They served to create farmer interest in IPM but follow-up meetings in successive crops were essential for farmers to implement the technology themselves.

season; therefore we returned to hold follow-up meetings in two villages where classes had been given previously.

No classes were given during the follow-up meetings, and we met with farmer leaders on a weekly basis during the crop season. The farmers agreed not to apply insecticide until after the meetings. During each meeting the farmer leaders reported their observations and told us whether they would apply insecticides as a result of their monitoring activities. After the brief reporting period, the group went to several fields where the pest problems were most evident and we checked the farmers' observations. If the farmers had misdiagnosed a pest problem or made an incorrect assessment of a population level, we corrected them in the field.

The results during the 1981 dry season showed that in two villages where no follow-up meetings were held, farmers applied insecticides equally frequently among those who attended classes

(6.7 times) or had not attended (7.1 times). Insecticide applications were significantly fewer among farmers in the two villages where we held follow-up meetings. Farmers who attended both classes and follow-up meetings applied insecticides significantly fewer times (2.4) than those who attended only follow-up meetings (4.0).

These results show that an extension technician covering all aspects of crop production can easily cover eight villages and that the current concept of assigning one technician per village is an inefficient use of time.

WEEDS

We have been placing emphasis on weed control in dry-seeded rainfed production systems where weed competition is a major obstacle to establishing a rice crop. However, we are also looking at weed control in direct-seeded flooded rice which is becoming increasingly popular in tropical Asia. We continue to screen herbicides for weed control in a range of conditions.

Herbicide applied with sprinkler bottle on transplanted rice

We continued sprinkler bottle application trials with herbicides, such as thiobencarb, which is formulated for use as a diluted spray and commonly applied after rice planting. Weed control and grain yield increases were the same when thiobencarb was applied without dilution or sprayed with water added both before and after transplanting (Fig. 23).

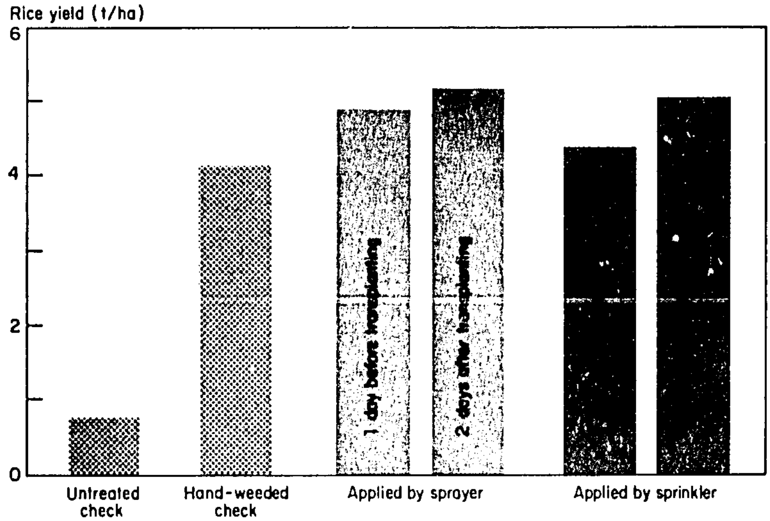
Control of *Scirpus maritimus* in direct-seeded flooded rice

Direct-seeded flooded rice culture has become increasingly important in the Philippines and other tropical Asian countries such as Malaysia and Thailand. In some Philippine provinces, about 50% of the total wetland rice area is planted to direct-seeded rice.

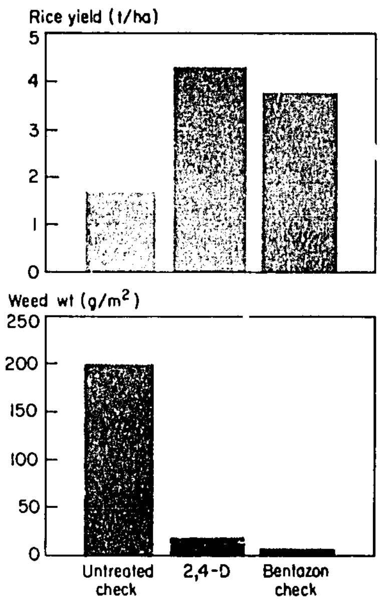
Weeds are more critical in direct-seeded than in transplanted rice, and are controlled mainly with herbicides where rice is broadcast-seeded. However, continued use of the same or similar herbicides often leads to infestation of perennial weeds such a *Scirpus maritimus*.

We tried chemicals that control *Scirpus maritimus* in transplanted rice on direct-seeded rice. One application of 2,4-D 25

23. Rice yield where thiobencarb was applied with sprinkler bottle was similar to that when thiobencarb was diluted and applied with a sprayer before and after planting.



days after seeding was comparable with bentazon and gave sufficient control for a rice yield increase of more than 2 t/ha (Fig. 24).



24. A single application of 2,4-D (0.75 kg ai/ha) provided adequate control of *Scirpus maritimus* and a corresponding increase in yield of direct-seeded wetland rice (IR36).

Application time of herbicides in wet-seeded flooded rice

Butachlor, a commonly used rice herbicide, is normally applied soon after emergence (6 days after seeding) of the weeds in wet-seeded rice to minimize injury to the crop. However, this herbicide provides better control if applied before weeds emerge from the soil surface.

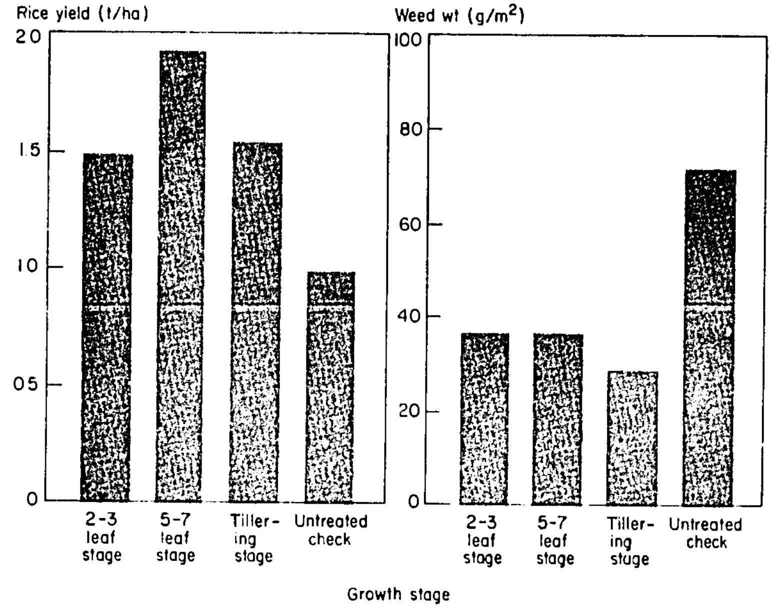
We examined the effect of butachlor on the weeds and the crop at various application times. We found butachlor applied 3 days before seeding onto puddled fields provided better weed control without reducing the crop stand and rice yield than when applied 6 days after seeding (Table 9).

Table 9. Butachlor (1.9 kg ai/ha) applied 3 days before rice seeding provided better weed control than when applied 6 days after, and produced equivalent crop stand and yield.[a]

Application time (days before seeding)	Weed wt (g/m^2)	Rice Stand (no./m^2)	Rice Yield (t/ha)
3	3 a	169 a	4.3 a
6	32 b	181 a	3.6 a

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

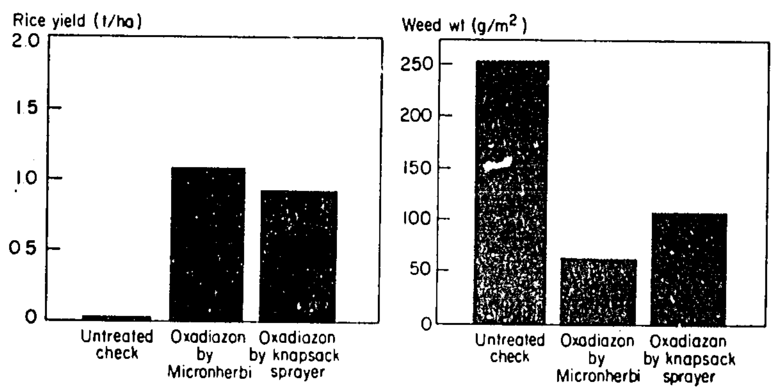
25. Bentazon (2.0 kg ai/ha) provided sufficient control of *Scirpus maritimus* L. and *Cyperus iria* L. and was safe to wet-seeded rice when applied at the 5-7 leaf stage of the crop. IRRI, 1982 wet season.



The effectiveness of most herbicides is influenced by their application time relative to the growth stages of both crop and weeds. In wet-seeded rice, we found that bentazon at 2.0 kg ai/ha gave adequate control of *Scirpus maritimus* L. and *Cyperus iria* L. and was least phytotoxic when applied at the 5- to 7-leaf stage of rice (Fig. 25).

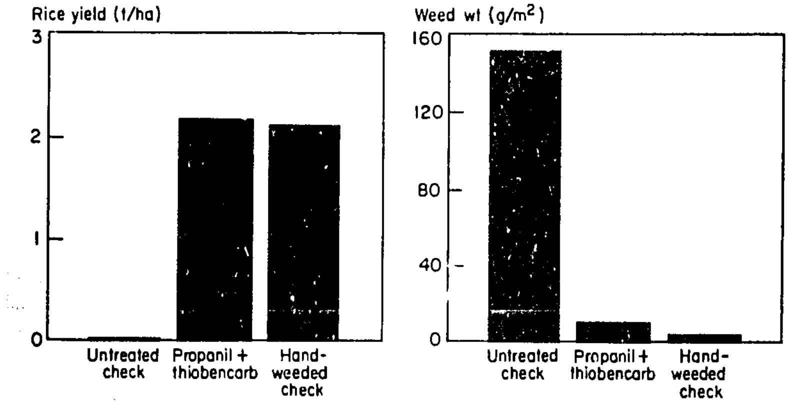
Herbicide application methods in dry-seeded rainfed bunded rice

The Micronherbi, a relatively new ultralow-volume sprayer, allows the application of herbicides where water supply is limited and the water source is inaccessible. Herbicides, such as oxadiazon, applied with the Micronherbi consistently provided weed



26. Weed control and grain yield of dry-seeded bunded rice provided by oxadiazon (0.6 kg ai/ha) applied with Micronherbi were comparable to those with the knapsack sprayer.

27. A single application of a mixture of propanil and thiobencarb (1.61 + 0.89 kg ai/ha) provided adequate control of weeds and gave rice yields comparable to those from 3 hand weedings. IRRI, 1982 wet season.



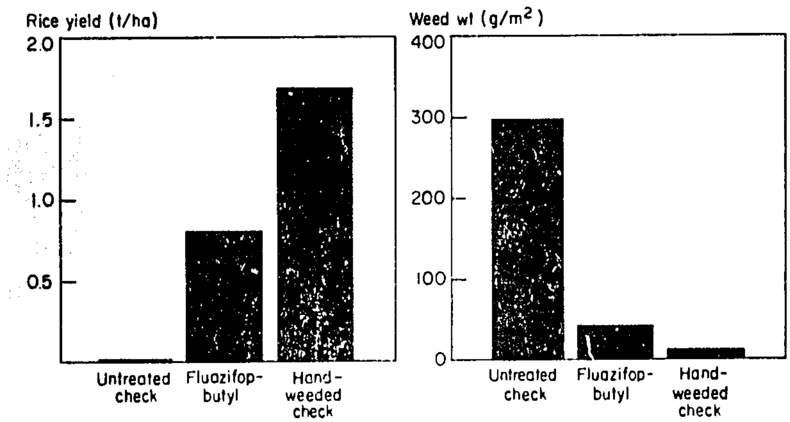
control and yield comparable with those obtained using the knapsack sprayer (Fig. 26).

Weed control in dry-seeded rainfed bunded rice

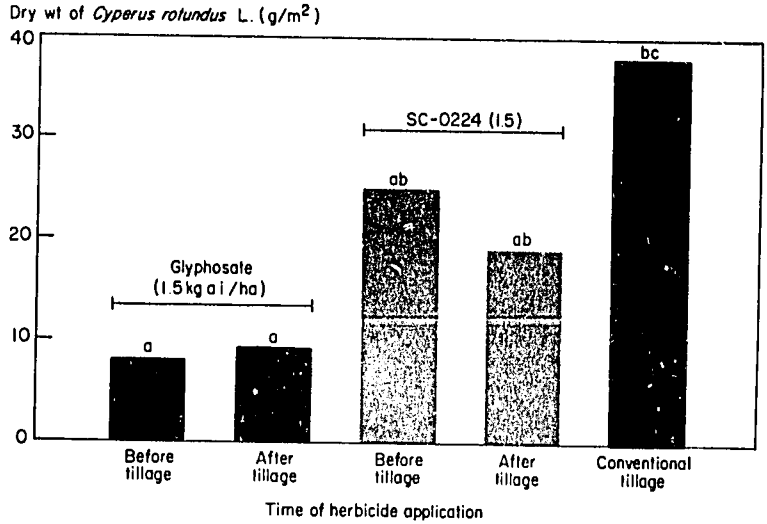
During the 1982 wet season, we tested herbicide combinations to control weeds in dry-seeded rainfed bunded rice. Herbicide combinations continued to provide good weed control and produced yields equivalent to those obtained from hand weedings. One application of a mixture of propanil and thiobencarb after emergence of rice and weeds provided adequate weed control to give a rice yield increase of more than 2 t/ha over the untreated control (Fig. 27).

Control of *Rottboellia exaltata* with herbicides in dryland rice

Rottboellia exaltata is becoming a potentially dominant grassy weed in dryland rice. We continued to search for chemicals to control this weed in dryland rice culture. One application of



28. A single application of fluazifop-butyl (0.25 kg) adequately controlled *Rottboellia exaltata* in dryland rice.



29. A combination of herbicides (glyphosate and SC-0224) and one rototilling provided adequate control of *Cyperus rotundus* L. in dryland rice. Bars with a common letter are not significantly different at the 5% level.

fluazifop-butyl 1 week after rice emergence provided sufficient control to give acceptable yield increases over the untreated check (Fig. 28).

Control of *Cyperus rotundus* L. in dryland rice

We continued our search for suitable technology to control *C. rotundus* in dryland rice. One preplant application of either glyphosate or the experimental compound SC-0224 at 1.5 kg ai/ha about 1 week before or after one rototilling provided sufficient control of the perennial weed (Fig. 29). However, neither herbicide controlled *Rottboellia exaltata* L.f., another difficult weed in dryland rice.

IRRIGATION WATER MANAGEMENT

Inefficient use of costly irrigation water remains a major limitation to maximizing the economic benefits from modern rice technology. In 1982, we continued our efforts to develop and evaluate techniques of water allocation and distribution in the different types of irrigation systems to increase effective water use. In a collaborative project with the Bangladesh Rice Research Institute and Bangladesh Water Development Board, we studied benchmark water use in a tubewell system.

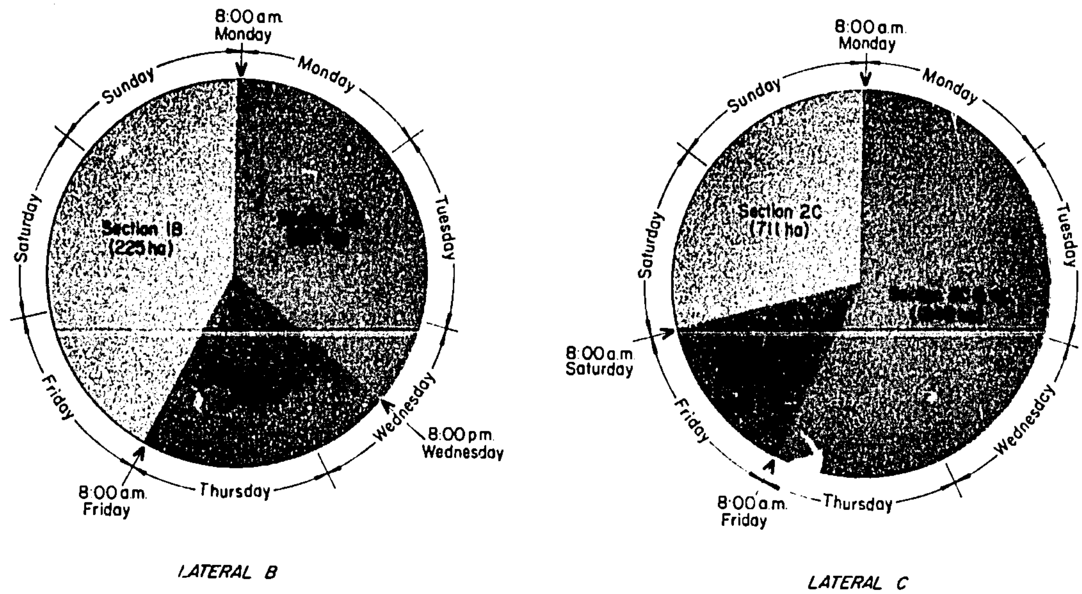
Group workers in Bayanihan construct and maintain their communal irrigation structure that diverts water from local river. In 1982, IRRI concluded a major study on the performance of such irrigation systems.

Improving allocation and distribution in pump irrigation

In collaboration with the National Irrigation Administration of the Philippines, we designed and tested an improved model to allocate and distribute water to the service area of the Libmanan-Cabusao Pump Irrigation System (LCPIS) in the Bicol Region. The model should have wide applicability. LCPIS started its irrigation delivery in the 1981 wet season (WS) with an irrigable area of 3,470 ha, but in that season only 48% of the area was actually irrigated. Irrigation water was delivered to each lateral continuously for all its turnouts and was to be used rotationally by the farmers within each 30-50 ha unit served from a common turnout. The water distribution was highly inequitable in the major secondary canal, lateral C, which has a total irrigable area of 2,097 ha. Only 678 ha of lateral C area was actually irrigated in the 1981 WS and most of that was localized near the head and middle reaches of the canal.

We designed the improved model with these objectives:

- to establish equity of water allocation and distribution within the head, middle, and tail reaches of the irrigable area,



1. Schedule of irrigation water delivery by section of lateral canal, LCPIS, 1982 DS.

- to increase the efficiency of irrigation water use by expanding area irrigated per unit volume of water pumped, and
- to test farmer acceptance and ease of field implementation.

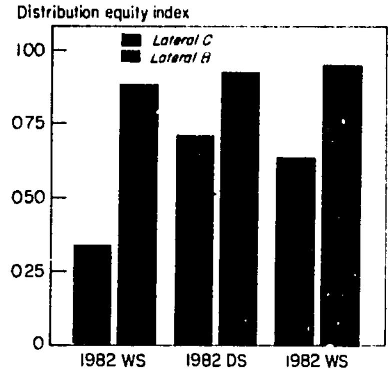
The method allows a predetermined section of a lateral canal to receive the canal flow for a specified period of time within each week of the season (Fig. 1). All farmers know that turnouts should remain open on a given day in only one specified section and all others upstream should remain closed.

The improved model was tested during the 1982 dry season (DS) and WS at laterals C and B of LCPIS. Lateral C has about 60% and lateral B 16% of the system's total irrigable area.

Water distribution equity. To measure the water distribution equity within each canal's irrigable area, we introduced the distribution equity index (DEI). The DEI concept is defined as the degree of success achieved in irrigating the different sections of a canal with respect to the proportions of area targeted for irrigation in those sections.

Figure 2 shows that the improved model of water allocation and distribution implemented in lateral C increased the DEI by about 110% in the 1982 DS and about 85% in the following WS compared with the 1981 WS benchmark value. In lateral B, the DEI was very high at the benchmark time and increased very slightly during the two following seasons when the improved model was applied.

Effective use of irrigation water. We determined the effective use of irrigation water in the 1982 DS and WS with respect to the



2. Distribution of water to the farmers at different parts of lateral C canal was more equitable in the 1982 DS and WS with implementation of the improved water allocation-distribution model.

total area irrigated, the irrigated area per unit of pumped water, water productivity, and yield.

In lateral C, total area irrigated increased by 20% during the first season of improved model implementation and by 55% during the second season (Table 1). In lateral B, the area irrigated increased from a relatively high value of 76% to 79% in the 1982 WS. Very substantial gains were made in 1982 WS compared with the 1981 WS in both laterals in water use, measured as the area irrigated per unit volume of water pumped, and water productivity, measured as the amount of grain produced per unit depth of pumped water used. These two values in the 1982 WS are higher for lateral B than for lateral C because a lower amount of water pumped per hectare of irrigated area was delivered to lateral B. For the 1982 DS, both irrigated area per unit of water pumped and water productivity are lower than the corresponding values in either of the two WS because of less rainfall and more pumped water delivered in the dry season.

Implementation and farmer acceptance. The improved allocation and distribution model seems practically easier to implement than the continuous allocation method because, in the improved model, a shorter reach of the canal receives irrigation water on any given day. For situations where the volume of water delivery to each canal turnout is difficult to control, the improved model offers a special advantage to tail-end farmers. The supervision requirements are fewer and easier to handle. Once the method is established, farmers in each section know their exclusive rights to the canal water during a specific period of each week.

Our experience indicates that farmer acceptance of the improved method is generally good because water is equitably

Table 1. Effective use of pumped water during 1981 wet season (bench mark) and 2 subsequent seasons with improved water allocation and distribution.[a] Laterals B and C, Libmanan-Cabusao Pump Irrigation System, Camarines Sur, Philippines.

Item	Lateral C			Lateral B		
	1981 WS	1982 DS	1982 WS	1981 WS	1982 DS	1982 WS
Total area irrigated (ha)	678.4	811.5	1,049.5	416.3	420.2	435.1
Area irrigated/unit pumped water (ha/m^3) × 10^4	0.71	0.94	2.45	1.10	0.86	5.59
Av rice yield (t/ha)	2.50	3.52	2.71[b]	3.38	3.48	3.54[b]
Rainfall (mm)	599	466	1,142	599	466	1,142
Productivity of water (kg/ha per mm)						
• pumped water	1.78	3.31	6.63	3.72	2.99	14.21
• pumped water + rainfall	1.25	2.30	1.75	2.25	2.13	1.92

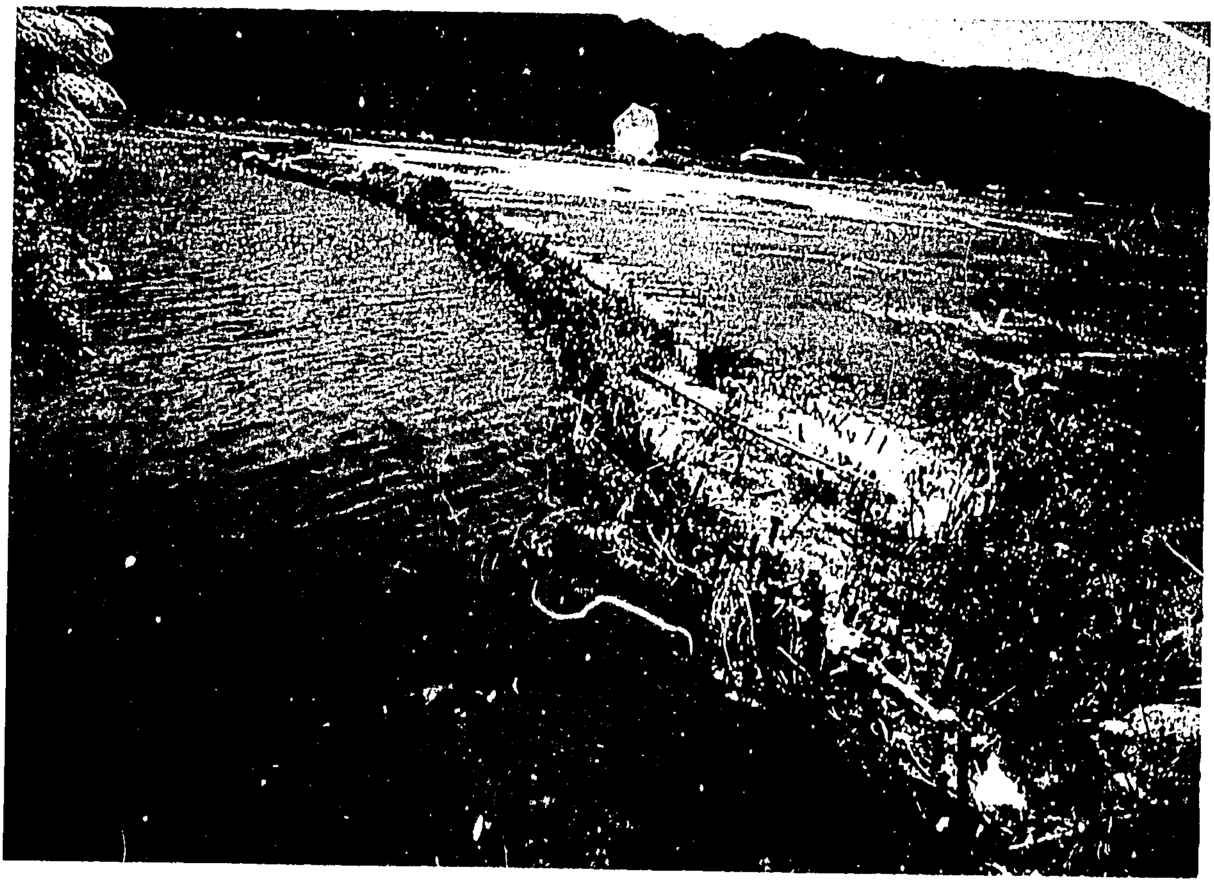
[a]WS = wet season, DS = dry season. [b]1982 DS yield and production were reduced by 2 major typhoons, the last one hitting many rice fields with the crop at the reproductive or ripening stage.

shared with all. The tail-end farmers are most enthusiastic. Top-end farmers' cooperation is achievable with assured water for their needs. Our training sessions, which brought together farm leaders from all sections of a lateral, proved helpful in bringing a common understanding of the usefulness of the new schedules.

