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RESEARCH HIGHLIGHTS FOR 1980

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1981
INTERNATIONAL RICE RESEARCH INSTITUTE
LOS BANOS, LAGUNA, PHILIPPINES • P.O. BOX 933, MANILA, PHILIPPINES

The International Rice Research Institute (IRRI) receives support from a number of donors, including the Asian Development Bank, the European Economic Community, the Ford Foundation, the International Fund for Agricultural Development, the OPEC Special Fund, the Rockefeller Foundation, the United Nations Development Programme, and the international aid agencies of the following governments: Australia, Belgium, Canada, Denmark, Federal Republic of Germany, Japan, Mexico, Netherlands, New Zealand, Philippines, Spain, Sweden, Switzerland, United Kingdom, United States.

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

Our cover:
A checkerboard pattern is created in IRRI's continuous cropping trials by rices that mature in less than 100 days. The plot at center front has IR9752-71-3-2, which matures more than 30 days earlier than IR8 and 10 days earlier than IR36. IR9752-71-3-2 is from a 1975 wet-season cross of IR28 and Kwang Chang Ai, one of the offspring of which was topcrossed with IR36 in the 1976 dry season (IR9752). Seeds of the early-maturing Kwang Chang Ai were given to IRRI Director General N. C. Brady during his first visit to China in 1974.

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Rice varieties for wider use

"What about the other three?"
That was the question in our *Research Highlights for 1975*. We asked the question because a look at the 10 years of intensive rice research that had followed the release of IR8 pointed to those with irrigation —only one in four rice farmers — as the main beneficiaries of the new rice technology.

Even though the "other three" with no irrigation had not been completely shut out (the fact is they benefited from a spillover of technology that was workable in rainfed fields), IRRI started to focus its research in 1975 more on problems of the rainfed rice farmer: his rain-dependent less-certain water supply, and poorer soils. Because the risk of crop failure is higher for the rainfed farmer, he has less easy access to credit and the inputs needed to increase rice production.

What have we achieved for him in the last 5 years?

It is clear, most of all to the scientist, that there can be no yearly "breakthroughs" in rice research. There have been and there will continue to be, however, outstanding new rices released to farmers, some of which allow the disadvantaged rainfed farmer to double, even triple, his rice production per hectare.

Among the varieties developed since 1975, which help the rainfed farmer to cope better with his adverse environment, we can point to:

- IR36, the rice now most widely grown by the Philippine rice farmers, most of whom do not enjoy assured irrigation. IR36 (IR2071-625-1) was named and released by the Philippine Seed Board in 1976. Its early maturity and multiple pest resistance made it an easy favorite of farmers in both irrigated and rainfed areas. To the rainfed farmers IR36 brought the chance to grow a crop in the short period when good rains were certain. If the rains failed for short periods, IR36 could stand moisture stress and then bounce back when rains returned. IR36 — with its good harvests from both irrigated and rainfed fields — was a mainstay in putting Philippine rice production at the point of exportable surplus in 1979, and enabling it to continue exporting subsequently.

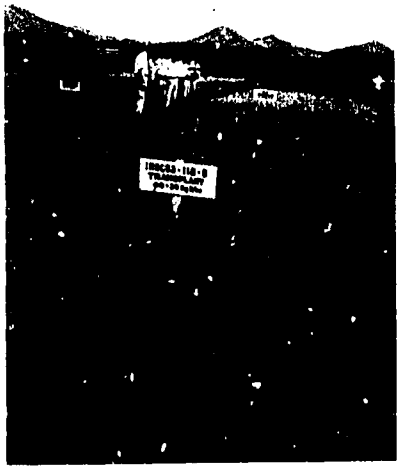
In this rainfed rice area 95% of Filipino farmers planted modern varieties — mostly IR36 — in 1980.