Communal system management

In 1982, we concluded a major study in collaboration with the National Irrigation Administration's (NIA) communal irrigation committee. The 100 communal irrigation systems studied were an 8% sample of 1,253 communals throughout the Philippines assisted by NIA from 1965 to 1978. Major considerations in the sample design were the development period, the system size, and the climatic type. Our major concern was to determine system performance.

The average cropping intensity obtained from the 100 communals was 1.67. The highest (1.8) was obtained in areas with a uniform annual rainfall distribution, and the lowest (1.56) in areas with distinct and pronounced WS and DS rainfall differen-



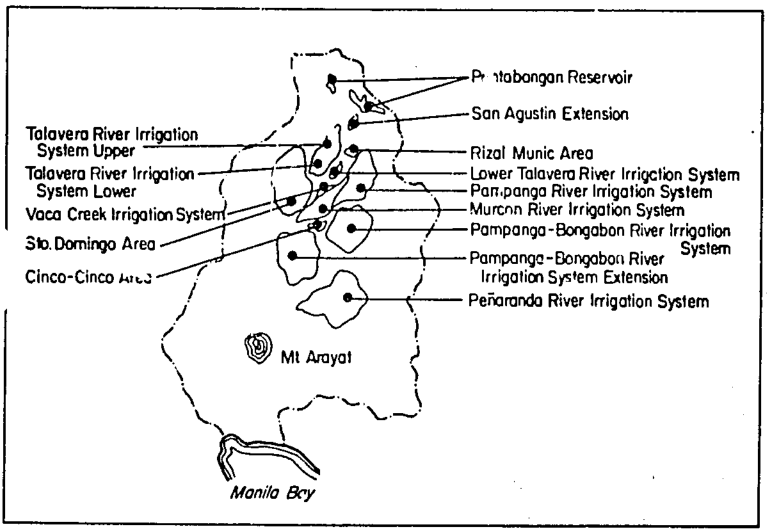
Most communal irrigation systems have only a temporary brush dam that requires replacement one or more times each year. NIA loans are used to finance construction of permanent concrete diversion structures.

ces. Average yields were 3.2 t/ha for WS and 3.1 t/ha for DS, reflecting the reliability of irrigation effects on seasonal outputs. Comparing these average yields to the national average irrigated yields of 2.8 t/ha indicates the national benefit of having 580,000 ha of irrigated rice in the hands of farmers who manage their own irrigation systems.

About 84% of the 100 assisted communals have permanent, concrete diversion structures; 46% have main canal capacity greater than the designed capacity; 80% have laterals, and 59% have farm conveyance ditches. Only 14% have control structures as part of the terminal facilities. Only 48% have designated personnel for water distribution and only 19% of them provide compensation for those persons. Only 17% have designated maintenance personnel, with the balance using group work for cleaning and system repair. Of the 953 farmers interviewed, only 50% expressed satisfaction with the operation and maintenance of the system, indicating a strong feeling that further improvement is necessary.

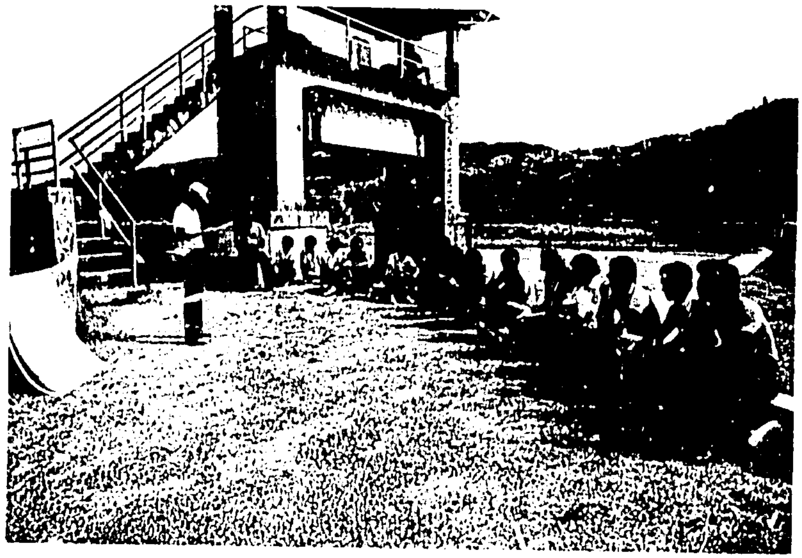
National system management

We completed the first year of a 2-year project with NIA collaboration to compare three intensity levels of irrigation system management and one remedial irrigation treatment (Fig. 3). The study is under the auspices of the Irrigation System Management Research Committee (ISMARC). The intensive model is being applied in the Lower Talavera River Irrigation System (LTRIS). It covers 2,500 ha, and involves measurement and control at the



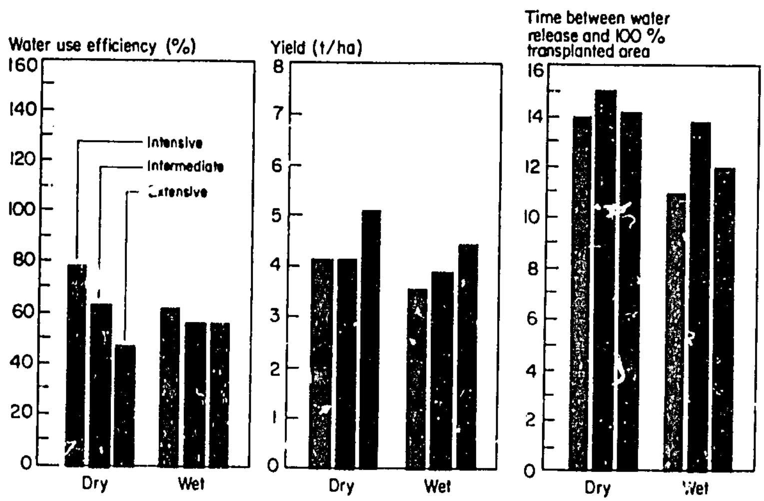
3. Irrigation System Management Research Committee sites in the Upper Pampanga River Integrated Irrigation System.

IRRI researchers and NIA personnel under ISMARC collaboration conduct periodic field inspection of research projects and review work progress.



lowest, most detailed level in the system — the turnout to rotational areas of 20 to 50 ha. The intermediate model is being applied in the Pampanga River Irrigation System (PRIS), covering 13,500 ha, and involves measurement and control of irrigation flows at the section boundary, an area of about 500 ha. The extensive model is being applied in district I covering 24,000 ha and involves measurement and control at the headgates of laterals which range from 300 to 2,500 ha.

The results indicate interesting tradeoffs between the water saved and the yields obtained and time saved in the annual cropping calendar (Fig. 4). The intensive model continues to



4. Irrigation system performance characteristics for 3 models of system management intensity.

have improved average water utilization efficiency, starting from 43% in DS, before the 1975 implementation of the improved management technique, to the present 80% which is perhaps above the practical maximum level before stress begins to reduce yields. WS efficiencies have been more variable and dependent upon the extraordinary rainfalls that represent uncontrolled excessive water inputs into the system.

Before implementation, water use efficiency (WUE) was 51% in WS and reached as high as 75% without typhoon occurrence; most recently it was 63% in the 1982 WS. Rice yields have likewise been highly dependent upon typhoon damage and range as low as 1.6 t/ha in the 1978 WS to as high as 4.8 t/ha in the 1977 WS, and from 2.5 t/ha in the 1979 DS to 4.1 t/ha in the 1980 DS. The 1982 yields equalled the DS high and were only 0.8 t/ha under the WS high.

The intermediate model has shown increased WUE up to the currently reported levels of 64% (DS) and 55% (WS) and which remains below the levels obtained in the intensive model (Fig. 4). On the other hand, yields in the PRIS area under the intermediate model have exceeded those of LTRIS under the intensive model and have reached a peak of 4.1 t/ha in 1980 DS and 3.9 t/ha in 1982 WS.

The extensive model had the lowest WUE level (46%) in the 1982 benchmark season. It improved markedly to 56% in the 1982 WS. Yields in district I for the extensive management model were 5.1 t/ha in the 1982 DS and 4.4 t/ha in WS, both substantially above the levels of the two other treatments in LTRIS and PRIS.

In all three treatments, the time between the first water released and 100% transplanting of the area was 14-15 wk in DS and 11-14 wk in WS (Fig. 4). These durations demonstrated asynchrony in farmers' crop growth schedules in the areas served by these systems.

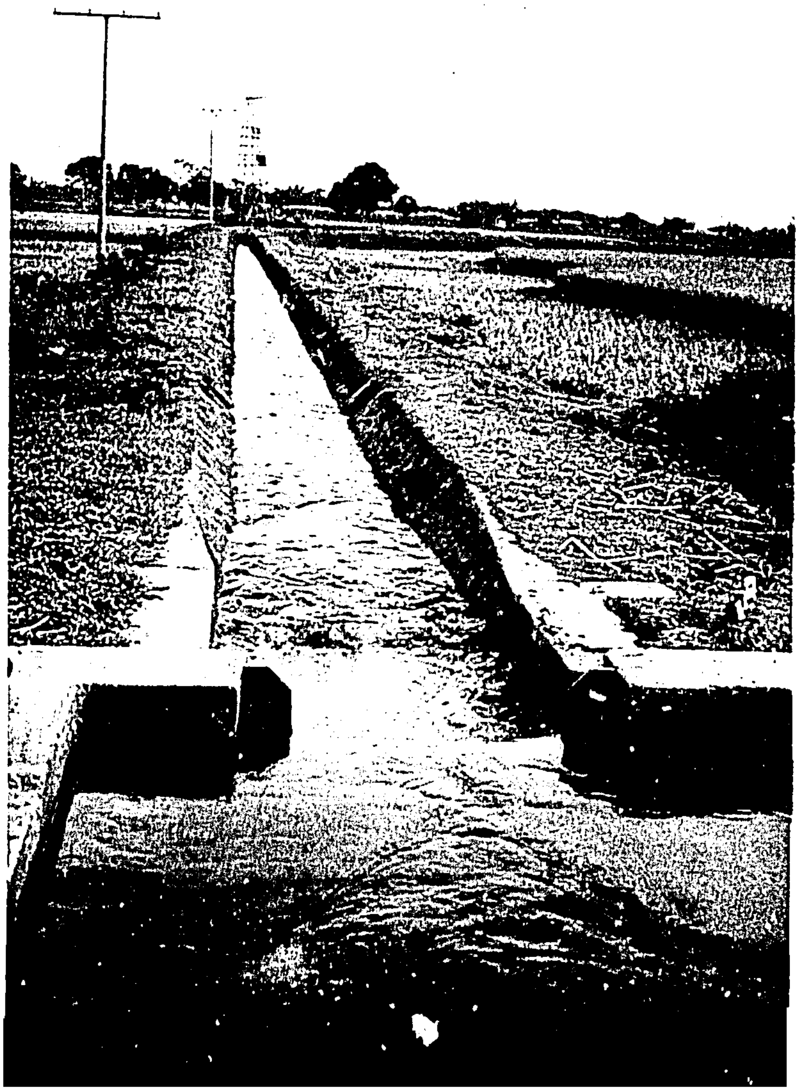
Two-thirds of the farmers interviewed in district III, who had an irrigation management program to minimize drainage problems, were generally satisfied with DS water allocations. Too much water for some was the one problem with WS allocations. The 8,000-ha area comprising portions of two zones has about 400 ha affected by over-irrigation, lack of drainage outlet capacity, and structure blockage of overland flow when typhoons bring excessive rainfall.

Thirty percent of the respondents experienced water shortages during DS. The interviewed farmers generally believed that lack of standing water longer than 7 days caused yield reduction due to enhanced weed growth, retarded plant growth, unfilled grains, and eventual plant wilting. Only 50% of the farmers were aware of the NIA cropping schedule for WS and DS and only 57% knew of the NIA suspension schedule for more effective use of rainfall and flood prevention.

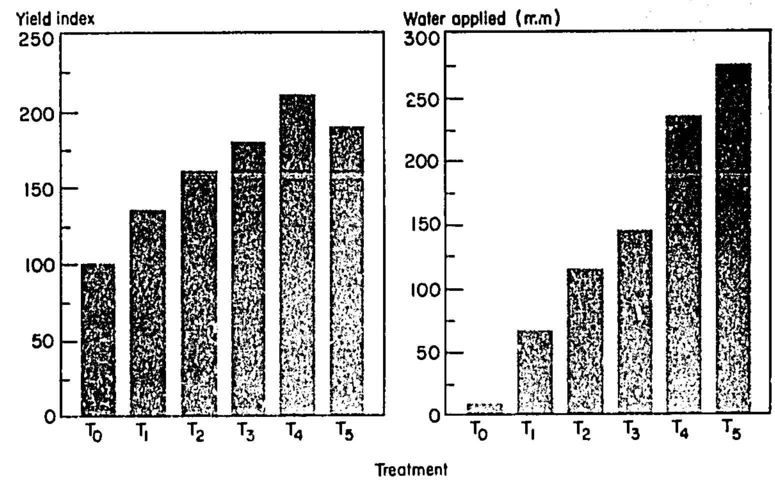
Benchmark water use in Bangladesh

The Thakurgaon tubewell system in Bangladesh has 378 tubewells, each with a discharge capacity ranging from 57 to 114 liters/sec., and a lined main canal length ranging from 290 to 670 m. Irrigation water is used to supplement rainfall for the aus and aman rice crops, and mostly for wheat in DS. Tubewell water use has been extremely low — averaging only about 7.4 irrigated ha per tubewell during the 1982 DS for wheat cultivation in 10 sample tubewells. The average designed irrigable area is more than 80 ha/tubewell. Because this is the period of greatest poten-

This kind of water discharge, common from a single tubewell in the Thakurgaon system, can adequately irrigate 60 to 80 ha. Unfortunately, water use has been extremely low — averaging only 7.4 irrigated ha per tubewell.



5. Irrigation water regime treatments and corresponding yields and amounts of water applied. The subscript denotes the number of irrigations. The first irrigation was applied 20 days after sowing and subsequent ones at 15-day interval.



tial economic contribution of the wells, we looked for reasons why their use is so limited in the DS.

Optimum water requirement for wheat. We determined the water requirement for dry season wheat in the sandy loam soil through a field experiment using the randomized complete block design. The highest-yielding irrigation schedule was four soil-saturating irrigations requiring about a total 240 mm of water (Fig. 5).

Input-output relationship for wheat. Wheat yield in farmers' fields was related to number of irrigations, chemical inputs used, soil clay percentage, and the number of days sowing is delayed after 15 November. For each irrigation, the yield increased by 311 kg/ha, but each day of delay in sowing after 15 November reduced yield by 8 kg/ha because of the adverse effect of colder temperature.

Low tubewell capacity use. Tubewell capacity use in DS is very low because:

- Most farmers lack confidence in the system's ability to deliver water reliably. In 1982 DS, 52 of 61 sample farmers using tubewell water reported inadequate water. About 98% of 150 farmers interviewed indicated that they would use irrigation water in 1983 DS if the water supply can be assured.
- Tubewell operating hours are extremely low. The 10 sample tubewells were operated for an average period of only 125 h during the entire 1982 DS. Electrical power supply interruptions and absence of pump operators from the site are the major reasons.
- Water losses in conveyance and operation are very high

because of deteriorated linings in the main canals, the sandy loam soil, and a disorganized water delivery schedule.

Ninety-four percent of 150 farmers interviewed indicated that water shortage was the most serious limitation to increasing DS cropped area. The other reasons cited were high cost of fertilizer (90%), nonavailability of modern variety seeds (39%), and high insecticide cost (16%).

SOIL AND CROP MANAGEMENT

IRRI's research on soil and crop management is aimed at identifying the most efficient production practices for new plant varieties. This involves studies on land preparation, crop management, and crop nutrition for various rice culture types.

SOIL CHARACTERIZATION

Decomposition of organic matter in rice soils

Although organic manures are assuming increasing importance in rice production, we have little information on the decomposition of organic matter in flooded soils in the tropics. Generally, we think flooding slows down decomposition.

In field experiments at IRRI, we incorporated ^{14}C-labeled rice straw into permanently submerged soil. After two rice crops in 1 year, we regained less than 20% of the incorporated straw. This indicates that without adequate inputs of organic substances into the paddy soil the decrease of humus will lower soil fertility.

Humus characterization in wetland soil

Humus contains almost all of a soil's nitrogen (N), 20-80% of its phosphorus, and most of its sulfur. Soil humus provides 50 to 80% of the N taken up by rice crops, even when the plants are fertilized. When we extracted humus with 0.1 M NaOH and 0.1 M $Na_4P_2O_7$ from different wetland soils, we noted:

- the composition of humus differs according to soil properties and management,
- the amount of extracted humus decreased with increasing acidity,
- acid soil has more fulvic and less humic acid,

Using a sophisticated plant growth chamber, Rick Capistrano, IRRI research assistant, labels rice plants with radioisotopes. Up to 1,000 g of mature, labeled straw can be produced in one season for field experiments to determine organic matter decomposition.

- cultivated soil with straw incorporation has only slightly less amounts of extracted humus humic acid and fulvic acid than uncultivated soil covered by grass. If the straw is removed the amount of each is much lower.

Chemical kinetics of potassium-deficient soil and phosphorus-deficient soil

In the greenhouse, we studied the kinetics of the soil solutions of potassium (K)-deficient soil and phosphorus (P)-deficient soil. The addition of K to the K-deficient soil increased not only its concentration in the soil solution, but also the availability of calcium and magnesium. P fertilization of P-deficient soil evidently influenced the kinetics of P, ammonium (NH_4), and K. The higher P concentration in the soil solution of the fertilized soil causes better plant growth and faster uptake of NH_4 and K.

Potential of coastal saline soils

More than 20 million ha of uncultivated saline soils in the humid tropics are suitable for rice production. In 1982, we tested 14 varieties in farmers' fields at six coastal saline areas of the Philippines.

Farmers reported yields below 0.5 to 1.0 t/ha from traditional varieties. Yields from salt-tolerant rices, such as IR44, were as high as 5 t/ha in the wet season with moderate amounts of fertilizer. Two rice crops are possible on vast areas of coastal saline soils in South and Southeast Asia if farmers grow early-maturing, salt-tolerant cultivars.

Nutrient status of rice on saline and sodic soils

Soil salinity and sodicity are highly limiting factors in agricultural production. More than 60 million ha of soils with these problems are uncultivated in South and Southeast Asia, although they are climatically and physiographically suited to rice.

We amended a nearly neutral soil to a wide range of salinity and sodicity levels and studied the soil solution kinetics in relation to the nutrient status of rice. Sodicity increased the concentration of nitrogen and sodium in the plant, but depressed most of the other elements. Salinity, however, increased the concentration of most elements in the plant. Only potassium and silica were negatively affected. Salinity depressed grain and straw yield more than sodicity.

Availability of micronutrients in aerobic soils

To find the best method for determining available iron, manganese, copper, and zinc in aerobic soils planted to rice, we tested three extraction methods with DTPA, NH_4OAc, and 0.05 *M* HCl, which are simple, reliable, rapid, and inexpensive. We used 30 selected Philippine soils ranging in pH from 4.0 to 8.3.

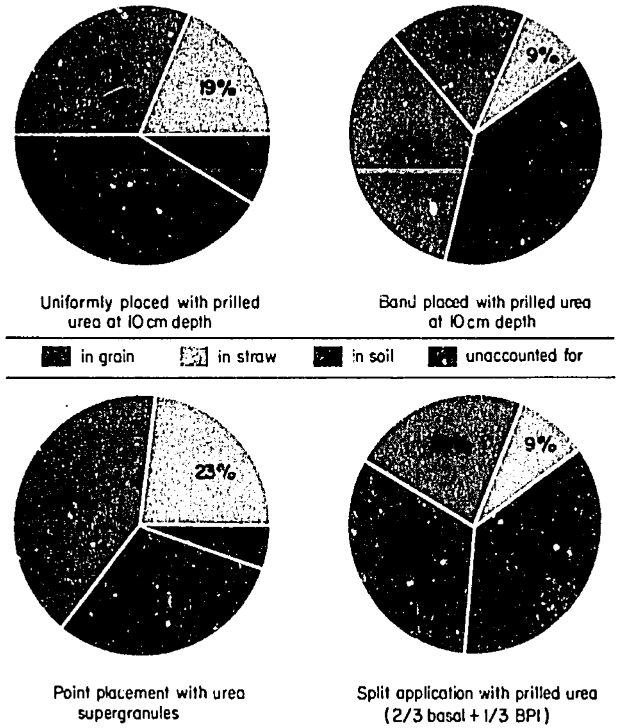
We measured nutrient uptake in rice plants grown on these soils under aerobic condition for 8 weeks. None of the methods was suitable for iron. The 0.05*M* HCl extraction worked best for the other nutrients. Correlations of copper, zinc, and manganese in plants and soil test values were highly significant.

MANAGEMENT OF SOIL AND FERTILIZER NITROGEN

^{15}N balance of urea N by deep placement techniques

We calculated the balance of ^{15}N-labeled urea from field experiments using deep placement techniques in wetland rice soil. Only 4% of the applied nitrogen (N) was unaccounted for with point,

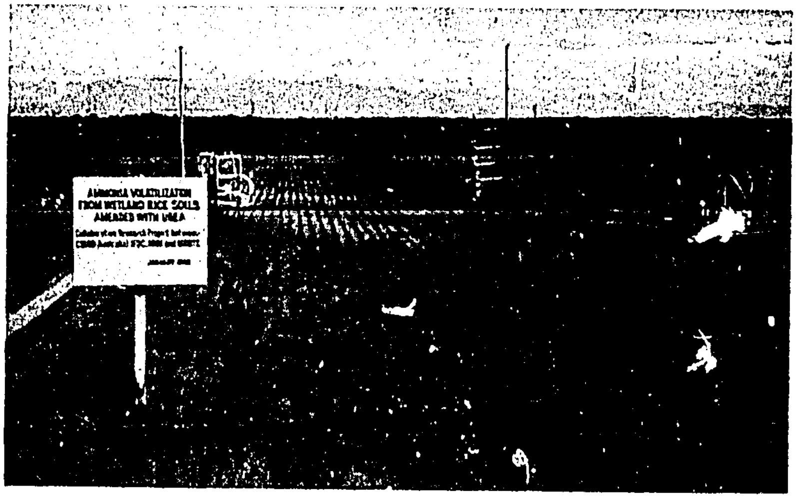
1. Balance of ^{15}N-labeled urea at harvest with various placement methods. IRRI, 1981 wet season.



deep placement of urea supergranule (USG) after harvest of the wet season crop (Fig. 1). In contrast, there was a substantial loss of N fertilizer when prilled urea was applied in split doses (two-thirds basal-incorporated and one-third topdressed at panicle initiation). About 35% of the applied N was not recovered at harvest. Uniform deep placement resulted in high recovery of ^{15}N (92%). This confirms that the high total ^{15}N recovery obtained with point, deep-placed USG is mainly a function of placement depth.

Ammonia volatilization losses

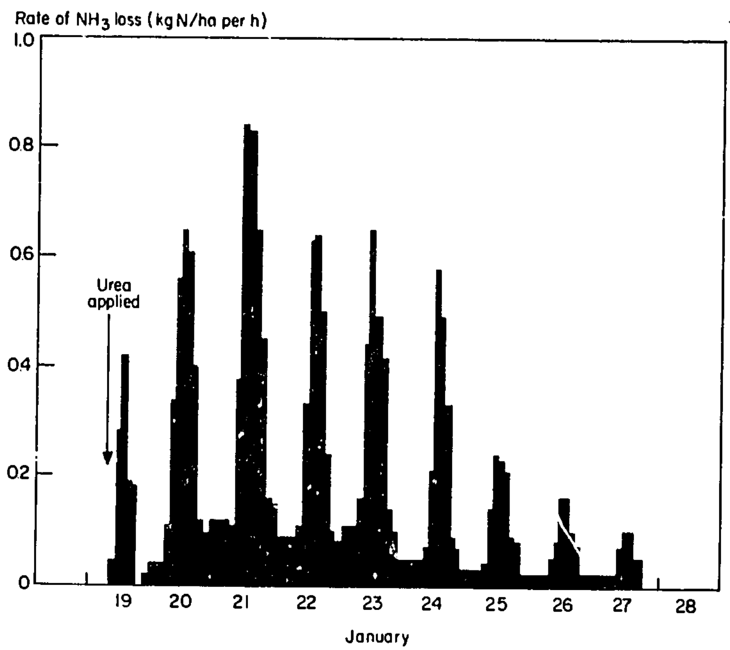
Ammonia (NH_3) volatilization from floodwater can be considerable where urea is topdressed on wetland rice soils. However, few measurements of NH_3 loss have been made in the field using techniques which do not bias the NH_3 loss. In a collaborative project with the International Fertilizer Development Center (IFDC), we used a micrometeorological technique in the field (Fig. 2) at the Maligaya Rice Research and Training Center (MRRTC) and IRRI to determine NH_3 loss where urea was topdressed to the floodwater or broadcast and incorporated before transplanting. Ammonia volatilization accounted for 47%



2. Measurement of NH_3 volatilization using micrometeorological equipment at the Maligaya Rice Research and Training Center showed the importance of incorporating N fertilizer to reduce N-loss.

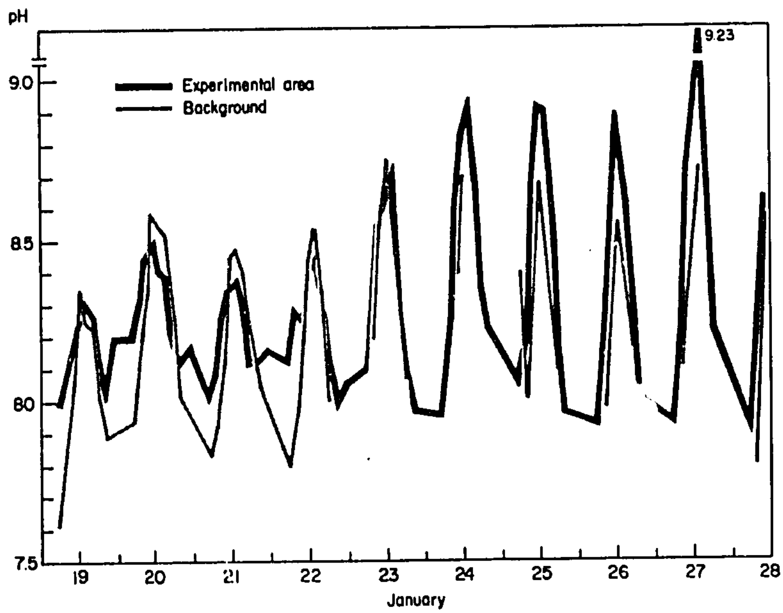
of the urea-N topdressed 14 days after transplanting at MRRTC (Fig. 3). Floodwater pH in this study (Fig. 4) and all other studies showed a pronounced diurnai pattern. This implied that biotic organisms, especially algae, were responsible for the high floodwater pH needed for significant NH_3 loss.

We found a smaller NH_3 loss at IRRI (27% urea-N topdressed 21 days after transplanting). Incorporating urea before transplanting at MRRTC and IRRI reduced the NH_3 loss to 13-15% of the N applied.



3. Ammonia fluxes from urea (80 kg N/ha) topdressed 14 days after transplanting.

4. Floodwater pH over time for the experimental area (urea topdressed 14 days after transplanting) and background areas (not fertilized).



^{15}N studies conducted concurrently with the NH_3 volatilization measurements showed that 48% (MRRTC) and 60% (IRRI) of the ^{15}N-labeled urea was lost 10 days after urea was topdressed. In comparison, only 18-23% of ^{15}N was unaccounted for during comparable periods where urea was broadcast and incorporated before transplanting. These results emphasize the importance of incorporating fertilizer N to reduce N-loss.

Role of urease inhibitors

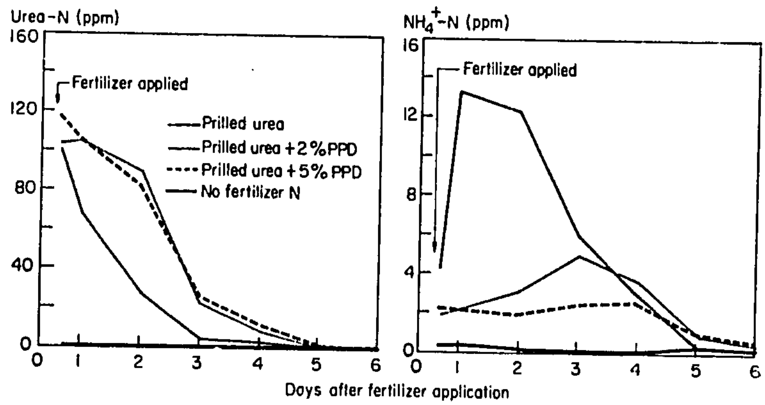
We evaluated the potential of urease inhibitors for reducing NH_3 volatilization losses from broadcast urea in wetland rice. In earlier greenhouse studies at IFDC, we found that urea with phenylphosphorodiamidate (PPD) retarded urea hydrolysis and delayed the appearance of aqueous ammonia in the floodwater.

In field studies at IRRI, we found that PPD delayed the hydrolysis of urea broadcast into the floodwater 20 days after transplanting (Fig. 5). Although PPD retarded urea hydrolysis, it did not increase grain yield and total N uptake, compared with the control without urease inhibitor.

Nitrogen sources and application techniques

During the 1982 dry season, we assessed the effects of varying moisture levels and N sources and methods of application on the grain yield of IR52 and Kinandang Patong. We established the

5. Floodwater urea-N and NH_4^+-N after application at 20 days after transplanting of 67 kg N prilled urea/ha, and urea with 2% and 5% phenylphosphorodiamidate or PPD (av of 2 sampling times at 0700 and 1300 h, except during the 5th and 6th day when samples were taken once at 1300 h). IRRI, 1982 dry season.



plants by uniform irrigation then used a line source sprinkler (LSS) system to create a soil moisture gradient ranging from well-watered to droughty.

We observed a significant cultivar response to irrigation level and N treatment. In both cultivars, yield differences among the six N treatments were not significant with very limited water supply. When water supply was adequate (390 mm from LSS), the highest yield of 946 g/m^2 was obtained in IR52 plots fertilized with urea + dicyandiamide (a nitrification inhibitor). This yield, however, was comparable with yield from three split applications of urea or ammonium sulfate and from basally incorporated sulfur-coated urea. Kinandang Patong yielded highest (305 g/m^2) with an adequate water supply and no N application.

These and other results suggest that, with limited moisture supply, high N application is not advantageous because it will aggravate drought stress. With adequate moisture, properly timed application of urea or ammonium sulfate may increase yields as well as modified urea fertilizers.

Placement machines for nitrogen fertilizer

We continued testing applicators developed for deep placement of N fertilizers and compared them with either the farmers' practice of urea application or our improved method and timing. The floodwater N concentration was measured for 6 days starting 1 day after fertilizer application to evaluate the magnitude of N losses.

Our findings during the dry season confirmed previous results that deep-placed prilled urea or USG by machine performed as well as hand placement. Deep-placed fertilizers produced low N concentration in the floodwater which indicated relatively lower N losses.

Of several placement machines tested in the dry season, we tested two promising modified units (IRRI transplanter with liquid injector and deep plunger) again during the wet season at IRRI and at the Maligaya station. Point placement of N using the two machines gave significantly higher yields than the farmers' practice of urea application. The two placement machines performed equally well although the increases of grain yield (0.4 and 0.6 t/ha) over researchers' timing of applying urea in split doses were not statistically significant. Our improved timing produced 0.5 t/ha higher grain yield than farmers' timing of urea application.

BIOLOGICAL NITROGEN FIXATION

We continue to study the present and potential contribution of biological nitrogen (N) fixation to the N nutrition of the rice crop.

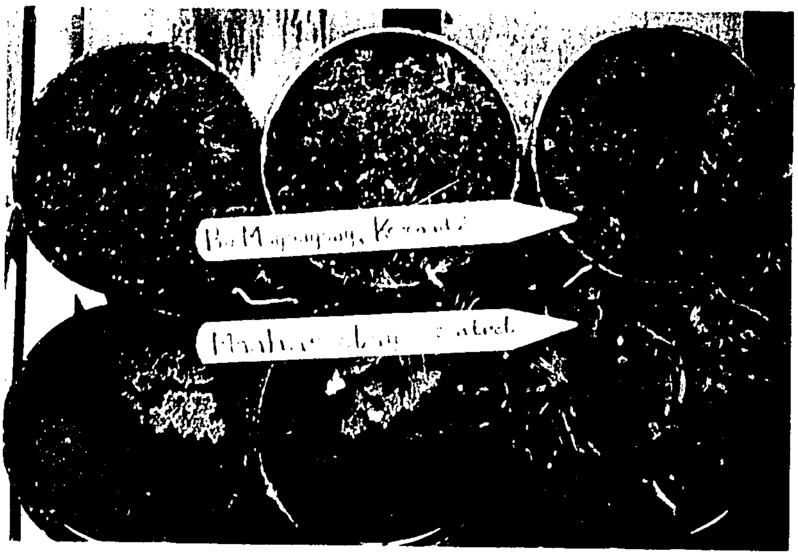
Composition of blue-green algae

After an extensive study in 1982, we found that N-fixing blue-green algae (BGA) average 44% carbon, 6.3% N, and 1% phosphorus on a dry matter basis and 94% water on a fresh weight basis. This composition varies with environmental conditions, physiological state, and the nature of the BGA strain.

The BGA biomass equivalent to 10 kg N/ha averages 4.3 t/ha on a fresh weight basis, which corresponds to an algal layer a few millimeters thick. Therefore an algal biomass of agronomic significance will most often be visible to the naked eye (Fig. 6).

6. This algal bloom on the IRRI farm is easily visible. It has a fertilizer equivalent of about 6 kg N/ha.

7. Without phosphorus fertilizer, azolla grew well in a soil from South Cotabato (above) but grew poorly in Maahas soil (below).



Availability of soil phosphorus and azolla growth

We found that high availability of phosphorus (P) stimulated azolla growth in South Cotabato, Philippines. Soil samples from the fields of farmers who use azolla were placed in small pots and flooded. A few fronds of *Azolla pinnata* were placed in each pot. After 2 weeks, the water surfaces in pots containing the phosphate-rich South Cotabato soils were fully covered by azolla (Fig. 7). In the phosphate-deficient Maahas soils, azolla showed much less vigorous growth. Soils containing more than 25 μg available P per gram could support good azolla growth without fertilizer.

Antigenic identity of *Anabaena azollae* in azolla

Azolla is symbiotically associated with the N-fixing BGA *Anabaena azollae*. If there were more than one kind of BGA associated with azolla, selection of the best combination to improve N-fixing efficiency may have been possible. However, using the direct immuno-influorescence technique (Fig. 8), we found that the symbiont is probably the same in the various *Azolla* species and strains.

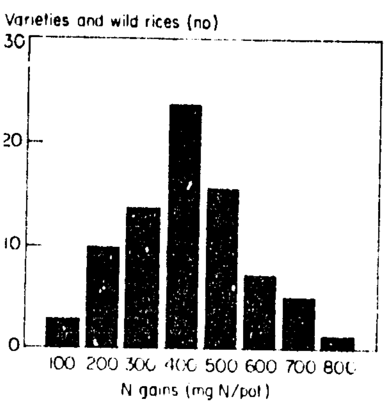
Stimulation of nitrogen fixation by rice

The rice plant can stimulate development of an increase in N in flooded soils. We completed a survey of 90 rice varieties and wild rices for their ability to stimulate N gain and found wide variation (Fig. 9).

Over three rice crops, N gained in potted soils ranged from 858 mg/pot for Raminad #3 and 776 mg/pot for Oking Seroni to 240

8. We used photomicrographs of *Anabaena azollae* cells stained with a homologous fluorescent antibody to discover that several strains of *Azolla* from around the world share identical and highly specific antigens with the BGA *A. azollae*.

mg/pot for Cigalon and 188 mg/pot for Pokkali. These values correspond to 57, 52, 16, and 12.5 kg N/ha for one rice crop. BPI-76 and IR42 also performed well as stimulators of N fixation. These results show the possibility for breeding rice varieties which stimulate greater N fixation.



9. Frequency distribution of N gains for 90 rice varieties and wild rices.

Insect pest of azolla

We have identified pyralid larvae as a potential serious pest of azolla in South Cotabato and Laguna in the Philippines (Fig. 10). The larvae destroy the azolla by feeding on the leaves.

MANAGEMENT OF OTHER NUTRIENTS

External phosphorus requirement

During the 1982 wet season, we conducted a greenhouse experiment to determine the external phosphorus (P) requirement of rice using four P-deficient soils, based on Olsen and Bray II P determinations (Table 1). The soils came from different parts of Luzon in the Philippines. The external P requirement is the optimum soil solution P concentration which is in equilibrium with soil P, adequate for normal plant growth. The soil solution P concentration was adjusted to different levels based on P-

10. Pyralid larvae have killed the azolla in this pond at South Cotabato, Philippines.

sorption isotherms. The results indicate the external requirement of rice is 0.07-0.09 ppm P (Fig. 11).

However, Quingua soil gave a higher yield than other soils in the control treatment, indicating more P availability under flooding than is determined by the Olsen and Bray II methods.

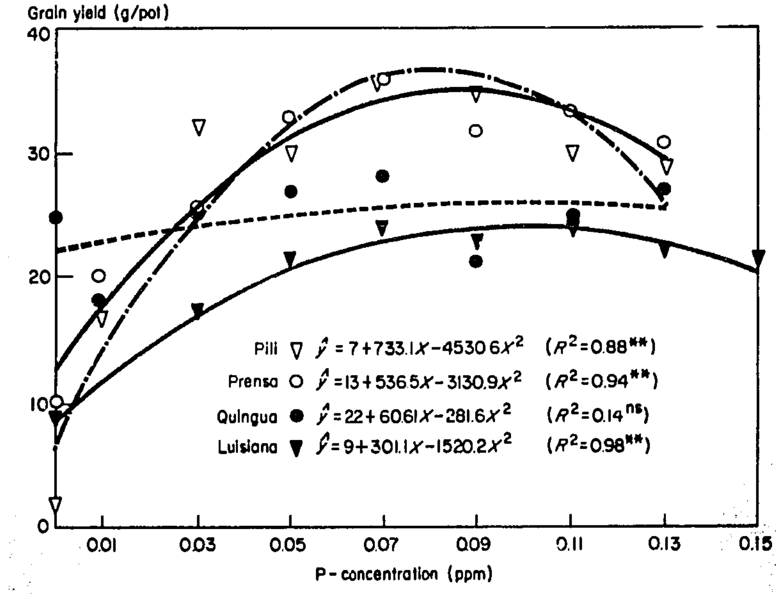
Fertilizer phosphorus sources

Rice yield responses to P fertilizer are becoming more frequent as soils are cropped more intensively and crop yields are increasing from greater use of modern varieties. Indigenous or imported commercial phosphate rock (PR) may offer low-cost P fertilizer, but the relative agronomic value of the materials must be deter-

Table 1. The four soils used in the experiment belong to different soil series and textural groups, and are low in available phosphorus (P). They needed different amounts of P to equilibrate at 0.07 ppm and 0.09 ppm soil solution P concentration.

Soil series	Texture	pH	Available P (ppm)		P (ppm) added to increase soil solution concentration to	
			Olsen	Bray II	0.07 ppm	0.09 ppm
Prensa	Sandy loam	5.3	2.9	1.8	29	42
Quingua	Silty loam	5.4	7.3	2.5	90	106
Pili	Clay loam	5.4	4.9	0.9	175	205
Luisiana	Silty clay	4.6	5.0	0.6	359	452

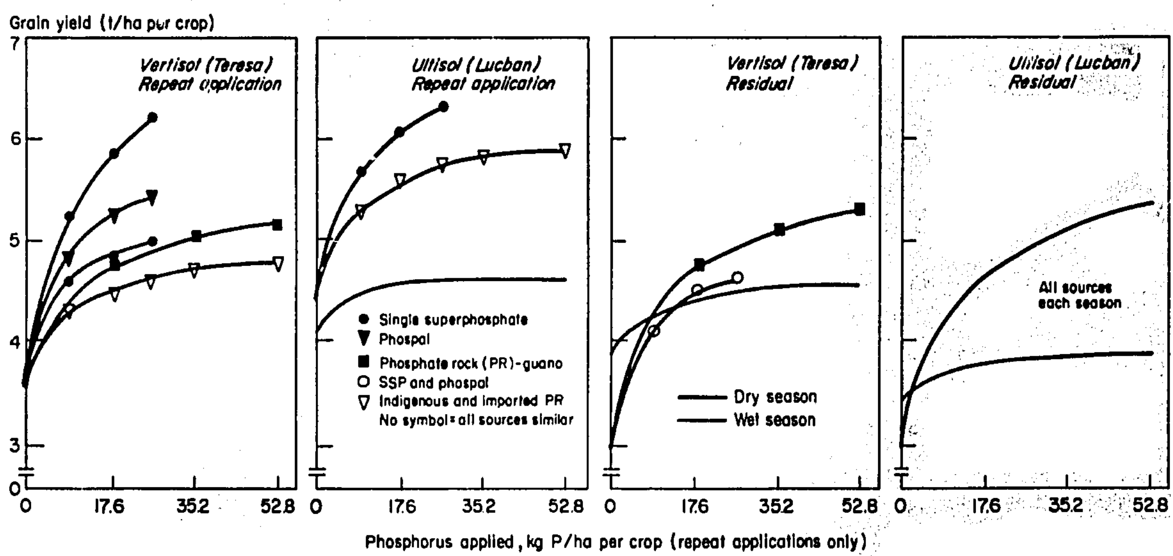
11. Response of IR36 rice to different soil solution P concentrations in four soils.



mined to identify their potential role as P sources for rice.

Two P source trials initiated during the 1977 wet season were terminated in 1982 after 11 successive croppings. Repeated P fertilizer applications to five crops on an Ultisol (silty clay, pH 5.0, Bray II P — 5 ppm) gave mean maximum yield responses of 0.5 t/ha per crop in the wet season and 2.0 t/ha in dry season (Fig. 12). During the dry season, single superphosphate (SSP) was

12. Irrigated rice yield respon. . to fertilizer phosphorus sources and residual fertilizers.



superior to both Phosmak (a commercial apatite) and local PR derived from guano, which gave similar yield responses. During the wet season, yields were limited by factors other than P availability and all sources gave similar yields. Mean yield responses for the three crops during the dry season following cessation of P application (responses to residual P fertilizer) were as much as 2.1 t/ha per crop and were similar for all P sources.

On a Vertisol (clay, pH 6.5, Bray II P – 3 ppm), mean yield increases due to repeated P fertilizer applications were as much as 1.5 t/ha per crop during the wet season and 2.7 t/ha per crop during the dry season.

The relative effectiveness of the P sources follows:

wet season: SSP > phospal (calcined iron aluminum phosphate) = PR (guano)

dry season: SSP > phospal > PR (guano)

As on the Ultisol, yield responses to residual P fertilizer were similar among sources, but yield increases were greater on the Vertisol.

Ranking of sources by relative effectiveness for 11 crops was similar to ranking for 5 crops because responses to residual P fertilizer were similar among sources.

When 87 kg P/ha was applied during 5 seasons each kilogram of P applied as SSP produced more than 50 kg of rice on the Ultisol and 35.2 kg on the Vertisol for the total of 11 crops. In comparison, the PRs produced about 40 and 60 kg of rice/kg of P on the two soils. Thus, considering total yield responses of 11 crops the PRs were 70 to 80% as effective as SSP.

INTERNATIONAL NETWORK ON SOIL FERTILITY AND FERTILIZER EVALUATION FOR RICE

Collaborative research trials

In many of the 5th INSFFER trials on nitrogen (N) fertilizer efficiency in irrigated rice, N applied as sulfur-coated urea (SCU) or urea supergranules (USG) was technically more efficient than N from urea applied best split. This situation was particularly evident at low N rates. Over all experiments, some 23-25% less N as SCU, or 30-32% less N as USG provided the same yield increment as N in the form of prilled urea (PU). This is equivalent to about 20 kg grain/kg of N as urea and about 30 kg grain/kg of N as modified materials. When considering only the sites where a significant difference between response functions of urea and the modified materials were observed, the efficiency figures rose above 30% for SCU and 40% for USG.

In the rainfed rice trials, no significant differences were observed among PU, SCU, and USG at the rate of 29 kg N/ha. However, significant differences between SCU or USG and PU at 87 kg N/ha were observed in four sites. The comparative advantage of the modified N fertilizers over PU was less evident in deepwater rice.

Azolla application continues to show effects on grain yield. An average yield increment equivalent to 30 kg N/ha from urea was obtained from 13 trials in seven countries. Planting density or pattern had no apparent effect on the benefits derived from azolla.

Nitrogen continues to be the limiting element in the long-term trials conducted in the 12 sites reporting. Phosphorus and potassium responses were observed in four sites each.

Responses to heavy application of slowly and highly reactive rock phosphates were comparable with responses to ordinary superphosphate at low rates of phosphorus. No differences in agronomic effectiveness among phosphatic materials were apparent in 13 residual trials conducted in the Philippines and Thailand.

RICE CROP CULTURE

Controlling volunteer rice in ratoon crop

Volunteer rice is considered a weed in the ratoon crop. Its response to herbicides makes it more difficult to control.

Plants from a main rice crop grown in the field were cut 15 cm from the ground and transplanted in drums as the ratoon crop. One hundred newly harvested seeds of IR9752-71-3-2 were broadcast in each drum as the volunteer rice.

We found that pretreatment with plant growth regulators such as GA_3, kinetin, CCC, and TIBA before herbicide application satisfactorily controlled volunteer rice and improved the performance of ratoon rice.

Application of butachlor alone at 2.0 kg ai/ha at early postemergence of volunteer rice and preemergence of weeds controlled the volunteer rice, grasses, and other weeds. However, rice crop growth was slightly inhibited as reflected in the reduction in number of tillers per plant. Foliar application of GA_3 or kinetin 1 day before butachlor application prevented this adverse inhibition. The grain yields from these treatments were as good as that of the hand-weeded control. Similar results were obtained with CCC or TIBA prior to 2,4-D application.

Table 2. Comparison of four methods of raising seedlings and planting on acid sulfate soils (averaged for two rices — IR26 and IR4683-54-2, 1982 dry season).

Method	Grain yield[a] (t/ha)
Direct seeding	3.9 b
Dapog seedlings	5.2 a
Semi-dapog seedlings	5.0 a
Transplanting of 3-week-old seedlings	5.6 a

[a]Means followed by a common letter are not significantly different at the 5% level.

Raising seedlings and planting on acid sulfate soils

On acid sulfate soils, farmers in the Philippines often use the dapog or semi-dapog method of raising seedlings. Dapog is the raising of seedlings at high seed rates without soil for 14 days. Semi-dapog differs from dapog in that soil is used and roots are cut before transplanting.

Using two rices, we compared both methods with direct seeding and transplanting of 3-week-old seedlings raised in a conventional seedbed at two sites. Direct seeding gave the poorest growth and lowest yield. The other methods did not show significant differences (Table 2). Direct seeding on acid sulfate soils is not desirable.

CLIMATIC ENVIRONMENT AND RICE

In 1982 we continued to study the relationship between nitrogen response and solar radiation, drought stress and grain filling, and oxygen release from rice roots. We studied calcium peroxide coating of rice seeds as a means to modify the microenvironment of the seeds placed in submerged soils.

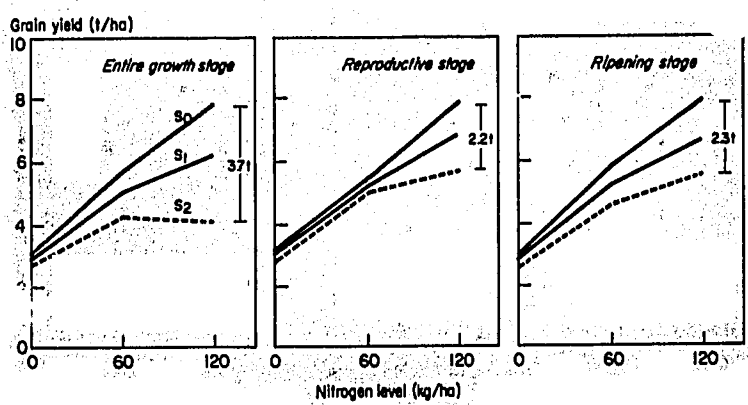
Nitrogen response and solar radiation

Nitrogen (N) response reaches its peak at the highest level of solar radiation and decreases as the level of solar radiation decreases. We found that the magnitude of the solar radiation effect on N response varied with the growth stage and radiation level. For example, we observed as much as a 3.7 t/ha yield difference by varying the solar radiation from 40 to 100% during the whole

In one of our studies on climate and rice, we found an important relationship between the level of solar radiation and nitrogen response in rice. By varying the amount of solar radiation striking rice plants, we observed substantial yield differences at high levels of N application, but little difference with no additional N.

growth stage of the rice plant when 120 kg N/ha was applied (Fig. 1). During the reproductive and ripening stages, the yield differences were 2.2 and 2.3 t/ha at the 120 kg N/ha rate. With no additional N, solar radiation had little effect on yield.

When solar radiation varied during whole growth period, grain yield was closely related to total dry matter production, which is



1. Interaction between nitrogen response and solar radiation at different growth stages. S_0, S_1, and S_2 represent 100, 60, and 40% sunlight.

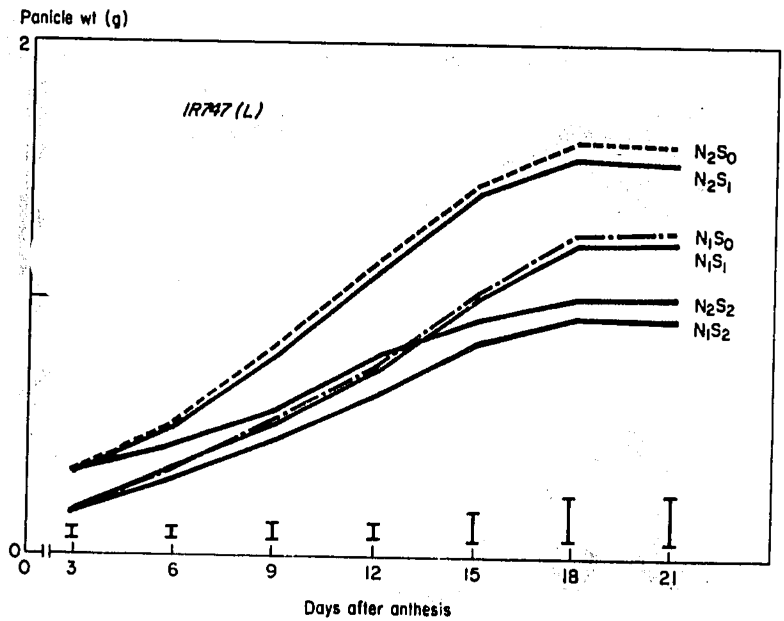
closely related to spikelet number. During the reproductive stage, solar radiation effect on yield was related mostly to spikelet formation. During the ripening period, solar radiation affected the number of filled spikelets and grain weight.

A moderate yield of 4-5 t/ha can be obtained with 60 kg N/ha at about 300 cal/cm^2 per day, which is average solar radiation at many locations in monsoon Asia. Higher yields can be obtained with a higher N application and higher radiation level.

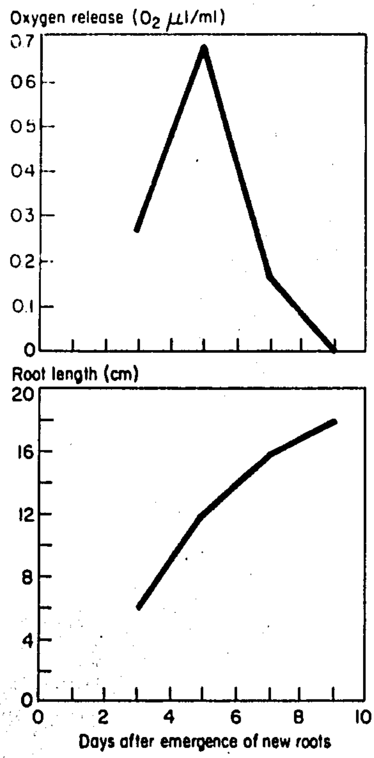
Drought stress and grain filling

Drought stress affects rice yield in different ways depending on growth stage. During the grain-filling period, drought stress (50% field capacity) decreased panicle weight by 29% at a low N level and by 40% at a high N level (Fig. 2). Drought stress, however, did not have any influence on the duration of grain filling. We attributed the greater reduction in panicle weight at the high N level to a lower amount of reserve starch accumulated before anthesis. During the grain-filling period, the reduced photosynthesis caused by drought stress appears to be partially compensated for by translocation of reserve starch from the culm and sheath. Because starch accumulation before anthesis is much less in high N plants, the yield reduction is greater.

We suggest that N application and variety choice be geared to reserve carbohydrate accumulation when drought is anticipated during the grain-filling period.



2. Panicle weight of IR747 at various harvests; as affected by drought stress (S), and nitrogen (N) levels. Vertical bars indicate standard errors of the mean.



3. Relationship between oxygen release and root length of newly developing nodal roots of 7-week-old plants.

Oxygen release from rice roots

We found that only young roots release molecular oxygen, which may detoxify harmful substances produced under highly reductive soil conditions.

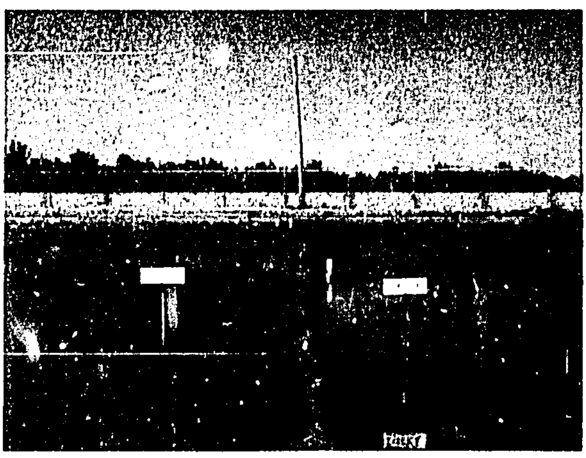
Oxygen released from the roots decreased sharply as the plant aged. This suggests that older plants would have a very low rate of oxygen release because the proportion of their old roots to total root mass increases with age. To verify this, we measured the oxygen release rate of old and new roots separately. The old roots of 7-week-old plants did not release oxygen at all. Oxygen release from new roots was moderately high at the initial stage of root elongation, reached a peak, and declined to zero as elongation was completed (Fig. 3). This suggests that oxygen release may protect newly developing roots against harmful substances produced under highly reductive soil conditions, but it is not present to protect fully elongated mature roots. However, oxygen transported to old roots from the shoot for respiration may generate some other mechanisms to protect root tissue.

Calcium peroxide as an oxygen supplier

We found that coating rice seeds with calcium peroxide (CaO_2) can ensure good crop stands in wet direct seeding.

A CaO_2-seed ratio of 1 to 1 by weight is recommended. However, we found that the ratio can be reduced to as much as 0.3:1. With proper land preparation, seeding rates as low as 20 kg/ha can be used without a yield decrease.

One person can sow 1 ha/day with a two-row, manual seeder. Using CaO_2 in direct wet seeding has been tested successfully in field experiments at IRRI and other sites (Fig. 4).



4. Note the dramatic effect of calcium peroxide-coated seed vs uncoated check for broadcast wet seeding (left) and machine direct seeding (right) in plots at Cagayan, Philippines.

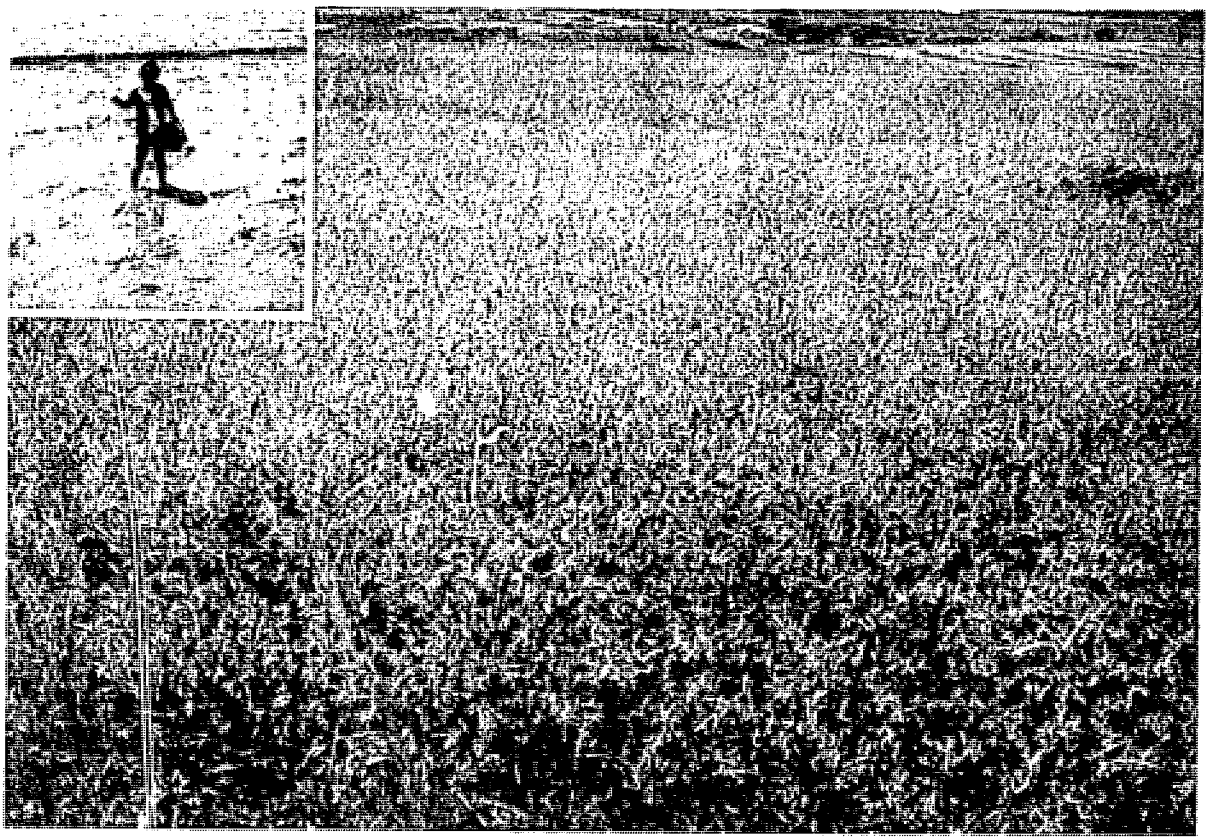
CONSTRAINTS ON RICE YIELDS

National average rice yields continue to be well below practical and potential yield levels. The constraints preventing a farmer from obtaining higher yields can be economic and social, institutional, or those related to the environment. We continued to draw the attention of national policy makers and research systems to their need for identifying the precise constraints responsible for the yield gap and removing them.

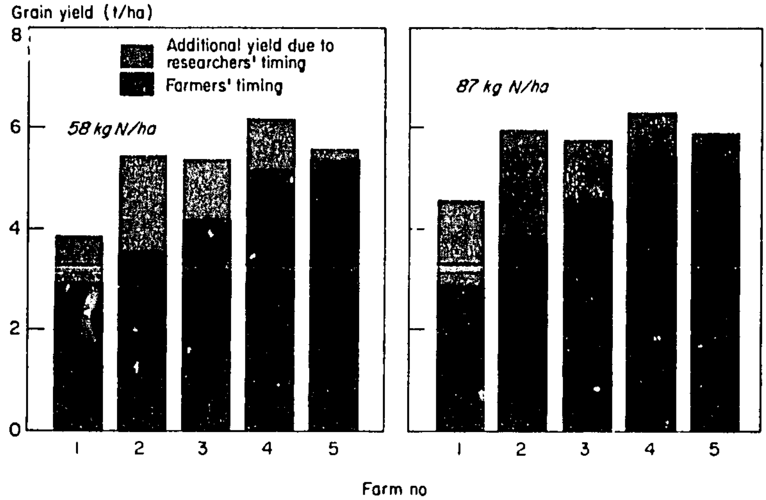
Timing of nitrogen application

During the dry season, we compared farmers' method and timing of nitrogen (N) application with researchers' timing at two rates of applied N.

At the Libmanan site in Camarines Sur Province, farmers' timing (half dose of N applied at 18 days after transplanting and



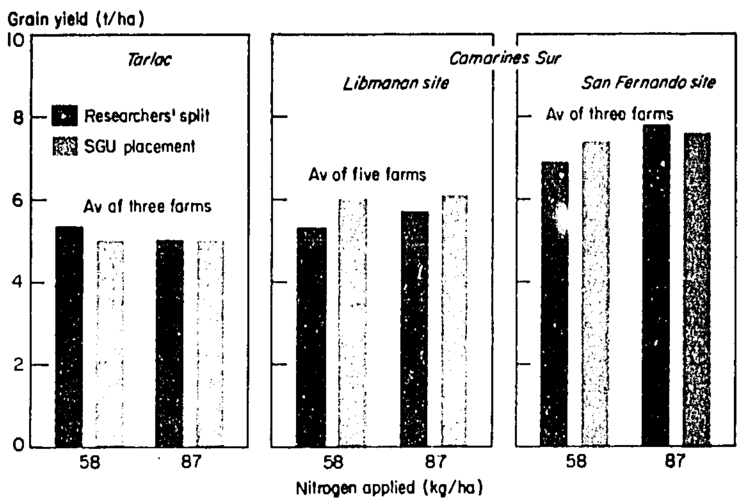
Weeds are a common problem for farmers who direct seed on puddled soil in irrigated or rainfed areas. Although most farmers use herbicides to control weeds, weeds remain an important component of the yield gap between yields obtained from researchers' inputs and those of farmers, particularly in rainfed areas.



1. Farmers' timing (18 days after transplanting and early booting stage) was less efficient than the researchers' timing at both 58 and 87 kg N/ha across all farms.

the remaining dose at early booting) was less efficient than the researchers' timing at both 58 and 87 kg N/ha across all farms (Fig. 1).

Increasing nitrogen fertilizer efficiency in irrigated rice
We compared the effectiveness of deep placement of urea supergranules (USG), as demonstrated in the IRRI and INSFFER trials, with the researchers' split application of prilled urea in irrigated farmers' fields in Tarlac and Camarines Sur Provinces. Results from five sites in Libmanan, Camarines Sur, showed an average yield advantage of 0.7 t/ha at 58 kg N/ha and 0.4 t/ha at 87 kg N/ha with deep-placed USG over split-applied urea (Fig. 2). Grain yields in San Fernando, Camarines Sur, were



2. In the Tarlac site, yields at 58 and 87 kg N/ha were comparable for both deep-placed urea supergranules (USG) and researchers' split application of prilled urea. Varying degrees of drought stress caused by frequent shortage of irrigation water supply affected the trials at that site. In the Libmanan site, deep-placed USG gave higher yields than did split-applied urea regardless of N rate. However, in the San Fernando site, the average yield with deep-placed USG was higher than that of the researchers' split only at 58 kg N/ha.

particularly high because of good water control. In that site, deep placement of USG produced a relatively higher yield than the researchers' split, but only at the lower N level. However, with poor water control, as was the case in the Tarlac site, researchers' split was as efficient as deep placement of USG.

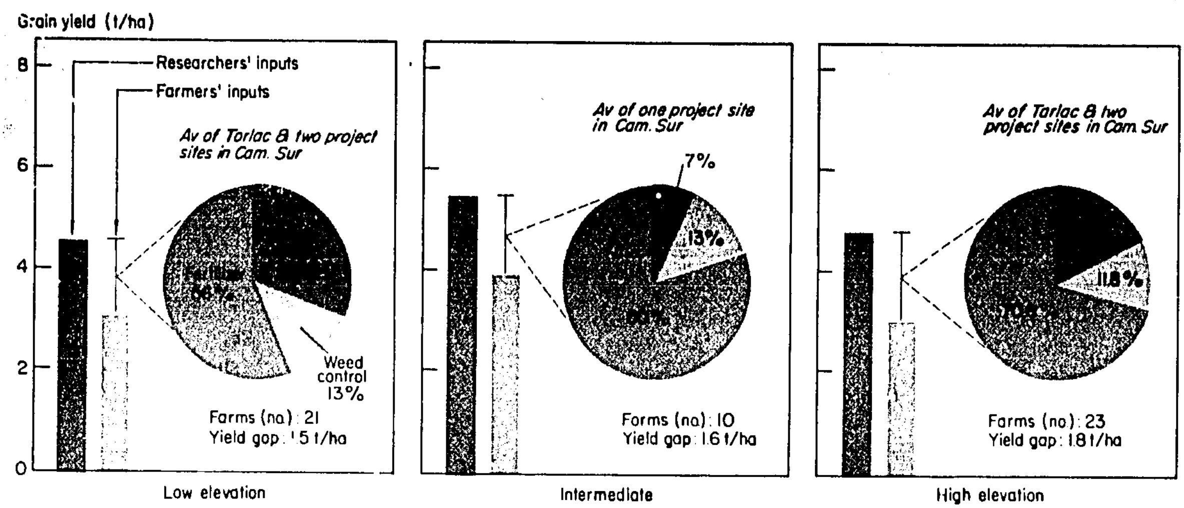
Yield gaps in rainfed rice farms

During the wet season, we evaluated the combined and separate effects of fertilizer, insect control, and weed control on rice yield at levels we believed to give high yields on rainfed farms.

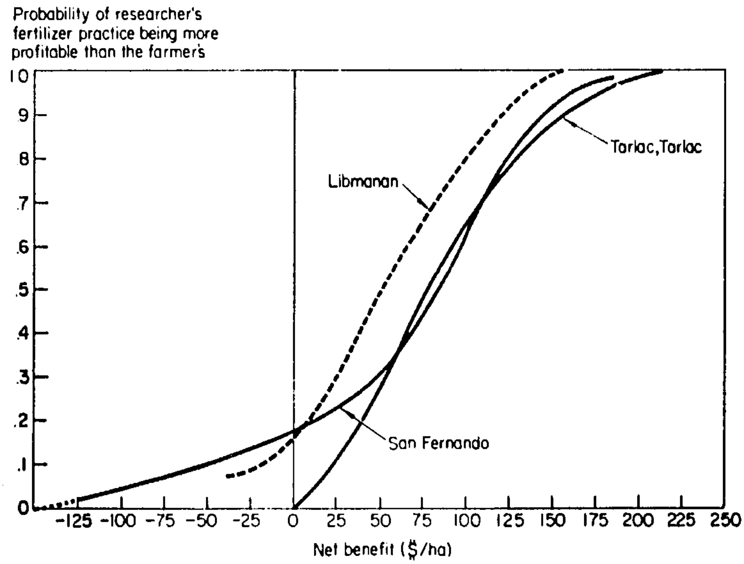
Direct seeding on puddled soil, particularly in irrigated areas and in rainfed locations in the upper landscape positions in the Camarines Sur study areas, is becoming popular. Farmers practicing this method of crop establishment have weed problems. Most farmers use herbicides to minimize weed infestation. A majority of the farmers in all test sites in Tarlac and in the two sites in Camarines Sur used either IR36 or IR50.

The magnitude of the gap between yields with farmers' inputs and with researchers' inputs in all landscapes (except in the low-elevation areas of the San Fernando site in Camarines Sur) in the three study areas ranged from 1.5 t/ha (low-elevation in Libmanan) to 1.9 t/ha (high-elevation in Tarlac). Figure 3 shows yields and the yield gaps at three landscape positions.

The mean researchers' yields across sites in Tarlac and in Libmanan and San Fernando in Camarines Sur were 4.6 t/ha at low elevation area and 4.8 t/ha at high elevation area. At the intermediate landscape position at San Fernando, the mean researchers' yield was 5.5 t/ha. The farmers' yields in the three



3. Variations in yield gaps between landscape positions on rainfed farms in Tarlac and Camarines Sur Provinces. Fertilizer contribution to the yield gap was highest in all test sites.



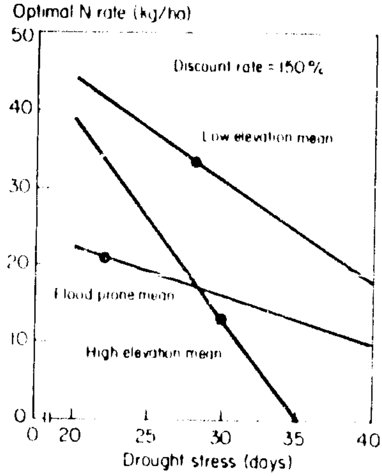
4. Smoothed cumulative frequency distributions of net benefits of researchers' fertilizer practices over farmers' at the constraints sites.

landscape positions were 1.5-1.8 t/ha lower (Fig. 3). In each case, fertilizer was the largest factor contributing to the size of the yield gap. As in many less favored, rainfed rice environments, the price farmers receive for rice is lower and the cost of purchased inputs is higher than in more favored areas with better infrastructure where response to inputs is also more certain.

We assessed the profitability of shifting each component of the technology from the farmers' to the researchers' levels. On average it was profitable to increase fertilizer use toward the researchers' 58-30-30. However, it was not profitable to close the yield gap using insecticides or herbicides.

Farmers are concerned with profit levels and stability. The dispersion of the benefits of the researchers' fertilizer practice over the farmers' is shown in Figure 4. In all cases, it was profitable to use the researchers' fertilizer rates at Tarlac. At the sites in Camarines Sur, however, 15 to 30% of the farmers would have been worse off by increasing their fertilizer rate to the researchers'. We are examining the issue of income stability and variability as determinants of farmers' fertilizer management.

A cross site analysis of 1981-82 constraints trials in Camarines Sur showed that the incidence of drought stress was a significant determinant of N response and rice yields. At prevailing interest rates in the region, the high profit N-rate was sensitive to the incidence of drought stress (Fig. 5). The probability of drought stress is highest in high elevation positions, and the optimal N-rate is most sensitive to the incidence of drought stress in this landscape. Based on our experiments, returns from applying fertilizer are better in low-elevation than in flood-prone or in high-elevation sites. Indeed, more farmers apply fertilizer and at higher rates, in lower elevations than in flood-prone areas or high-elevation, drought-prone areas.

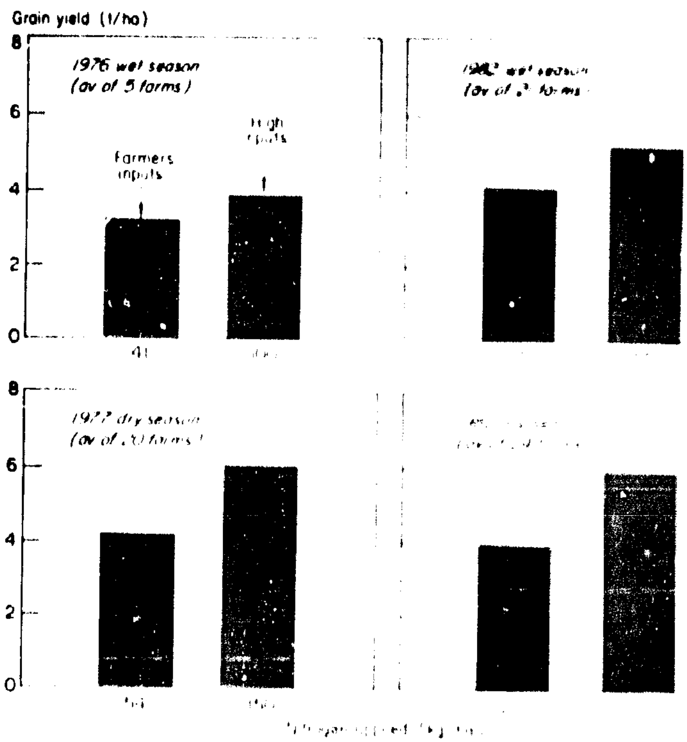


5. Optimal N rates at various levels of drought stress in three water regimes for rainfed rice.

Changes in input use and grain yield

To understand why rice yields with modern varieties at the farm level were not increasing as rapidly as researchers had expected, IRRI initiated on-farm research in Camarines Sur in the mid-1970s.

During the 1976 wet season, the input levels, particularly N fertilizer and insecticides used by the farmers in the irrigated sites, were higher than those used during the 1982 wet season. Average yield with farmers' inputs during the 1982 wet season was about 1 t/ha higher than the yields obtained by farmers in 1976. Similarly, the N level used by the researchers in the 1976 wet season was about twice as much as that used in the 1982 wet season, but the yields were considerably higher in the 1982 wet season (Fig. 6). These results suggest that over the years both farmers and researchers learned to produce high rice yields on farms.



6. Changes in N fertilizer use, grain yields, and yield gaps during a 6-year period in yield-constraints experiments on irrigated farms in Camarines Sur, 1976-82.

CONSEQUENCES OF NEW TECHNOLOGY

In our research on the consequences of new rice technology, we assess effects on rice production, incomes, distribution of incomes, employment and social welfare, and women's role. In 1982, we analyzed data from a survey on new technology and land tenure.

New technology and land tenure

We studied small samples of rice farmers in Bangladesh, Thailand, and Nepal to determine differential use levels of modern rice technology that affect land tenure differences.

Bangladesh. A complete enumeration of the farm-operating households in four villages of Joydebpur subdivision of Dacca district showed 128 owned parcels and 52 share-rented parcels planted to rice by 110 farmers during the 1981 aus season. Thirty farmers operated at least one parcel in each type of tenure so we conducted the analysis on a parcel basis. About 80% of the parcels were planted to modern varieties.

Owned parcels produced 3.6 t/ha while share-rented parcels produced 3.0 t/ha (Table 1). The amount of manure was the only input that was different between the two tenure types. Contrary to our expectations, levels of purchased fertilizer, animal power, and labor were similar.

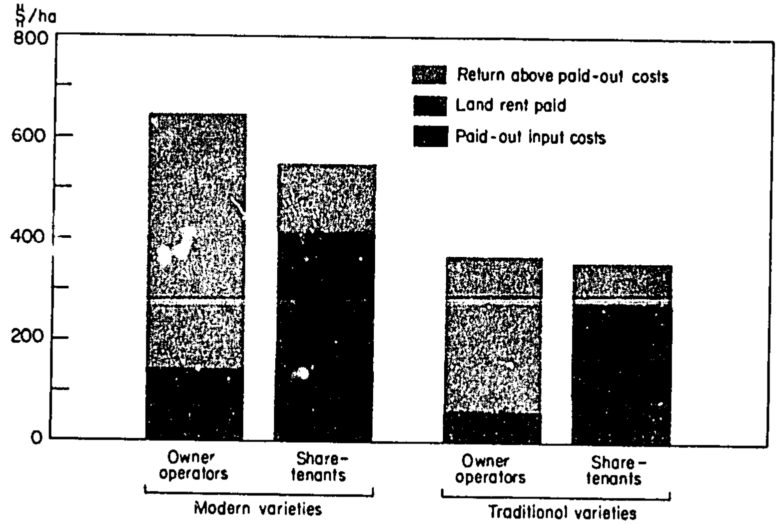
While paid-out input costs were similar for the two tenure classes, net income from rice production, as measured by returns

Table 1. Yield and input use on owned and share-rented parcels producing modern rice varieties.[a] Four villages in Dacca District, Bangladesh, 1981 aus season.

Output and input	609 parcels on 30 farms		144 parcels on 110 farms	
	Owned	Share-rented	Owned	Share-rented
Yield (t/ha)	3.6	3.1**	3.6	3.0**
Animal labor[b] (days/ha)	36.2	37.5	36.6	35.1
Human labor[c] (days/ha)	110.1	104.3	110.7	95.4
Seed (kg/ha)	62.2	54.0	60.6	52.8
Manure (t/ha)	3.3	1.3***	3.0	1.1**
Fertilizer (kg/ha)	213.3	213.7	270.0	197.0

[a]Difference between owned and share-rented was significant at the 1% (***) and 5% levels. [b]Preharvest animal labor. [c]Preharvest human labor.

1. Farmers growing modern rice varieties in four villages of Dacca, Bangladesh, produced much higher output values than those growing traditional varieties. Share-tenants had very small returns left after paying for inputs and land rent. Both tenure groups used similar input levels.



above paid-out costs, were three times as high for owners as for share-tenants (Fig. 1). Both owners and tenants obtained 1.7 times higher net income from modern varieties than from traditional varieties.

Thailand. In 1981, we surveyed 83 farmers in four irrigated villages in Chainat Province, Central Thailand. Market access was good for two villages and poor for two. Farmers were classed as tenants and owners. Owners had significantly higher net cash incomes than tenants, but farmers in poor market access (PMA) villages had, on the average, the same incomes as farmers in good market access (GMA) villages (Table 2).

There were no significant differences in the per hectare use of farm inputs by farmers of different tenure categories in villages with the same market access (Table 2). In GMA villages, the owners' higher incomes were mostly traceable to revenue differences; in the PMA villages, they were traceable to differences in

Table 2. Farm incomes[a] obtained by four groups of 83 farmers, Chainat, Thailand, 1980-81.

Group		Revenue ($/ha)		Cash costs ($/ha)	Net cash income ($/ha)
Market access	Tenure	From rice	Total		
Good	Owner	592 ab	822 a	365 a	457 ab
Good	Tenant	470 b	475 c	353 a	122 c
Poor	Owner	655 a	678 ab	186 b	492 a
Poor	Tenant	460 b	504 bc	206 b	298 bc

[a]Baht converted to US$ at ฿20/$. In each column any 2 values followed by the same letter are not significantly different at the 5% level.

both costs and revenues. Thus, input differences could not explain the observed differences in output.

We hypothesized that land quality differences existed between owners and tenants. Because all farms were irrigated, we compared two irrigation quality factors that may affect crop performance: the distance to the irrigation canal and the number of months fields were irrigated during the dry season.

The data clearly show that owners tend to operate plots that are closer to the irrigation canal and have irrigation water longer during the dry season. These differences conferred a distinct land productivity advantage and, in the absence of input productivity differences (confirmed by other analyses), may explain the higher incomes of owners.

Landowners in these villages operate their plots with good irrigation and high land quality and rent out those with poorer irrigation. In the GMA villages, which also appear to have somewhat better irrigation than the PMA villages, some owners are able to have more profitable three-crop patterns.

Nepal. We selected a random sample of 146 farmers from lists of owners and tenants in 24 villages of 11 towns in Kapilvastu district of Nepal. Some villages were near the Indian border, others were farther away. Modern varieties and fertilizer were used by only 17% of the sample. Modern varieties were grown without fertilizer by 30% of the sample, but there was no relationship between location relative to the Indian border and use of modern technology. Modern variety growers had higher yields than those who grew traditional varieties, and among modern variety growers, fertilizer users had higher yields and profits than nonusers (Table 3).

Table 3. Yield and input cost on owned and share-rented parcels with four alternative technology levels. Kapilvastu district, Nepal, 1980.

Tenure	Yield (t/ha)	Input cost ($/ha)				Return above paid-out costs ($/ha)
		Fertilizer	Power and other	Labor hired	Land rent	
			Modern varieties			
Owned	1.8	25	5	67	0	132
Share-tenanted	1.6	16	8	24	88	60
Owned	1.5	0	2	50	0	145
Share-tenanted	1.2	0	5	18	64	55
			Traditional varieties			
Owned	1.2	24	37	70	0	−4
Share-tenanted	1.3	22	3	22	65	33
Owned	1.0	0	2	39	0	79
Share-tenanted	1.0	0	6	9	56	52

Share-tenants used somewhat lower levels of inputs than owners, but differences in the land rent paid was the major cause of differences in the returns above paid-out costs of the various categories. Although all yields were quite low, yields of parcels growing modern varieties with fertilizer were highest. Farmers using fertilizer had higher yields than farmers not using fertilizer. Farmers using fertilizer also used higher levels of other purchased inputs and, as a result, the average return above paid-out costs (including rent) was $44/ha lower for fertilizer users than for nonusers.

We examined the substantial difference in use of modern technology within the sample to determine whether it was related to irrigation or tenure. Chi-square tests showed that the hypothesis of independence could not be rejected. There were two levels of share rents: 40% and 50%. Significantly more of the tenants paying 40% grew modern varieties. Aside from the share of output paid to the landlord, the test of independence between all other factors expected to be associated with modern variety use could not be rejected. A further analysis using multiple regression confirmed the lack of hypothesized relationships.

Conclusion. Clearly, the impact of tenure and other factors often believed to determine the use modern technology is not as simple and obvious as expected. There was no relationship in the study area in Bangladesh; in Nepal there was a strong relationship but we could not uncover the reason for it. In Thailand, poor quality land was rented out, which precluded high returns to tenants.

CROPPING SYSTEMS

The aim of cropping systems research at IRRI is to identify for specific regions more productive rice-based cropping systems which are acceptable to the small rice farmer. The research is farm-based with the farmer as an active participant in testing the new cropping systems.

In 1982 we screened root systems of soybean and peanut for drought adaptation, intensified work in wheat as an alternative crop after rice, studied the response of transplanted rice to mungbean green manure, evaluated the drought response of various grain legumes, and examined the potential of hybrid maize in the tropics.

A neutron probe, foreground, is used to monitor water changes in the soil profile beneath a crop of soybeans. With the leaf pressure chamber, on the [illegible], scientists can determine the leaf water potential in the field. These instruments enable scientists to measure deteriorating water relationships quantitatively in crops planted after rice.

ANALYSIS OF THE PHYSICAL AND BIOLOGICAL ENVIRONMENT

Classifying terrain by computer analysis of satellite imagery

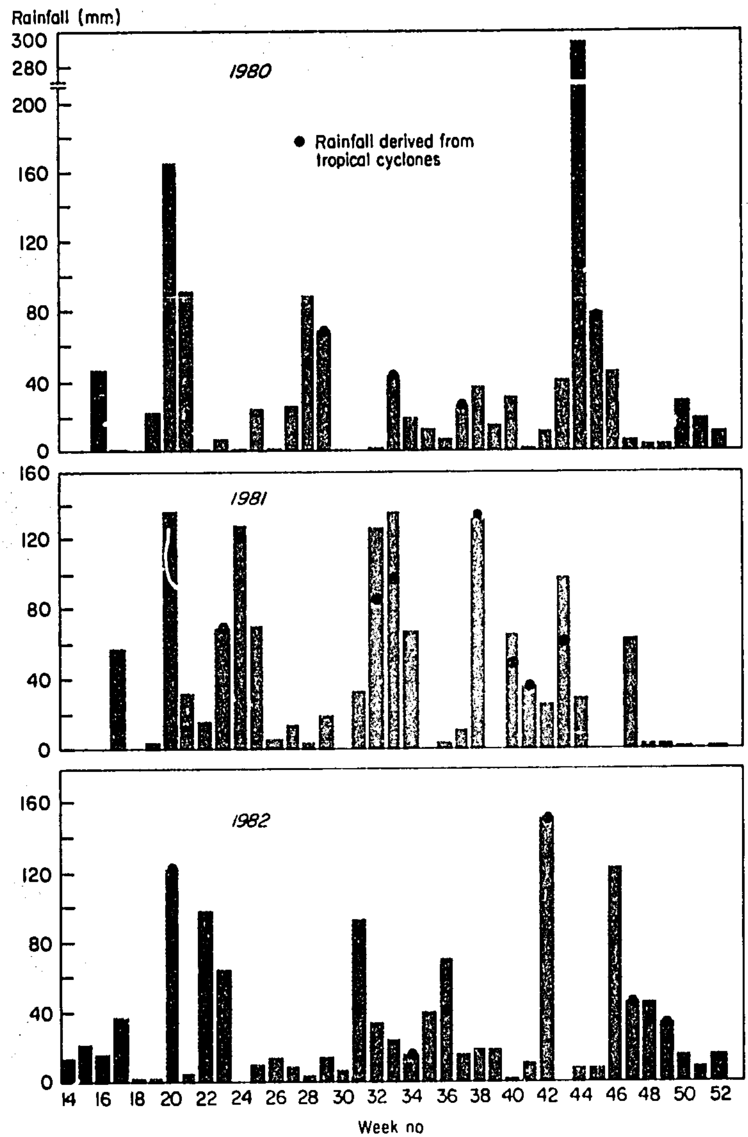
In rice landscapes, natural terrain factors determine seasonal hydrology patterns and profoundly affect the productivity of rice and crops grown before and after rice. For cropping systems research projects in which the first research phase is environmental characterization, we need a rapid land classification technique to identify the major land types in a target area. In the vast majority of projects, however, the capability for rapid land classification is limited.

Large land areas can be classified quickly by using a computer to analyze satellite imagery. With the assistance of IBM (Mexico), we classified land cover types in a portion of a LANDSAT image that covered the approximate target area of our Solana cropping systems project. Because the correspondence between cover types and alluvial terrain classes was known, we could identify alluvial land units on the image. The alluvial terrain classes were distinguishable because hydrological differences determine land use patterns.

On the date of image acquisition, rice stubble covered most of the old alluvial terrace, senescing maize or maize stubble covered the second terrace of the active floodplain, and green maize covered the first terrace. Sandy point bar deposits were found adjacent to the river. Villages could be identified on the alluvial land but not in the hilly and mountainous areas. The plant cover in hilly and montainous areas consisted of forest and grassland of various vegetation densities and mixtures.

The computer-classified portion of the Cagayan River Basin in Figure 1 shows the four main classes on the alluvial terrain (old alluvial terrace, first and second river terraces and point bar deposits). Some terrain class mixing is apparent but the results were adequate for our use. We have used prints of the image to locate areas of old alluvial deposits or similar landforms, on which traditional rice varieties predominate.

1. We are using computer analysis of satellite imagery as a rapid land classification technique. This computer-classified satellite image covering part of the Cagayan Valley shows areas in the alluvial plain and other land systems. Within the alluvial plain, point bar deposits are bright blue, first and second terraces of the active floodplain are yellow and rust, and old alluvial terraces are brown.

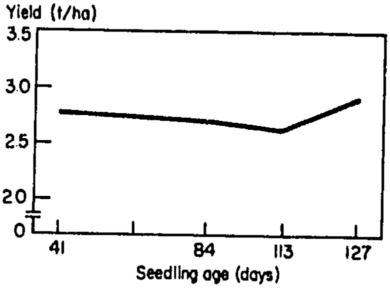


2. Uneven rainfall has contributed to the erratic performance of crops in environments similar to Solana. About half the growing season rainfall is derived from tropical cyclones.

Contributions of tropical cyclones

The long-term average April-December rainfall in Cagayan is 1,677 mm. During the 3 years of the cropping systems project, rainfall was below average (1,309, 1,613, and 1,245 mm). In all years, however, we have found the erratic rainfall distribution within the cropping year to be a greater problem than total rainfall.

For these 3 years, 58, 40, and 48% of the rainfall were derived from the cyclones (Fig. 2) and mungbean was affected directly by excess moisture and indirectly by the competitive advantage that



3. Unlike modern rice varieties, grain yields from traditional varieties are insensitive to seedling age, and therefore to transplanting delays forced by too little or too much rainfall. These grain yields were produced without nitrogen fertilizer.

soil moisture gives adapted weeds. The periodic submergence and drought caused by brief intervals of intense rainfall and extended periods of sparse rainfall directly affected rice crop performance. It also influenced the timeliness of field operations. For example, rice was transplanted only during brief periods when sufficient water for land preparation accumulated in the field.

Delayed transplanting is a common symptom of inadequate water for land preparation. The mean seedling age of the traditional varieties farmers transplanted was 92 days in 1980 and 67 in 1981. Unlike modern varieties, traditional photoperiod responsive varieties are not strongly influenced by seedling ages over a range of 40 to 120 days (Fig. 3).

Pattern studies in the Cagayan Valley

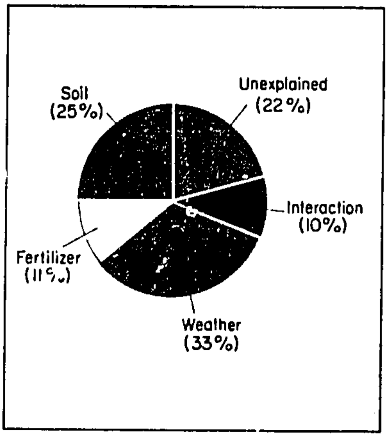
Previous trials in the Solana project in Cagayan suggested that mungbean could be a productive first crop before rice, but our studies showed, that to be safe and profitable, mungbean should be planted on well-drained terrain positions. In 1982, we continued our studies and obtained similar results.

The mean mungbean yield was 400 kg/ha from 10 fields on well-drained land, but only 220 kg/ha from 10 fields on poorly drained land. The mean harvest yield of 36 farmer cooperators was only 34 kg/ha; 17 farmers planted but did not harvest because the crops were ruined.

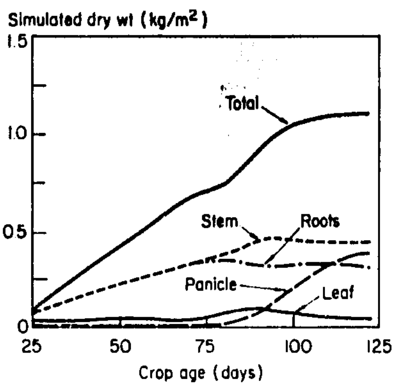
To test the adaptation of mungbean outside the Solana project area, poorly drained and well-drained units similar to those in Solana were located in 12 villages. The mean yield was 570 kg/ha across 12 well-drained fields, but only 120 kg/ha across 11 poorly drained fields. With the erratic rainfall patterns of Cagayan Province, almost all fields experienced some degree of excess moisture during the season. Yields on 10 of the poorly drained fields were zero or nearly zero, whereas yields on only 4 of the well-drained fields were extremely low. The land system classification we developed for the project has helped us to identify land where the risk confronting mungbean production is low.

Weather and rice yields

IR52 was central to most cropping patterns tested in the Solana Cropping Systems Project site. From the analysis of yields from 35 experiments conducted over seven landforms in the Cagayan River Basin, we found that while fertilizer, especially nitrogen, was an important factor contributing to yield increases, it accounted for only 11% of the yield variability detected in the



4. In the Cagayan Valley, two environmental factors, weather and soil, contributed to more than half the yield variability observed in fertilizer trials with IR52.



5. Simulated dry weights of various plant parts as a function of plant age for the case under severe vegetative drought stress.

study (Fig. 4). Weather alone accounted for 33% and soil factors for another 25%. Interactions among the weather, soil, and fertilizer variables accounted for 10% of the observed yield differences. Soil and weather plus a few unknowns had the major role in determining yields in this study.

Crop growth simulation

Crop growth simulation has the potential to increase the efficiency of cropping systems research targeted for specific environments. Before field research is initiated, crop simulation models can help us identify cropping patterns that have a strong possibility of being adapted to specific environments. After 2 or 3 years of field research, crop growth simulation can be updated and used to test long-term pattern stability by using validated models and historic weather records.

We tested a rice model for its sensitivity to changes in weather variables, which drive the simulation, and in crop and soil parameters, which are used to calculate crop growth and development during the growing season. The objective was to determine model realism and to identify the variables and parameters to which the model is very sensitive. These components must be accurately determined if the model is to be a useful yield predictor.

The simulated dry weights of plant parts in Figure 5 show the growth and development of IR36 exposed to severe drought during vegetative growth. The model was sensitive to the climatic variables of solar radiation, pan evaporation, a factor relating pan evaporation to transpiration, and day length. We found that the model was very sensitive to the soil water content and to a leaf nitrogen parameter and intermediately sensitive to model parameters for respiration and axial root resistance. It was not sensitive to initial seedling weight. Extremes for the light attenuation parameter caused large reductions of predicted panicle weight. We will continue to strengthen this model and introduce models for other crops into the system so that potential crop sequences can be tested by simulation.

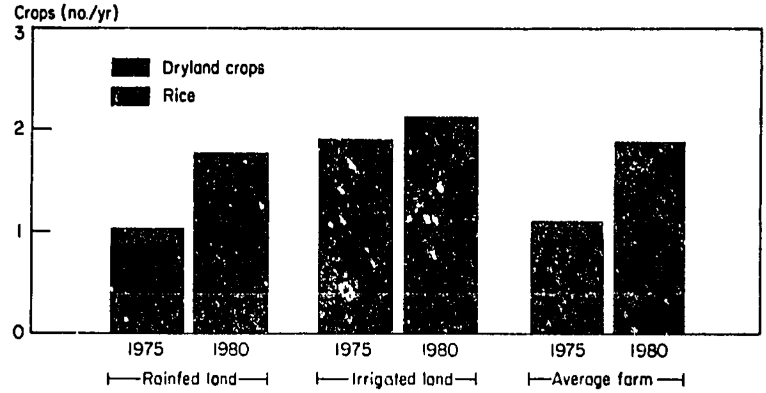
ANALYSIS OF THE SOCIAL AND ECONOMIC ENVIRONMENT

Impact of new cropping systems in Iloilo, 1975-80

Completion of 6 years of research in Iloilo Province, Philippines, provided an opportunity to make an overall assessment of IRRI's activity there.

In 1975 we began cropping systems research on rainfed farms

6. By adopting early-maturing varieties and early seeding techniques, Iloilo farmers grow more crops each year on both the rainfed and irrigated land. Cropping intensity rose 72% on an average farm because of the combined effect of multiple cropping technology and increased irrigation (from 5 to 25% of land).



in Iloilo to identify cultural techniques that would increase the number of sequential crops farmers can grow each year. Although we originally planned to dry-seed early-maturing rice varieties, early rains during the first year prevented that. We were forced to broadcast-seed onto wet, puddled soils. Farmers liked the improvisation and the "wet-seeding" method was launched in Iloilo.

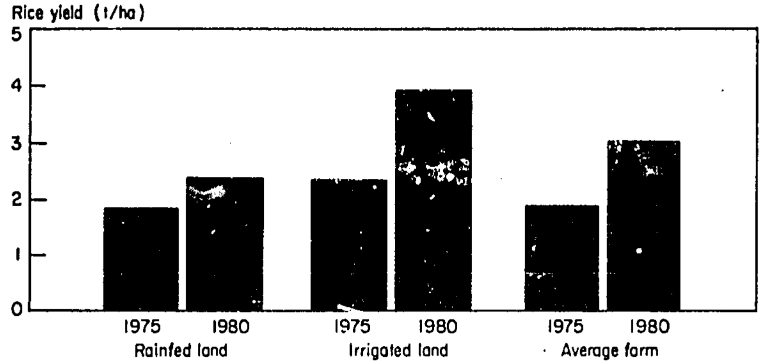
Coupled with the use of newly released early-maturing rice varieties IR28 and IR30 (and later IR36), the new technology made it possible to grow more rice and dryland crops on rainfed and partially irrigated lands. National authorities improved irrigation facilities in the area, extending the growing season by about 6 weeks on 25% of the land area.

Throughout the 6-year project, changes we observed on 45 farms reflected the general trends of the region as the new technology spread through the Philippine Government KABSAKA extension program. An increase in cropping intensity between 1975 and 1980 on rainfed and irrigated land was made possible by direct-seeding of early-maturing rice varieties (Fig. 6).

Along with growing more crops per year, farmers increased fertilizer use from about 20 to 40 kg N/ha. These and other measures increased yields (Fig. 7). We observed no improvements in dryland crop yields. The combined effects of higher yields and cropping intensity are shown in Figure 8.

Records of 1,380 rice plots kept by the 45 sample farmers showed that returns and net returns above variable costs are higher for modern varieties (MV) than for local ones, and for irrigated plots than for rainfed plots. What is more striking however is that these returns from improved technology are more stable relative to their mean level, than returns to traditional technology. These results contradict the views that modern tech-

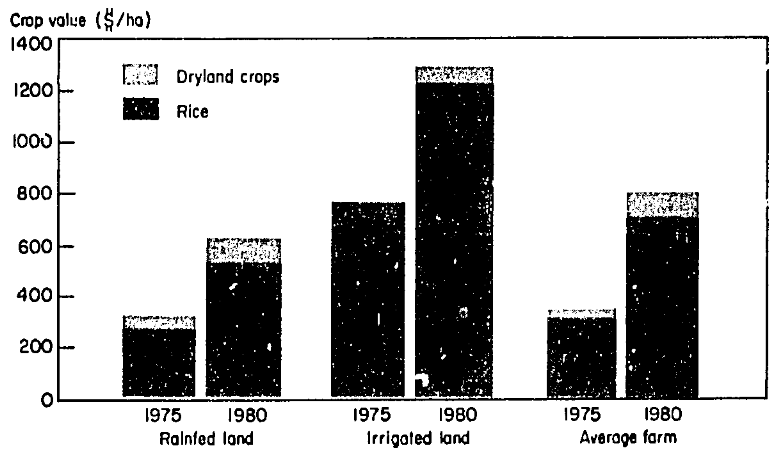
7. Rice yields increased on Iloilo farms when farmers adopted improved cropping practices.



nology displaces labor, requires much higher cash investment, offers lower rates of return on investment, and subjects farmers to greater risk than traditional technology.

Table 1 shows the composition of variable costs and the returns to cost, a form of the benefit-cost ratio. Four conclusions are evident:

- MVs result in the employment of as much labor as, or more labor than, local rice varieties.
- Cash costs for fertilizer and other materials used by farmers are a small fraction of total crop production costs, and not markedly higher on MVs than on traditional varieties.
- Total variable costs for producing the lowest-technology crop — transplanted, rainfed local rice variety — are not markedly less than those for producing the highest-technology crop — direct-seeded, irrigated MV rice.
- The rate of return on investment in labor and materials is uniformly higher for improved technology.



8. A 72% increase in cropping intensity and 42% increase in crop yields per farm resulted in a 140% increase in the value of crops on farms in Iloilo villages.

Table 1. Costs of production and rate of returns on costs of new rice technology on 45 farms in Iloilo, 1975-1980.

Management regime	Cost ($/ha)			Returns-to-cost ratio
	Labor	Material	Variable	
		Transplanted		
Rainfed				
Local	194	29	223	1.7
Modern variety	191	36	227	2.1
Irrigated				
Local	172	41	213	1.8
Modern variety	212	56	268	2.6
		Direct-seeded		
Rainfed				
Local	134	36	170	2.0
Modern variety	151	62	213	2.1
Irrigated				
Local	155	69	224	2.1
Modern variety	178	101	279	2.6

The data support the view of cropping systems researchers that a new technology should offer a 2 to 1 rate of return on current costs to be minimally attractive to farmers.

Finally, the records of sample farms provide helpful insight into farmers' use of purchased inputs and raise questions about the efficiency of inputs used. Nitrogen (N) fertilizer is the largest, often the only, cash expenditure in a farmer's crop budget. To obtain the highest yield response to N, we recommend incorporating it into the soil at rice planting time, with possibly additional applications no later than at panicle initiation 10 to 11 weeks before harvest

On sample Iloilo farms, only 17% of the fertilizer is applied at planting time. Another 23% is applied in the 2 weeks around panicle initiation, and the remaining 60% later when less of the N can be used by the plant. Farmers delay application because of late availability of funds and to observe the crop progress before investing in it.

The changes in labor and material input use and crop production have brought major changes in the farm household, structure of the labor force, and farm capital. Other studies are examining in some detail the general findings that children and farm operators now work less on farms, with the former getting more education and both being replaced by hired labor. All rice is mechanically threshed when previously none was, and by 1982 tractors had replaced the carabao on 33% of the riceland.

Adjustments are still in progress. Weeds appear to be increasing and farmers may need to return periodically to transplanting. We are continuing to monitor changes on the 45 farms. We will investigate major developments when the need occurs.

By the 1982-83 crop year, 13,500 ha in Iloilo and surrounding provinces were part of the government's KABSAKA program and direct-seeded with early-maturing rice varieties. Higher cropping intensity has resulted in the mechanization of plowing and harvesting and a consequent decline in draft animal ownership. More than 50 firms in the area manufacture small threshers, where before 1975 there were none.

PEST CONTROL IN RICE-BASED CROPPING SYSTEMS

Differential competitiveness of *Echinochloa colona* ecotypes

E. colona is among the most troublesome weeds of rice in rainfed fields. We found that competitiveness of ecotypes of *E. colona* increased when their association with rice was prolonged. The competitive ability of each ecotype, however, varied with stage of weed growth. The Pangasinan ecotype was more competitive with rice at all sampling times, but South Cotabato and Leyte ecotypes became competitive starting 30 and 45 days after seeding.

Different rice cultivars also showed different competitive abilities against *E. colona*. The weed was less competitive with IR52 than with Binato.

Differential response of *Echinochloa colona* ecotypes to herbicides

Ecotypes of *E. colona* vary in their susceptibility to herbicide inhibition of seed germination. The Batangas ecotype was the most susceptible and the Nueva Ecija ecotype was the most tolerant (Table 2). They also differed in susceptibility depending on the kind of herbicide. Seed germination of IRRI (red) and Camarines Sur ecotypes was not inhibited by a 3 ppm thiobencarb treatment, but was only slightly or moderately inhibited by butachlor. Germination of the Batangas, Cagayan, and Pangasinan ecotypes was inhibited by both herbicides, but the degree of inhibition differed with the herbicide.

Continuous application of the same weed control treatment

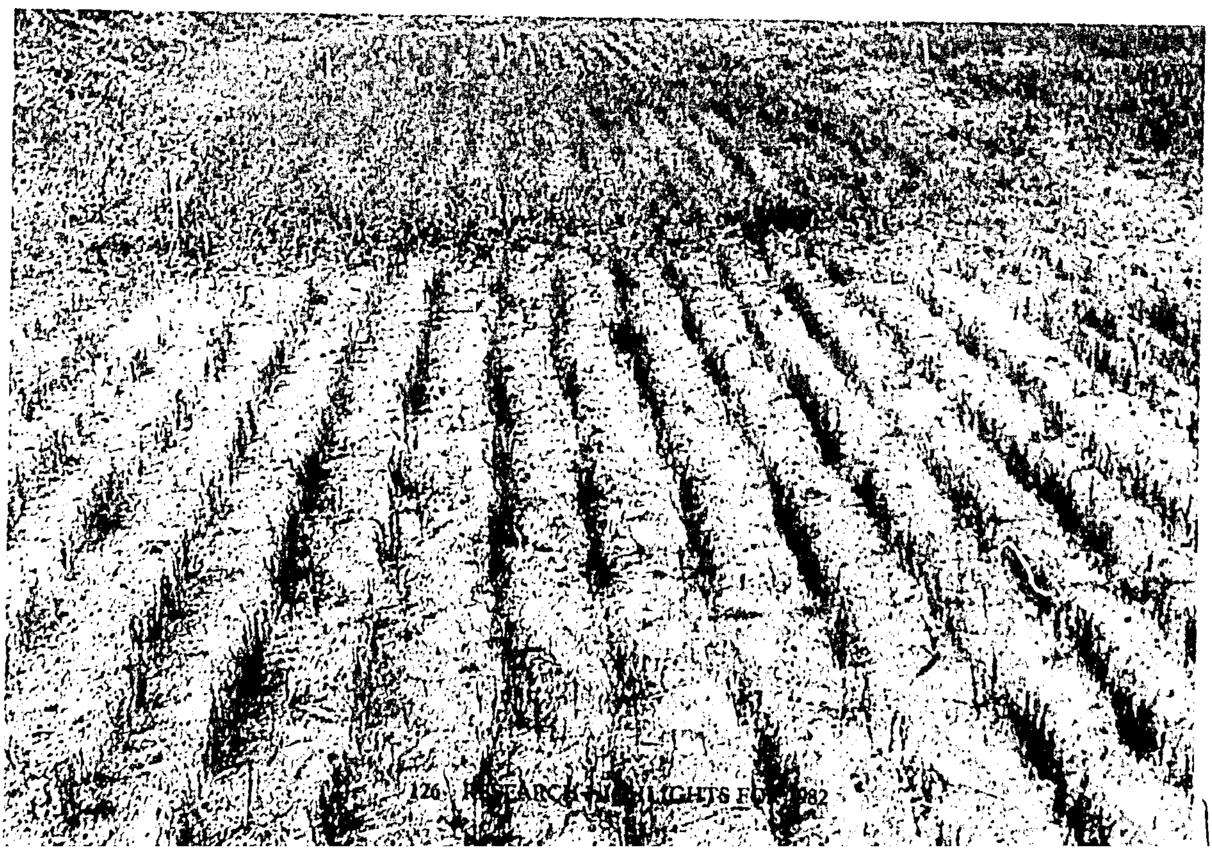
The dominant and annual grass *Rottboellia exaltata* in dryland rice was almost eliminated in the third year of a rice - mungbean

Table 2. ***Echinochloa colona*** **ecotypes differ in susceptibility to herbicides. The germination of one ecotype may be inhibited by butachlor but not by thiobencarb.**

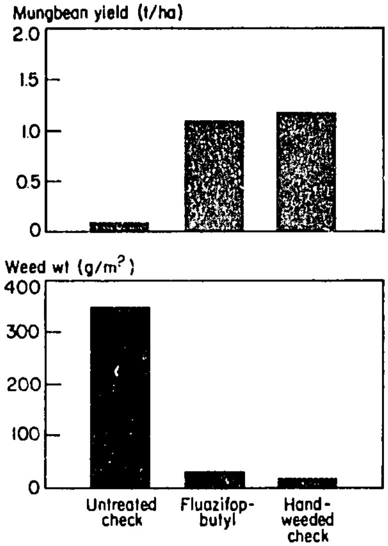
Ecotype	Inhibition of germination (% of control) at 3 ppm	
	Butachlor	Thiobencarb
Nueva Ecija	0	0
IRRI (red)	6	0
Batangas	22	13
Camarines Sur	12	0
Cagayan	4	3
Pangasinan	14	3

cropping system when the plot was kept weed free by three hand weedings for rice and two hand weedings for mungbean. However, other weeds such as *Cyperus rotundus* and *Ipomoea triloba* became dominant in the rice after 2 years of rice - mungbean cropping. One hand weeding, two hand weedings, and the application of pendimethalin followed by 2,4-D did not control weed regrowth later in the season.

Severe weed infestations and drought stress resulted in no rice yield even with several control treatments. Figure 9 shows the weed-free plot and weedy check in the fifth cropping.



9. Intensive hand weeding during the past 2 years in a dryland rice-mungbean cropping system resulted in drastic reduction of *Rottboellia exaltata* population as shown by the clean plot in the foreground vs weedy check in the background.



10. A single application of fluazifop-butyl (0.25 kg ai/ha) adequately controlled *Rottboellia exaltata* in mungbean.

Herbicide control of *Rottboellia exaltata* in mungbean

R. exaltata is an important weed of mungbean, one of the mainstay crops of farmers in dryland areas. In our search for chemicals for weed control in mungbean, we found that one application of fluazifop-butyl 2 weeks after crop emergence sufficiently controlled *R. exaltata* to provide mungbean yields similar to those of the hand-weeded check (Fig. 10).

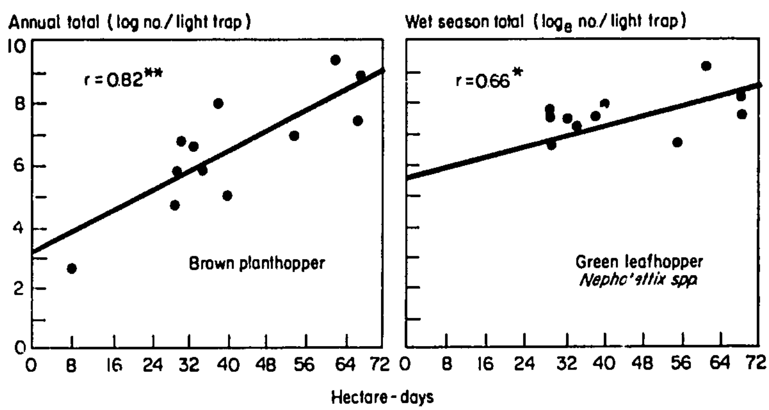
Rice cropping intensity and insect abundance

We have developed a predictive index which shows an exponential relationship between insect abundance and the space-time aspects of rice cropping systems based on rice cropping intensity (Fig. 11).

Low annual populations of brown planthopper and green leafhopper occurred in areas with the least amount of land cropped to rice, the fewest rice crops per year, and the earliest maturing varieties.

The significance of the exponential relationship for cropping pattern design is that increasing the number of rice crops from one to two is likely to result in far more than a 50% increase in pest incidence.

These results pertain to a mean intensity over a relatively wide area (314 ha within a 1-km radius). The effects may not be visible on a smaller scale. A 1-ha rice garden with four rice crops a year and with no significantly greater infestation than that in a surrounding double-cropped area does not invalidate our index. Because of the pests' dispersal behavior, a 1-ha area cropped year-round is not large enough to sustain increasing insect populations.



11. The exponential relationship of the abundance of two rice pests and rice cropping intensity measured by hectare-days can be used to design more pest-stable cropping patterns. Hectare-days is the product of the number of hectares under rice cultivation within 1 km of a site, the mean number of rice crops per year in those fields, and the mean crop duration in days.

Disease research in Solana

We continued assessing the plant disease situation at the Solana outreach site. Leaf blast which was not observed previously became an important disease causing damage to IR52 seedlings in seedbeds. Dry-seeded and wet-seeded IR52 plants in the field were also affected with disease severity ratings of 4 to 7. Mungbean planted after rice suffered from *Rhizoctonia* and *Sclerotium* damping-off.

Our survey of farmers' knowledge of plant diseases conducted at Solana revealed that tungro was the only rice disease farmers could correctly identify. They attributed other diseases they observed mostly to insect damage.

Chemical control

Interaction between pathogens as influenced by fungicides. We determined the interactions between soil-borne pathogens in the presence of seed-applied fungicides. When using carboxin + captan on seeds from Rhizoctonia (R) + Pythium (P)-infected soil, R could enhance the pathogenic ability of P by increasing the infection from 53.8% in P-infected soil alone to 69.6% in R + P-infected soil. With PCNB + thiadiazole, the percent infection in Sclerotium (S) + P soil was significantly lower than in P alone, but higher than in S alone. Because 90% of the infected seeds from S + P soil were colonized by P, S could be adverse to P, reducing infection. Seed treatment with orthocide RE-26745 could cause synergism between S and P because the infection produced by the combination of the two pathogens was significantly higher than that produced by either alone. Infected seeds from P + S soil were attacked equally by S and P.

Time and frequency of spraying fungicide. We conducted studies to determine the proper time and the most effective minimum spray frequency to control Cercospora leaf spot (CLS) of mungbean before rice. We found that mungbean sprayed once at 20 days after emergence (DE) and twice at 20 and 30 DE had the lowest infection at 39 DE among single and double sprayings. The best time to spray could be at 20 DE. Data on grain yield from the two trials were inconsistent with treatments. We observed similar results with powdery mildew of mungbean in the greenhouse.

Saprophytic survival of three soil-borne pathogens

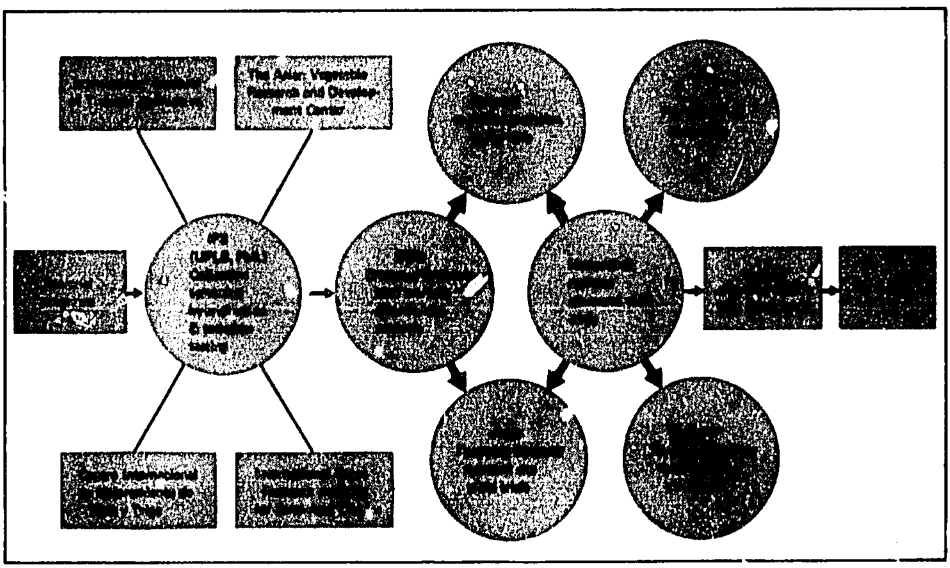
We buried mungbean stalks separately infected with *Rhizoctonia solani*, *Sclerotium rolfsii*, and *Fusarium* sp. in wetland and dryland ricefields. Our data showed that only Fusarium could remain highly viable in dryland for months. Although the recovery of Sclerotium was very low, it produced numerous sclerotial bodies in both dryland and wetland fields. We also buried stalks without the pathogens and found that in dryland fields, the percent of colonization by naturally occurring Rhizoctonia was higher than that of Sclerotium, but Sclerotium produced more sclerotial bodies than Rhizoctonia in both fields. Naturally occurring *Fusarium* sp. in the field was most efficient in colonizing the stalks in both fields, but was not recovered in succeeding months. Fusarium in the field could be different from that used in burying infected stalks. Our results suggest that Sclerotium could survive better in wetland fields by forming numerous sclerotia causing infection in the next crop.

SELECTION AND TESTING OF CULTIVARS

Variety testing and screening

One of the major constraints identified during the 1980 conference on cropping system research in Asia is the lack of suitable upland crops that fit the rice-based cropping systems. The participants strongly recommended establishing a breeding program for crop varieties adapted before and after rice.

In 1982, IRRI in collaboration with the Institute of Plant Breeding (IPB) of the University of the Philippines at Los Baños (UPLB) expanded the screening program at UPLB to include hybridization and selection. The upland crops varietal improvement scheme is shown in Figure 12. IPB will collect genetic



12. Scheme for varietal improvement of upland crops for rice-based cropping systems.

materials from international regional and national centers for screening and use in its breeding program. IPB tested 2,209 mungbean and 17 soybean accessions for use before rice and 2,233 mungbean, 787 soybean, and 544 peanut accessions for use after rice. We started hybridization in October 1982 by making 54 soybean, 55 mungbean, and 6 peanut crosses.

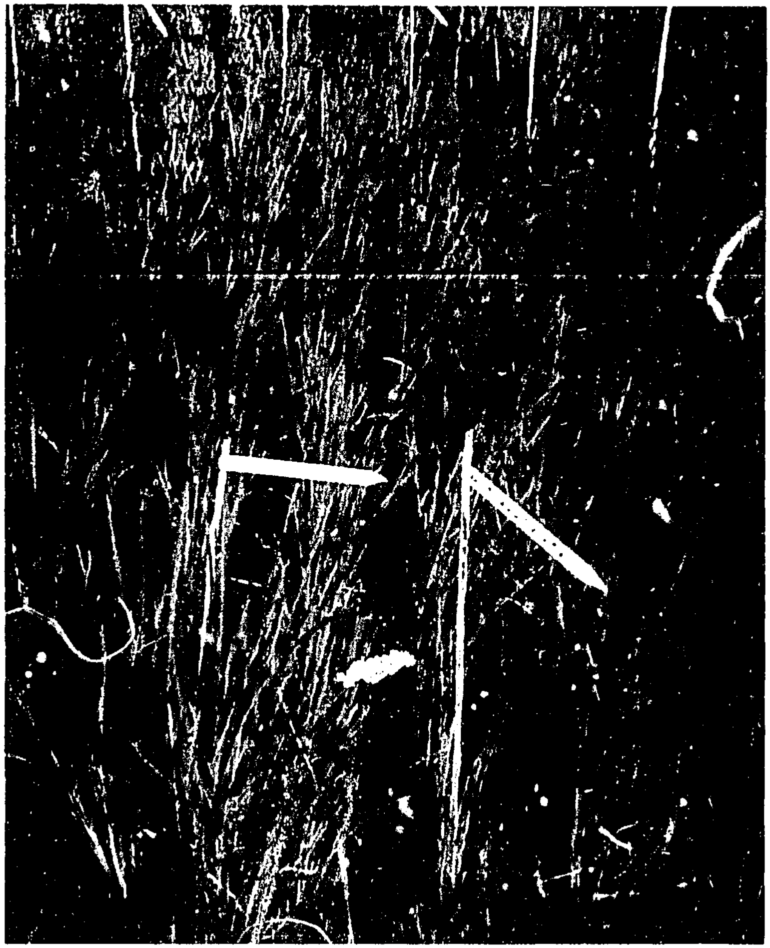
The most promising varieties of peanut, maize, soybean, cowpea, mungbean, and sorghum from IPB and national breeding programs are submitted to IRRI for testing in the Asian Cropping Systems Network (ACSN). Varietal testing within the ACSN also was expanded. Trials are conducted at the research station or cropping systems research site. IRRI distributed 47 trials before rice and 152 after rice to Indonesia, Thailand, the Philippines, Nepal, Sri Lanka, Vietnam, Burma, Bangladesh, and Malaysia. There were 42 trials of mungbean, 25 cowpea, 21 bush sitao, 31 soybean, 28 peanut, 18 sorghum, and 34 early-maturing maize. The most promising entries from the trials will be included in national regional or advanced testing programs.

Filling a gap in the cropping calendar

In Solana, northern Luzon, an area prone to flash floods, farmers must either forgo a wet season crop or plant tall, low-yielding traditional varieties very early in the season. In screening experiments, crosses of several short-statured lines, such as IR26702

Farmers in Solana grow tall traditional rices in low-lying fields and modern varieties in upper fields.

13. Lines from the cross IR26702 survived especially well under natural submergence in Solana.



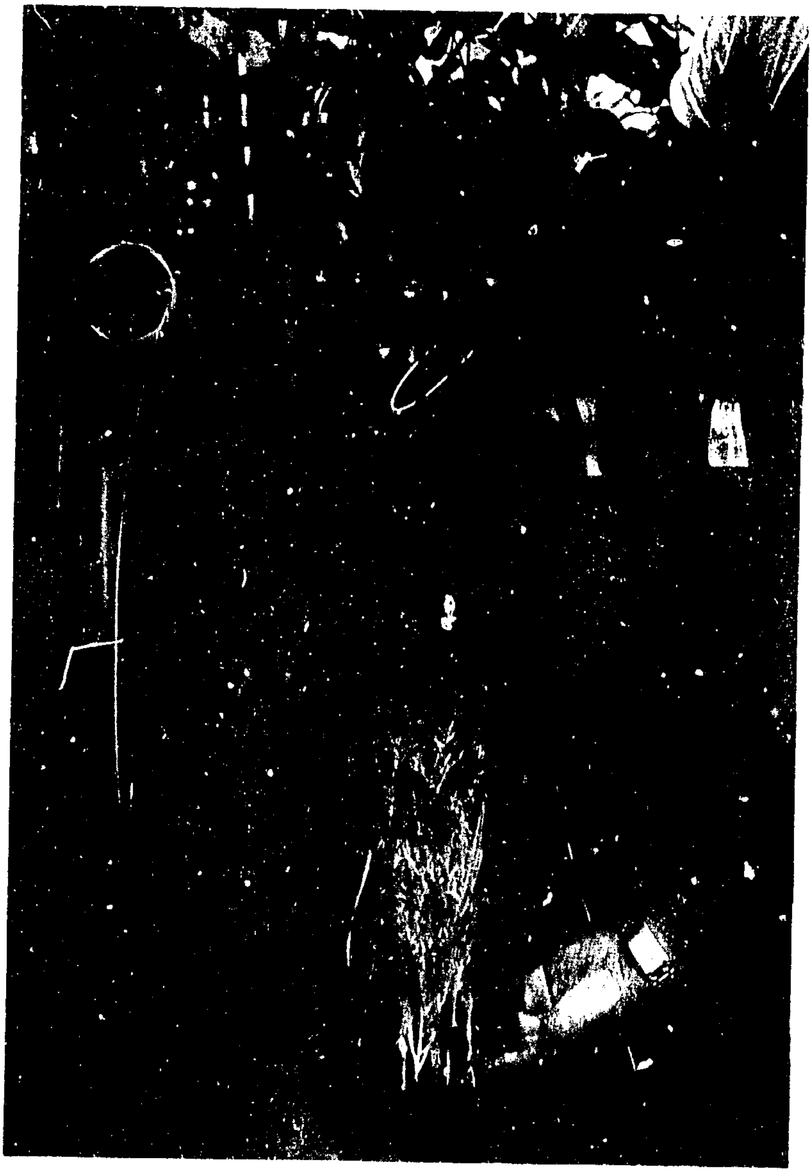
(Fig. 13), IR31031, and IR31023, with submergence-tolerant FR13A have had excellent survival. We are optimistic that we will be able to introduce short-statured modern varieties to fit the cropping calendar of farmers in Solana and other flood-prone areas.

AGRONOMIC MANAGEMENT IN RICE-BASED CROPPING SYSTEMS

Screening root systems of soybean and peanut cultivars

In grain legume cultivars, rooting depth and root volume are important for drought adaptation. Comparison of cultivar root systems in the field is laborious and time-consuming. To speed up cultivar screening, we evaluated a hydroponic culture method (Fig. 14). Among the 20 cultivars each of peanut and soybean compared, we observed a 30-40% variation in root depth and volume. Root length was positively correlated with leaf area,

14. Length and volume of grain legume roots can be determined rapidly on cultivars grown hydroponically. We are testing the correlation between these root parameters and growth in droughty fields.

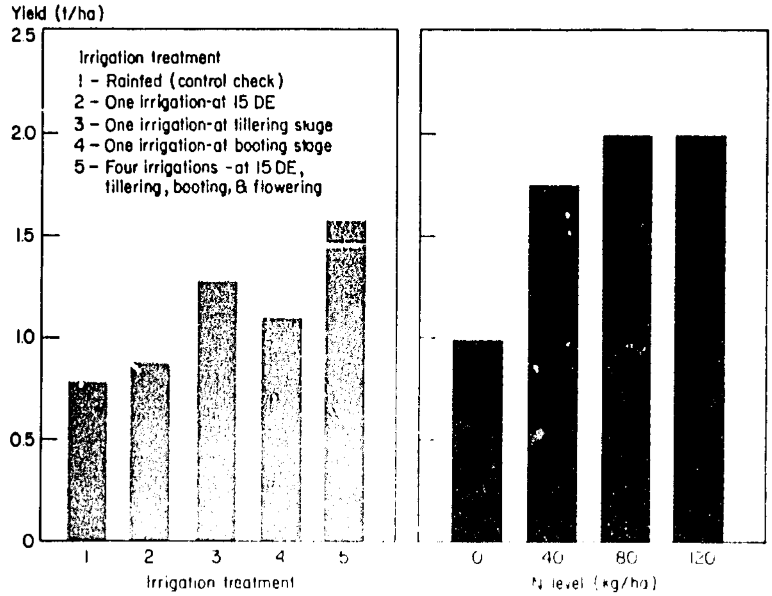


shoot dry matter, and root dry weight. Root volume was positively correlated with leaf area and shoot dry weight. We are now checking the field performance of the cultivars.

Tropical wheat as an alternative after rice

In many tropical rice growing countries, wheat consumption has increased as prosperity has improved. Because wheat must be imported into many of these countries, governments have shown interest in tropical wheat production. For several years, IRRI cropping systems scientists have evaluated wheat for its adaptation as a postrice crop. In 1982 at IRRI, the highest yield with the

15. As a crop to follow rice, wheat (Trigo I) has been found to respond to irrigation frequency and N rate. Better adapted cultivars are being sought in collaboration with CIMMYT. DE = days after crop emergence.



best management was 2.1 t/ha. We found the best adapted wheat variety to respond strongly to increased irrigation frequency and N fertilizer (Fig. 15). In 1982, collaboration was initiated with the International Maize and Wheat Improvement Center (CIMMYT) to identify wheat cultivars that are better adapted to the tropical environment.

Response of transplanted rice to mungbean green manure

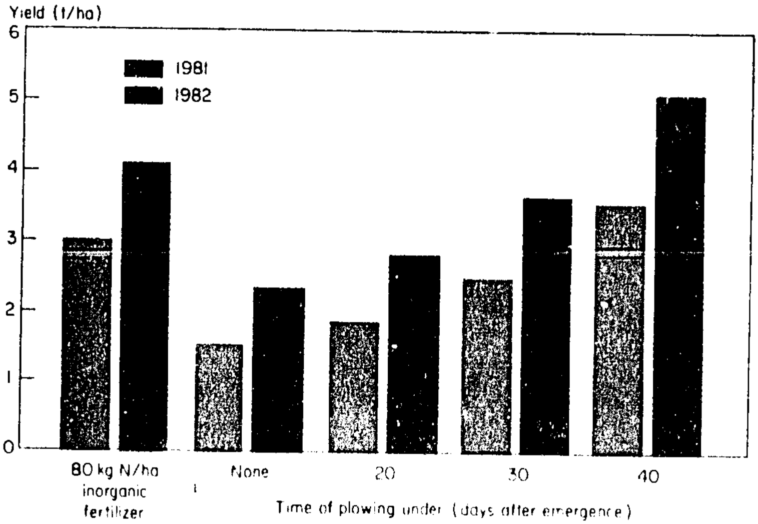
In 1982, an experiment we conducted confirmed responses of 2 t/ha produced by plowing under a 40-day-old mungbean crop before transplanting IR36 (Fig. 16). We are conducting more research on green manure to determine its response to management and environmental variables. Where the wet season onset is too abrupt to permit a farmer to grow a grain legume to maturity, he may utilize the early rainfall to grow a green-manure crop as a substitute for N fertilizer.

Evaluation of the drought response of four grain legumes

We compared the responses to increasing drought of four grain legumes that are frequently grown in the early dry season after rice (peanut, soybean, cowpea, and mungbean).

Peanut is recognized as a comparatively stable producer where available soil moisture declines over time. We sought to identify the plant attributes responsible for the greater stability peanut shows as soil moisture diminishes. Identifying these attributes

16. Plowing under a 40-day mungbean crop produced a greater yield response than applying 80 kg N/ha from inorganic fertilizer.



would help us to critically evaluate alternative postrice crop species and cultivars.

We used a line source sprinkler to set up a water gradient in a field. At the dry end of the gradient, seed yields of the four legumes were reduced by drought stress, but the reduction was least in peanut. Under dry conditions, water use was most efficient for peanut and cowpea and least efficient for mungbean.

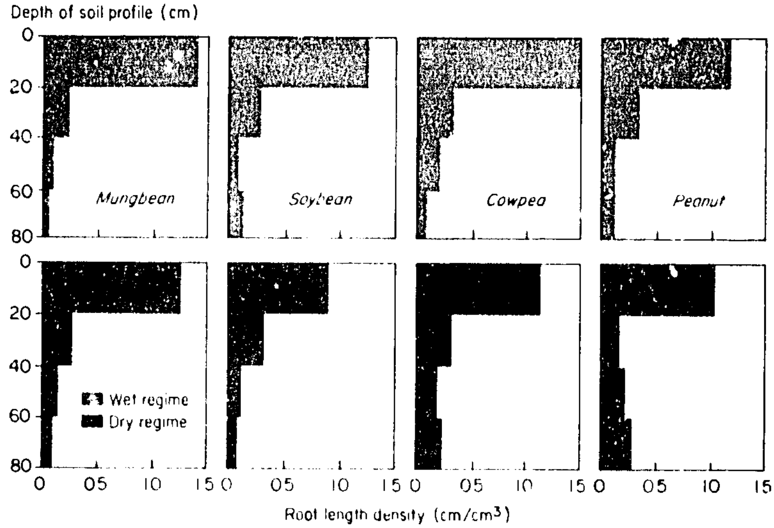
The relatively low seed yield reduction of peanut suggested that stronger adaptive mechanisms operated in peanut than in mungbean, soybean, and cowpea. Several attributes affected crop water status in the peanut crop. The mean leaf area expansion rate between 20 and 50 days after planting was highly influenced by drought stress. The expansion rate of peanut declined rapidly as the cumulative leaf water potential ($\Sigma\Psi_w$) decreased.

Measurements at 55 days after emergence showed that, at both the wet and dry ends of the gradient, peanut exhibited the greatest root length densities at lower depths (40-80 cm) (Fig. 17). The quantity of water extracted at the dry end was greatest for the peanut crop.

Slow leaf growth and reduced ground cover, accompanied by the deep root system, appeared to contribute to the drought tolerance mechanism in peanut. In cowpea, a deep root system and reduced leaf area were recognized as the adaptive mechanisms for drought tolerance.

At the dry end of the gradient, leaf water potentials (MPa) at noon on day 65 were 1.3 in mungbean, 1.2 in cowpea, 1.8 in soybean, but only 0.6 in peanut, an additional indication that

17. Root length density of 4 food legumes at various soil depths 55 days after emergence and for wet and dry ends of a gradient.



peanut had avoided stress. Canopy temperature was lowest in peanut.

In all crops, from day 35, when the plants were beginning to increase rapidly in size to day 65, when a substantial amount of pod filling had occurred, ($\Sigma\Psi_w$) was strongly correlated with the cumulative canopy-ambient temperature differences ($\Sigma\Delta T$). $\Sigma\Psi_w$ and $\Sigma\Delta T$ were correlated with total dry matter and grain yield. At the dry end of the gradient, peanut exhibited the highest (least negative) $\Sigma\Psi_w$ and the lowest $\Sigma\Delta T$ and mungbean and soybean showed high drought stress and major yield reductions. Peanut had the lowest $\Sigma\Delta T$ at all moisture regimes.

When a crop has adequate water, the temperature difference between the canopy and air will be near zero. As drought stress increases, the canopy temperature will increase relative to the air temperature. Because canopy temperature is easily determined by a hand-held infrared thermometer, $\Sigma\Delta T$ provides a measurement that can help us to evaluate species and cultivars within species for performance during drought.

Tillage and planting methods for mungbean

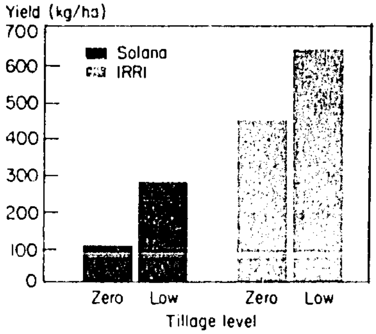
Because of its short maturity and market acceptance, mungbean is often a marginal crop early in the wet season before rice or at the end of the wet season after rice.

In the Solana project, yields of mungbean planted before rice suffer from low plant populations, weediness, and excess moisture. We compared tillage and planting methods in field experiments in Solana and at IRRI where experimental conditions can be more easily controlled. At both locations we found that, when the crop is flooded early, yields were superior where the soil had been plowed and harrowed. Yields from untilled fields were inferior (Fig. 18). Beneficial effects come from improved weed control, lower plant losses, and less stunted growth. The latter two factors are apparent responses to better soil aeration.

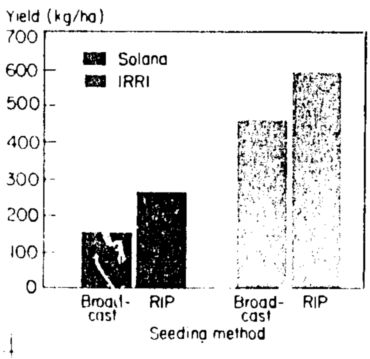
The low yields at Solana from both the zero and minimum-tillage treatments were attributed to a severe 2-day natural flooding that started 21 days after seeding. Where the soil was not tilled, plant population was reduced by 60%. At IRRI a 3-day artificial flooding started at 20 days after seeding decreased yields by 340 kg/ha and plant population by 28%.

At both locations, yields from rolling injection planter (RIP) seeding were superior to yields from broadcast seeding (Fig. 19). Although yields from RIP seeding were about equal to those from hand drilling, the RIP seeding was much less laborious.

In a comparison of RIP performance, we found that adding a weight to the RIP for deeper seed placement did not result in better germination on either upland or lowland soils. Initial germination was, however, greatest on the upland soil (Fig. 20).



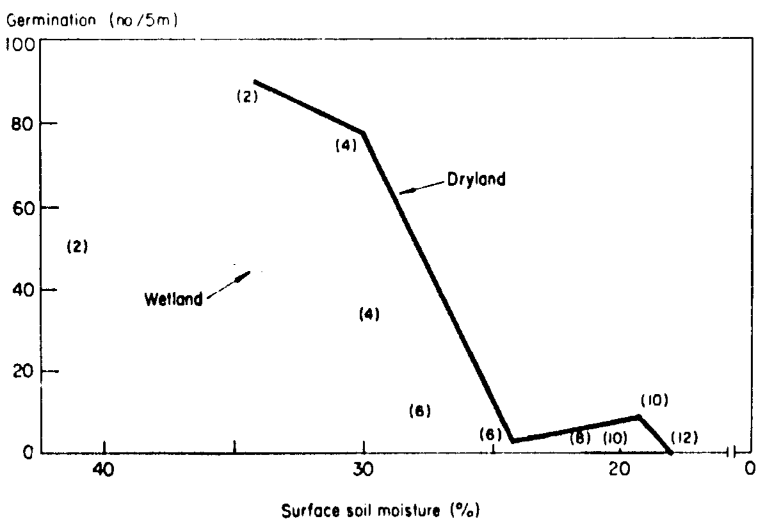
18. At Solana and IRRI, the higher yields from tillage treatments were attributed to better weed control, high plant populations, and less stunted growth. The low Solana yields were caused by natural flooding.



19. At IRRI and Solana, yields from the rolling injection planter seeding (RIP) were superior to yields from broadcast seeding.

Ratooning sorghum

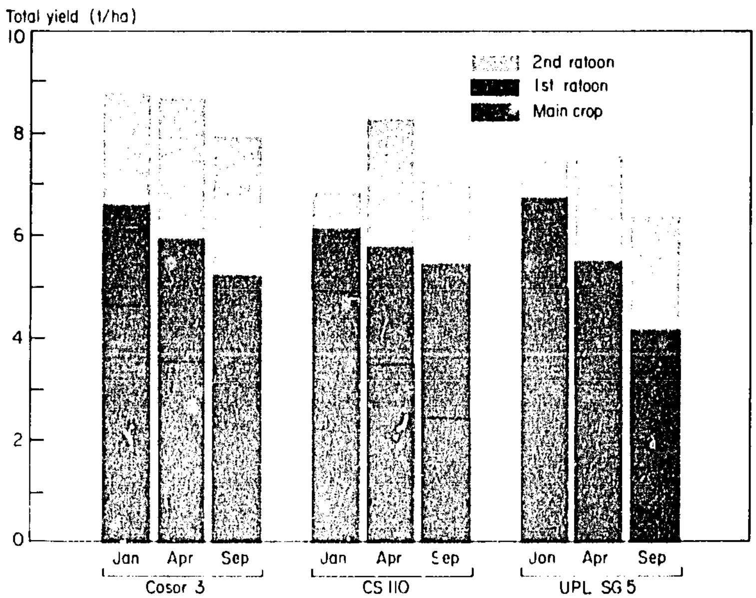
By ratooning sorghum, farmers can eliminate labor for tilling and planting second and third crops. We compared January, April, and September sorghum plantings with different varieties, plant populations, and alternative cutting management. From these three plantings the second ratoons were harvested the following December, March, and September. Most yield differences were



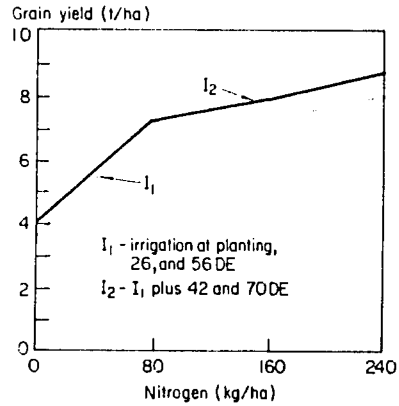
20. Germinated seeds declined sharply in upland and lowland soils as seeding delay lengthened and surface soil dried. Initial germination was greater in the upland soil, but declined rapidly on both soils when soil moisture dropped below 28%. Values in parentheses are days of delay in seeding.

By varying the number of stem nodes left above ground level during main crop harvest (foreground), first ratoon yields from Cosor 3 were only slightly affected. Yields from the first ratoon of Cosor 3 averaged 75% of the main crop yields.

attributed to varieties. Plant population and cutting heigh treatments, although significant on the first ratoon from th September planting, did not strongly affect yields and were no consistent across ratoons. Plant population and cutting heigh treatment effects were even weaker. Total yields from Cosor 3 were slightly greater and more uniform across planting dates thar those from the other varieties (Fig. 21). These results confirm th potential of sorghum as a crop requiring low labor input fo multiple harvests.



21. Total yield from the main crop, and 1st and 2d ratoons of the best variety exceeded 8 t/ha for January, April, or September plantings. Populations in excess of 200,000 plants/ha and cutting height had only a small influence on total yields.



22. Maize yield response to applied N was sharp up to 80 kg N/ha, producing a mean yield of 7.3 t/ha in the dry season. Two additional irrigations increased yields by an average of only 0.5 t/ha. DE = days after emergence.

Hybrid maize in the tropics

Maize hybrids recently developed for the tropics have exhibited high yield potential for dry season plantings. We repeated an experiment to confirm 1981 results. The objective was to determine the yield response of a hybrid (Hycorn 9) to irrigation and N fertilizer. We also examined the timing of N applications.

The high yields attained are shown in Figure 22. Across all irrigation and N application times, 240 kg N/ha increased yield by an average of 4.4 t/ha. Because of the sharp initial response, the first 80 kg N/ha accounted for 77% of the N response and resulted in a mean yield of 7.3 t/ha. By applying all 80 kg N/ha during an interrow cultivation at 25 days after emergence (DE), yields were increased by 0.4 t/ha over an application split at basal and 25 DE. The comparison of three irrigations (I_1) and five (I_2) indicated that the additional water boosted yields by an average of only 0.5 t/ha.

These maize yields are considerably higher than the 1-3 t/ha averages of typical small-scale farmers. Where national rice production targets are approached, we plan to examine the potential of maize and other crops as replacements for dry season rice where irrigation water cannot be efficiently and continuously distributed to meet rice crop requirements.

ASIAN CROPPING SYSTEMS NETWORK

The number of cropping systems research sites in the Asian Cropping Systems Network (ACSN) continues to increase. There are 108 operational rice-based cropping systems sites in 10 countries in Asia (Table 3). The sites represent a broad range of climatic zones, soil type, soil texture, and socioeconomic conditions in Asia. China officially joined the Network with two sites: Tung Xi County in Beijing and Sho Xiang County in Zhejiang.

We are happy that two institutes were established in countries collaborating with the ACSN. In the Philippines, the government created a Soil Resource and Farming Systems Institute at the University of the Philippines at Los Baños and the Agriculture Research Office (ARO) in the Ministry of Agriculture. The main thrust of ARO is to conduct farming systems research in 12 regions of the Philippines using ACSN methodology. In Thailand, the Government reorganized the Department of Agriculture and a Farming Systems Institute was created. The senior scientists in the Thai institute and ARO are ACSN collaborators.

We expanded collaborative research in 1982. We are monitor-

Table 3. Cropping systems research sites in collaborating countries in Asia, 1982.

Country	Sites (no.)	Rainfed wetland (no.)	Partially irrigated (no.)	Irrigated (no.)	Rainfed dryland (no.)	Deep water (no.)
Philippines	23	15	1	6	14	—
Bangladesh	25	14	2	10	—	2
Indonesia	21	6	—	—	16	1
Burma	7	2	4	2	—	—
Nepal	6	5	2	1	—	—
Sri Lanka	7	3	1	1	—	—
Thailand	7	7	—	1	—	—
Korea	9	—	—	9	—	—
India	1	—	—	—	1	—
China	2	—	—	2	—	—
Total	108	52	10	32	31	3

ing cropping pattern performance and environment in 31 cropping systems research sites. In all cases, promising alternative cropping patterns are biologically and economically better than dominant farmers' cropping patterns. The collaborative research on varietal testing was expanded with 47 trials for crops distributed before rice and 152 after rice.

Because more intensive cropping will result in rapid loss of soil fertility and reduced productivity, ACSN scientists agreed to collaborate on long-term cropping pattern and fertilizer studies. Korea, Nepal, Indonesia, Burma, China, and IRRI are conducting the studies in wetland irrigated rice; Indonesia and IRRI, in dryland rice; and Bangladesh, Burma, Indonesia and IRRI, in rainfed wetland.

Another collaborative research project is on farm implements for intensive cropping. The objective is to evaluate the rolling injection planter in establishing upland crops grown after rice with zero and optimum tillage. Indonesia, Pakistan, Thailand, Bangladesh, Korea, Nepal, Sri Lanka, and Burma received planters for evaluation.

Rice - wheat cropping patterns are very common in subtropical Asia. The International Maize and Wheat Improvement Center (CIMMYT) and IRRI decided to offer their joint expertise to help national programs increase the productivity of cropping patterns involving rice and wheat either in two-crop or three-crop patterns. The collaborative research will be carried out through the ACSN and will initially focus on identification of better varieties with multiple resistance to pests and diseases.

CIMMYT provided us with 14 promising wheat varieties. Thirty-three trials were distributed to Bangladesh, Nepal, Egypt, China, Korea, Pakistan, Burma, Thailand, Indonesia, Sri Lanka, Bhutan, Philippines, and India.

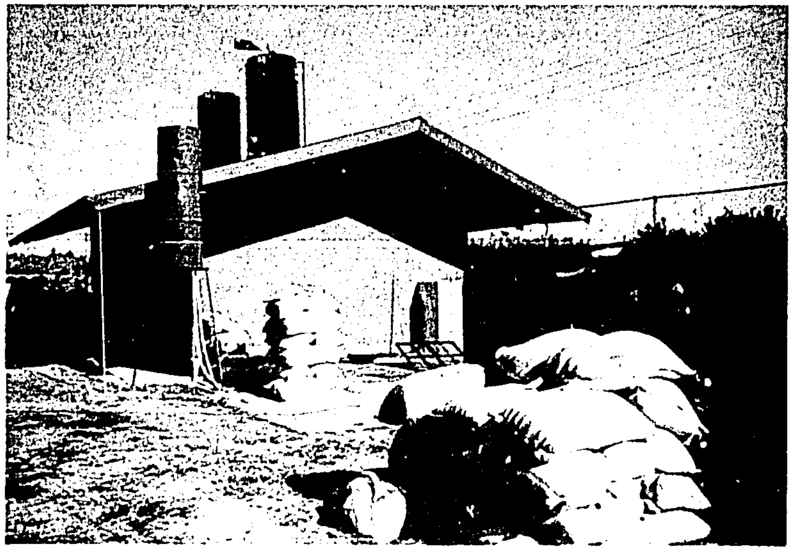
MACHINERY DEVELOPMENT AND TESTING

Our agricultural engineers continue to examine how rice farmers can cut their operating costs. To reduce the postharvest losses resulting from traditional drying methods, we have been testing a new inexpensive system.

Because we know that significant yield increases can be achieved by placing fertilizer at depths of 5 to 15 cm in wet paddies, the development of fertilizer placement machines remains a priority.

To alleviate labor shortages at harvest time, we have been collaborating with the Chinese Academy of Agricultural Mechanization Sciences (CAAMS) in developing and testing of mechanical reapers suitable for use on medium-sized rice farms.

Yong Woon Jeon, postdoctoral fellow from Seoul National University, and Leonie S. Halos, IRRI research assistant, check the rice in one of the vertical trays of the warehouse type grain dryer. The energy-saving facility is designed to dry 3-6 t of rice daily.



1. The warehouse grain dryer with two vortex wind machines burns rice hulls, sawdust, and coconut husks and shells for the heat source.

Warehouse grain dryer

We have been testing a warehouse-type dryer that uses rice hulls or any agricultural waste material as the heat source (Fig. 1).

The rice hull furnace will also heat water. The center tube-type furnace was fabricated from oil drums, but the bricks in the structure made of rice hulls and soil will improve dryer efficiency.

Two unique wind machines on the roof of the dryer create air movement without an external power source. As the wind strikes the vanes of the towers, internal vortexes of air are formed. The resulting low pressure area creates upward air movement.

The rice for drying is placed in vertical trays in the structure. We continue to look at ways to reduce the cost of construction by using indigenous materials and to reduce the labor required to load and unload rice. The design of the warehouse dryer is applicable for village or cooperative level operation.

Fertilizer applicators for deep placement

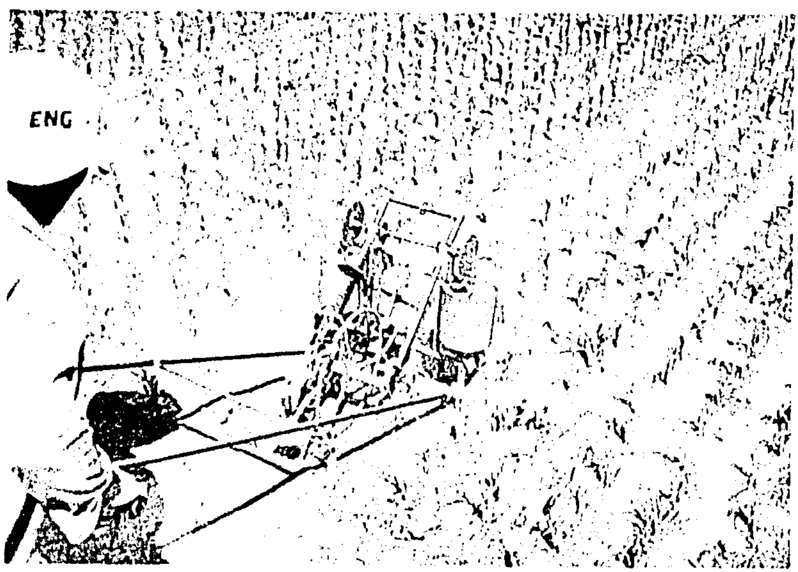
Because gravity drop-type mechanisms are not satisfactory for deep fertilizer placement in wet paddies, we began exploring new force-feed concepts such as the rolling presswheel (Fig. 2) and granule shooting.

We improved both our two-row spring auger applicator for prilled urea by making it a vertical auger (Fig. 3) and our transplanter-mounted liquid fertilizer applicator by mounting it on a four-row transplanter to enable operators to walk between the nonfertilized rows.

We studied experimental manual and power driven deep placement applicators developed in the People's Republic of

2. With the rolling presswheel applicator, fertilizer is dropped on top of the wheel, conveyed into the ground by the wheel, and scraped off and deposited at the bottom of the furrow.

China and at IRRI, and came up with a set of farmer acceptance criteria. For example, essential features of manually operated applicators include continuous operation, adequate sealing of ground placement openings, a pulling or pushing force of 7 to 10 kg, smooth unidirectional movement during operation, and a work life of 4 to 6 seasons. We will focus our development efforts toward meeting such critical specifications to achieve better market acceptability.



3. This vertical auger fertilizer applicator is placing prilled urea 5 cm below the soil surface.

4. This cup-type metering mechanism can handle supergranule urea (above), prilled, and forestry-grade fertilizers.

In an attempt to develop a machine which can deep place more than one kind of granular fertilizer, we designed a cup-type fertilizer metering mechanism (Fig. 4).

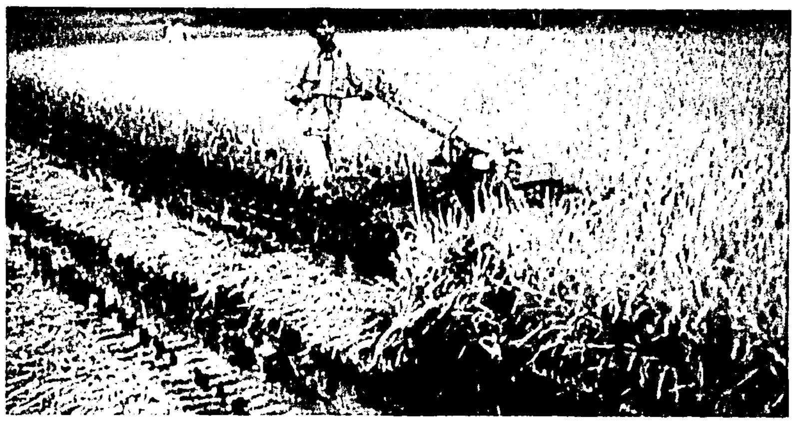
CAAMS-IRRI ·.aper

In 1982, prototype reaper units developed in collaboration with CAAMS were sent to the Philippines, Indonesia, Thailand, Burma, and Pakistan for testing and adaptation to local farming and manufacturing conditions.

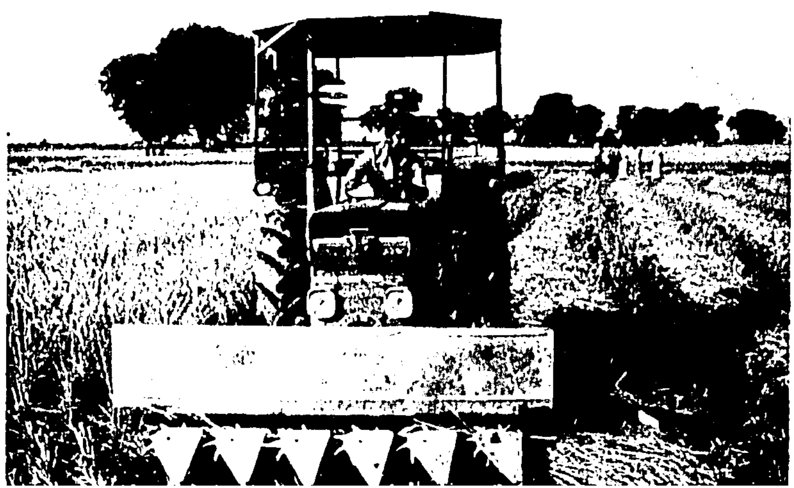
The response to the reaper has been especially strong in the Philippines (Fig. 5) and Pakistan (Fig. 6). Tests are also under way in Burma, Indonesia, and Thailand to determine local adaptability.

Rolling injecti n planter

We modified and t:sted the rolling injection planter developed by the International Institute of Tropical Agriculture for no-till planting of dryland crops. Although the planter was developed for planting with trash on the surface, we found it worked well on prepared seedbeds.



5. In the Philippines, the 1.0 m-reaper is appropriate because it is suitable for small ricefields and adaptable to the commonly used two-wheel tractor.



6. In Pakistan, the reaper swath was increased to 2.2 m because the ricefields are large and four-wheel tractors are the only appropriate power units.

TRAINING AT IRRI

IRRI continued to offer resident training and educational programs to assist research and extension organizations, primarily in developing countries, to strengthen their capabilities in rice and rice-based cropping systems research methodology.

The programs include postdoctoral research fellowships, MS and Ph D degree programs, special nondegree research programs, and formal training courses.

In 1982, 247 fellows and scholars participated in research-oriented training programs (Table 1). These included 40 postdoctoral fellows, 43 Ph D and 108 MS degree candidates, and 56 nondegree scholars. During the year, 16 postdoctoral fellows, 12 Ph D, 22 MS, and 36 nondegree scholars completed their training. Most of them obtained their degrees from the University of the Philippines at Los Baños but three fellows got their Ph D

Participants in IRRI training programs conduct field trials besides attending lectures. Here INSFFER trainees lay out a fertilizer experiment.

Distribution of IRRI research fellows and scholars by country and by training programs, 1982.[a]

Country	Research-oriented				Formal training courses								Special courses[b]	Total
	Postdoctoral fellows	Ph D	MS	N.D.	GEU	INSFFER	RPTP	CSTP	IPM	IWMT	AEC	Ag Econ		
Philippines	4	4	10	2	3	3	3	5	7	5	11	3	—	60
Bangladesh	3	5	24	4	2	1	2	7	3	3	2	—	—	56
China	2	—	15	11	11	6	—	—	—	—	2	—	—	47
Sri Lanka	1	1	13	3	4	—	6	6	3	3	1	2	1	44
India	12	3	1	5	5	1	8	—	4	2	2	—	—	43
Thailand	2	4	6	—	3	2	—	8	7	2	4	1	3	42
Indonesia	—	1	6	—	3	2	4	4	5	4	4	2	2	37
Burma	—	—	7	6	4	4	—	3	—	2	—	1	—	27
Vietnam	1	1	—	10	2	2	—	2	6	1	—	—	—	25
Pakistan	1	4	8	—	1	1	—	—	—	—	—	1	—	16
Korea	4	5	1	3	—	—	—	1	—	—	1	—	—	15
Malaysia	—	—	—	—	1	2	—	1	4	1	—	1	—	10
Japan	4	1	1	3	—	—	—	—	—	—	—	—	—	9
Nepal	—	1	8	—	—	—	—	—	—	—	—	—	—	9
West Germany	2	4	—	1	—	—	—	—	—	—	—	—	—	7
USA	1	1	2	1	—	—	—	—	—	—	—	—	—	5
Egypt	—	—	—	1	2	—	—	—	—	—	1	—	—	4
England	1	—	—	2	—	—	—	—	—	—	—	—	—	3
Netherlands	—	2	1	—	—	—	—	—	—	—	—	—	—	3
Cameroon	—	—	—	—	1	—	—	1	—	—	—	—	—	2
Ecuador	—	—	1	—	—	—	—	—	—	—	1	—	—	2
Senegal	—	—	1	1	—	—	—	—	—	—	—	—	—	2
Taiwan	—	—	1	1	—	—	—	—	—	—	—	—	—	2
Brazil	—	—	—	—	1	—	—	—	—	—	—	—	—	1
Belgium	—	1	—	—	—	—	—	—	—	—	—	—	—	1
Canada	—	1	—	—	—	—	—	—	—	—	—	—	—	1
Colombia	—	1	—	—	—	—	—	—	—	—	—	—	—	1
Cuba	—	—	—	1	—	—	—	—	—	—	—	—	—	1
Ghana	—	—	1	—	—	—	—	—	—	—	—	—	—	1
France	1	—	—	—	—	—	—	—	—	—	—	—	—	1
Italy	1	—	—	—	—	—	—	—	—	—	—	—	—	1
Morocco	—	—	—	1	—	—	—	—	—	—	—	—	—	1
Nigeria	—	1	—	—	—	—	—	—	—	—	—	—	—	1
Panama	—	1	—	—	—	—	—	—	—	—	—	—	—	1
Peru	—	1	—	—	—	—	—	—	—	—	—	—	—	1
Upper Volta	—	—	—	—	1	—	—	—	—	—	—	—	—	1
Venezuela	—	—	1	—	—	—	—	—	—	—	—	—	—	1
Total	40	43	108	56	44	24	23	38	39	23	29	11	6	484

[a]N.D. = nondegree, GEU = Genetic Evaluation and Utilization, INSFFER = International Network on Soil Fertility and Fertilizer Evaluation for Rice, RPTP = Rice Production Training Program, CSTP = Cropping Systems Training Program, IPM = Integrated Pest Management, IWMT = Irrigation Water Management Training, AEC = Agricultural Engineering Course. [b]Two trainees in Farm Management (5-22 July 1982) and 4 trainees in Entomology Cropping Systems Training course (6 Dec 1982-3 Jan 1983).

degrees from universities abroad — one each from Cornell University, University of Missouri, and Seoul National University.

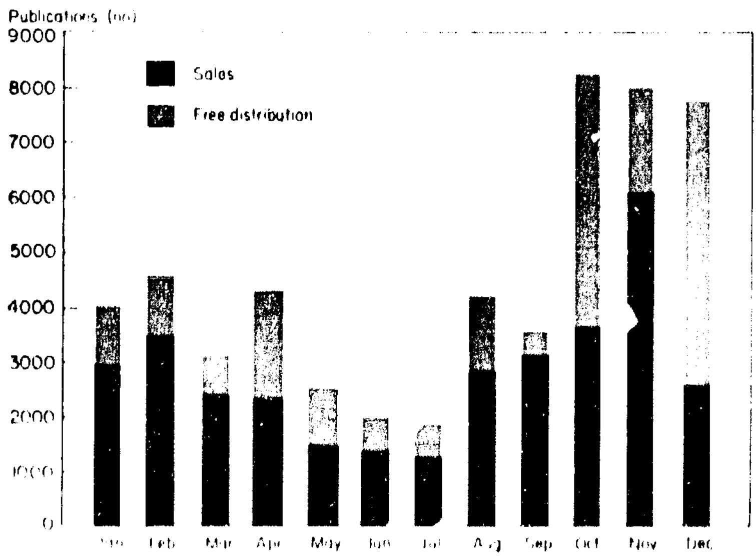
A total of 231 scholars participated in eight regular formal training courses (Table 1). The course on Agricultural Economics Research Methodology was offered for the first time. In addition, there were six participants of special courses offered during the year — two in farm management and four in cropping systems entomology.

The 2-week rice production course was offered six times during 1982. It is an introductory course on various aspects of rice production. It is also open to expatriate scientists who wish to update their knowledge of recent rice production technology. In addition to the participants of the regular training courses, there were 77 participants in the 2-week courses.

INFORMATION SERVICES AND LIBRARY

The Information Services Department (ISD) released 15 major publications during 1982. Distribution of IRRI books in 1982 totaled about 54,000 copies. About 25% were given free (mostly to key Third World libraries) and the remainder were sold.

IRRI and the China National Publications Import and Export Corporation cosponsored the first Internatinoal Agricultural Research Center (IARC) Book Exhibition in China in May 1982. About 300 books, periodicals, slide sets, and films published by



1. Information Services Department publication distribution, 1982.

the IARCs were displayed at 10-day exhibitions in Beijing, Ch'angsha, and Sian. After the Exhibition, the educational materials were rotated in New Book Show Rooms across China.

IRRI exhibited 220 major books, audiotutorial modules, and periodicals at the 1982 Frankfurt Book Fair.

A Farmer's Primer on Growing Rice is being copublished in 24 languages. The revision of *Field Problems of Tropical Rice* is being translated, in advance of release of the English edition, into 10 languages (the original *Field Problems* was copublished in 12 languages).

The 61-module audiotutorial series (sets of color slides, cassette tapes, booklets on rice training and research) was completed in 1982, and work was initiated on a 36-module series on rice-based cropping systems.

The library added 7,060 monographs to its collection bringing the overall monographic collection to 62,422, and now receives 2,625 journal titles.

In 1982, in cooperation with Department of Statistics, the library published the first two computerized supplements to the International Bibliography of Rice Research — the 1980 supplement with 4,714 titles and 1981 supplement with 6,750 titles. The computerized system has speeded up the publication of the supplements as well as provided the information required for the computerized literature search system being developed.

INTERNATIONAL ACTIVITIES

The increasing number of well-trained scientists in national programs and the corresponding improved research capabilities of the national programs permitted us to continue emphasis on:

- international networks and
- collaborative research

IRRI scientists coordinated these rice research networks:

- International Rice Testing Program,
- Asian Cropping Systems Network,
- Agricultural Machinery Network, and
- International Network on Soil Fertility and Fertilizer Evaluation for Rice

In 1982, we had cooperative country projects in Bangladesh, Burma, Egypt, India, Indonesia, Pakistan, Philippines, Sri Lanka, and Thailand.

We had formal meetings/discussions concerning research and training collaboration with scientists/administrators of the following national programs: Bangladesh, China, Cuba, India, Indonesia, Japan, Korea, Thailand, and Vietnam.

Research on yield constraints in farmers' fields was done in response to country requests.

IRRI had liaison scientists posted to Indonesia and Malaysia, Africa, Latin America, and Thailand in 1982.

FINANCES

The Institute received $21,977,201.86 during 1982.

The United States Agency for International Development (USAID) gave $7,775,671.77 — $5,900,000 for core operations; $36,000 to assist in the implementation of the Philippine national and regional applied research and extension programs in rice-based cropping systems; $621,495.53 for industrial extension of small-scale agricultural equipment developed at IRRI; and $6,391.41 for training costs of Razia Soltana and Metengue Diack.

USAID also released $1,211,784.83 for continuing contracts:

- $112,749.98 for a contract between IRRI and the Government of Sri Lanka for assistance in implementing rice and cropping systems research projects with funds provided by USAID loan
- $157,203.07 for a contract between the Arab Republic of Egypt and the Regents of the University of California and IRRI for a technical assistance relationship for increased production and improved quality of rice in Egypt through the development and adoption of improved agricultural practices and varieties of rice
- $22,516.82 for the services of an industrial engineer for the small scale agricultural equipment extension project of the Government of Indonesia
- $52,056.08 for technical services and equipment to conduct a demonstration program in Luwu, Indonesia project area, of the IRRI designed and Indonesian manufactured hand tractor and accessories
- $419,205.91 for supporting a 3-5 year project for accelerated development and use of improved rice technology in Indonesia

- $183,132.93 for collaborative rice research in Pakistan.
- $111,770.01 for a project on consequences of mechanization on small farms.
- $70,000 for the water management applied research and training in connection with the memorandum of agreement between the Bicol River Basin Development Program, IRRI; the National Irrigation Administration and the Joint Project Implementation Letter No. 15 of January 26, 1981.
- $5[illegible]50 to support setting up of a Nutritional Evaluation Laboratory as a regional center for research on the nutritional value of high-protein cereals and legumes and weaning foods of children.

The Japanese Government gave $3,400,000 for partial support of the GEU program including expenses of germplasm collection and maintenance; for partial support of Soil and Crop Management Program; and for partial support of Control and Management of Rice Pests.

The Ministry of Overseas Development, United Kingdom, gave $1,102,320 for the core program.

The Canadian International Development Agency gave $1,208,250 for core operations; $527,464.86 for cooperation between the Bangladesh Rice Research Institute and IRRI; and $406,255.81 for cooperative research on rice, rice-based cropping systems, and development of machines for small-scale farming between the Government of Burma and IRRI.

The International Development Research Center (IDRC), Canada, gave $297,039.48. Of that $112,438.26 was part of a 3-year grant for cropping systems outreach in South and Southeast Asia; $156,023 for the IRRI/UPLB cooperative research project on varietal improvement of dryland legume crops for rice-based cropping systems; $8,135 as part of a 4-year grant to support a multiple cropping research project at the Bangladesh Rice Research Institute; $20,000 to enable Dr. M. Sahidul Hoque to undertake postdoctoral studies at IRRI; and $143.22 towards the training cost of Mr. Amadou Makhtar Diop.

The European Economic Community gave $2,010,311.51 for water management, scholarships for candidates from developing countries, and partial support of the GEU program.

The Australian Government gave $1,107,229.56 of which $655,140 was for core operations, including travel of Australian scientists; $406,713.46 for expansion of technical assistance and collaborative relationships with the Bangladesh Rice Research Institute; and $45,376.10 in support of the consultancy study concerning the International Board for Soil Resources Management.

The Federal Republic of Germany gave $530,660 for core operations; $207,650 towards the project on the effects of organic matter on paddy soils; $5,795.99 for support of a visiting scientist in soil microbiology; and $20,730 to support the International Board for Soils Resources Management.

The International Development Association gave $1,230,000 for core operations and capital expenditures.

The United Nations Development Programme released $1,637,200 of which $1,540,200 was for the International Rice Testing and Improvement Program; $12,000 toward annual meetings of the Rice Testing Program and Biological Nitrogen Fixation components of the project; and $85,000 to undertake expanded research on rice/weather relationship.

The International Fund for Agricultural Development gave $1,600,000 for research on rice-based cropping systems.

The Government of India gave $115,445 for the core program.

The Government of Denmark gave $126,063.66 for the core program.

The Government of the Philippines gave $250,000 for the core program.

The Government of Sweden gave $256,572.53 for the core program.

The Government of New Zealand gave $18,477.50 for the core program.

The Government of Spain gave $25,000 for the core program.

The Government of Belgium gave $136,454.29 for the core program and $20,992.97 for the collaborative research with FLKU (Fakulteit der Landhovwwetenschappen Katholieke Universiteit Leuven).

The Swiss Federal Council, represented by the Swiss Development Corporation, gave $136,800 to support the studies of nitrogen fertilizers used for rice.

Since February 1978, a contract between IRRI and the International Fertilizer Development Center has supported a joint project on the fate and efficiency of nitrogen fertilizers in lowland rice. IFDC reimbursed IRRI $33,481.53.

Since 1980, a contract between IRRI and the International Food Policy Research Institute (IFPRI) has supported a major collaborative research on rice policy in Southeast Asia. IFPRI reimbursed IRRI $51,931.58.

The Ford Foundation gave $263,300 — $150,000 for core operations and capital expenditures; $100,000 in support of rice research and development in Bangladesh; $12,000 for fellowships of Asian students; and $1,300 for a workshop in socioeconomic constraints.

The Rockefeller Foundation gave $154,177.35 — $150,000 for core operations and capital needs; $2,177.35 toward expenses of a postdoctoral appointee; and $2,000 as an outright and unrestricted contribution for the cordial reception accorded to RF fellows.

Other donors were:

- Office of Rural Development, Korea, seed multiplication program and cooperative research program $70,000.00
- Philippine Council for Agriculture and Resources Research, cooperative applied research on rainfed rice $42,994.29
- National Food and Agriculture Council, strengthening the settlement program to carry out agrarian reform policies and programs $15,374.08
- Ministry of Agriculture, implementation of the Philippine national and regional applied research and extension program in rice and rice-based cropping systems $40,698.80
- International Board for Plant Genetic Resources, field collection of indigenous rice germplasm in South and Southeast Asia $11,000.00
- Imperial Chemical Industries, research grant $5,000.00
- Stauffer Chemical Company, weed control $3,000.00
- Ciba-Geigy, agrochemical research $3,000.00
- Monsanto, herbicide research $3,020.12
- American Cyanamid Overseas Corporation, weed control and insect control $2,000.00
- Hoechst, AG, research work at IRRI $4,545.45
- American Chemical Society, International Conference on Chemistry and World Food Supplies (Chemrawn II) $65,910.00
- SKW Trostberg Aktiengesellfschaft, soil fertility research $6,000.00
- Montedison, herbicide and pesticide research $6,000.00

- KenoGard, entomology research $1,000.00
- FMC International, entomological research $3,000.00
- International Potash Institute and Potash and Phosphate Institute, soil fertility research $14,383.73
- UNESCO
  - Travel grant to enable Dr. Clodualdo Maningat to carry out a cooperative research program on grain science at Kansas State University $2,500.00
  - Travel grant to enable Ms. Rhodora Romero to work in the laboratory of the Centre National de Recherche Scientifique (CNRS) in Gif-Sur-Yvette on "Rice Microspore Culture" $2,700.00
- Food and Agriculture Organization of the United Nations:
  - Support of the 2d Integrated Pest Management Course from September 6 to December 12, 1982 .... $16,300.00
  - Assist in conducting a rice monitoring program $2,500.00
  - To cover expenses for analyzing data on crop losses due to seeds $1,000.00

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*Left during the year

**On study leave

***Joined and left during the year

****Joined during the year

†Part time

††Acting until April 1982

†††Died during the year

+Outreach