- IR42, named in the Philippines in 1977, has been outstanding on farms with adverse soils. IR42 (IR2071-586-5-6-3) gives high yields in fields with low nitrogen fertility, has moderate tolerance for zinc and phosphorus deficiencies, and resists most of the major rice pests (Table 1). Many farmers among "the other three" of 1975 got in IR42 a rice that could double their yields. One IRRI soil scientist called IR42 "the answer to the poor rice farmer's prayers."
- IR52, named in 1980 in the Philippines, has good drought resistance and all the other desirable characteristics of the

Table 1. The resistance of IR42 to pests and other adverse conditions contrasts markedly with that of IR8, released 11 years earlier.[a]

Adverse factor	IR8	IR42
Diseases		
Blast	MR	R
Bacterial blight	S	MR
Grassy stunt	S	R
Tungro	S	R
Ragged stunt	S	R
Insects		
Green leafhopper	R	MR
Brown planthopper	S	R
Stem borer	MS	MR
Nutrient deficiencies		
Nitrogen	MS	R
Phosphorus	MR	MR
Zinc	S	MR
Iron	S	MR
Soil toxicities		
Salinity	MR	MR
Alkalinity	S	MR
Iron toxicity	S	MR
Boron toxicity	MR	MR
Peat soil problems	MS	MR
Drought	S	MR
Submergence	S	MR

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

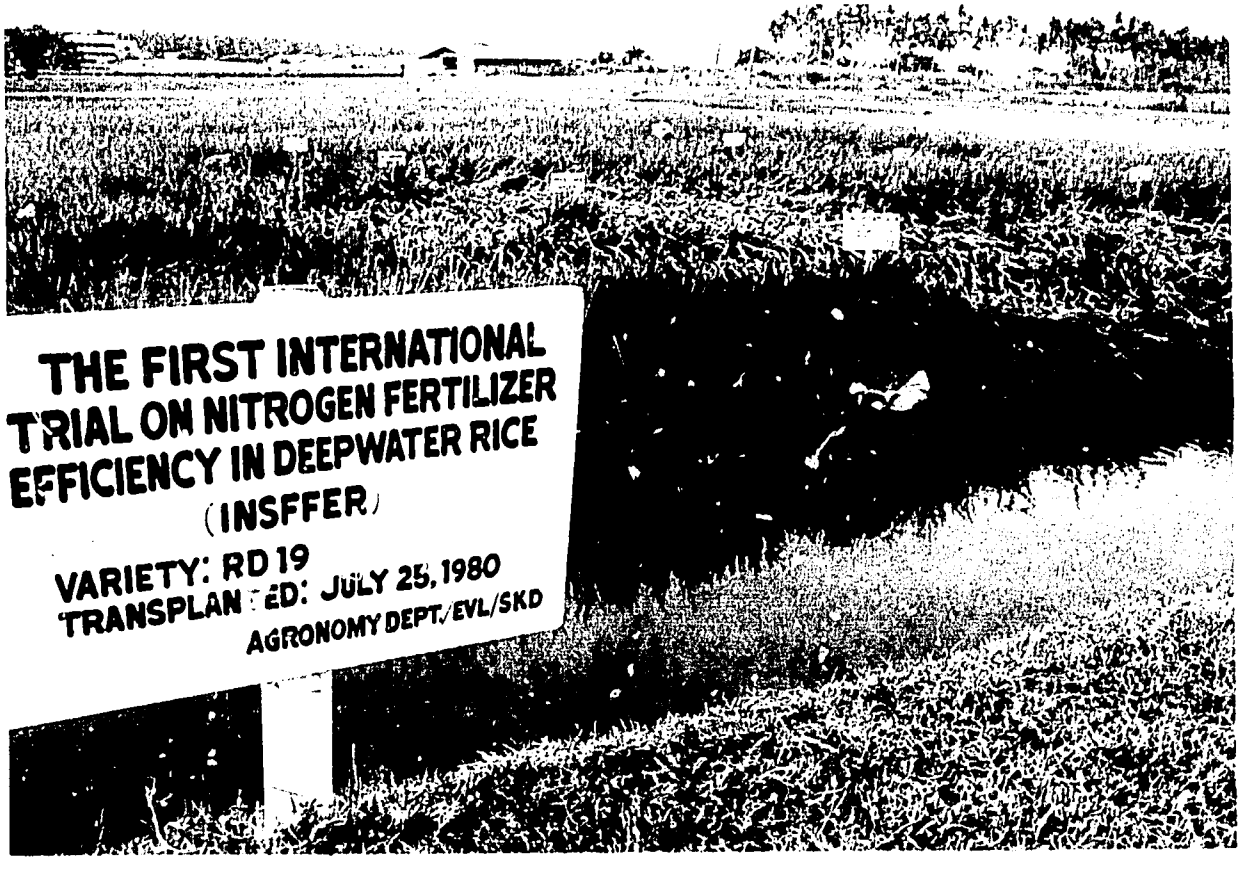


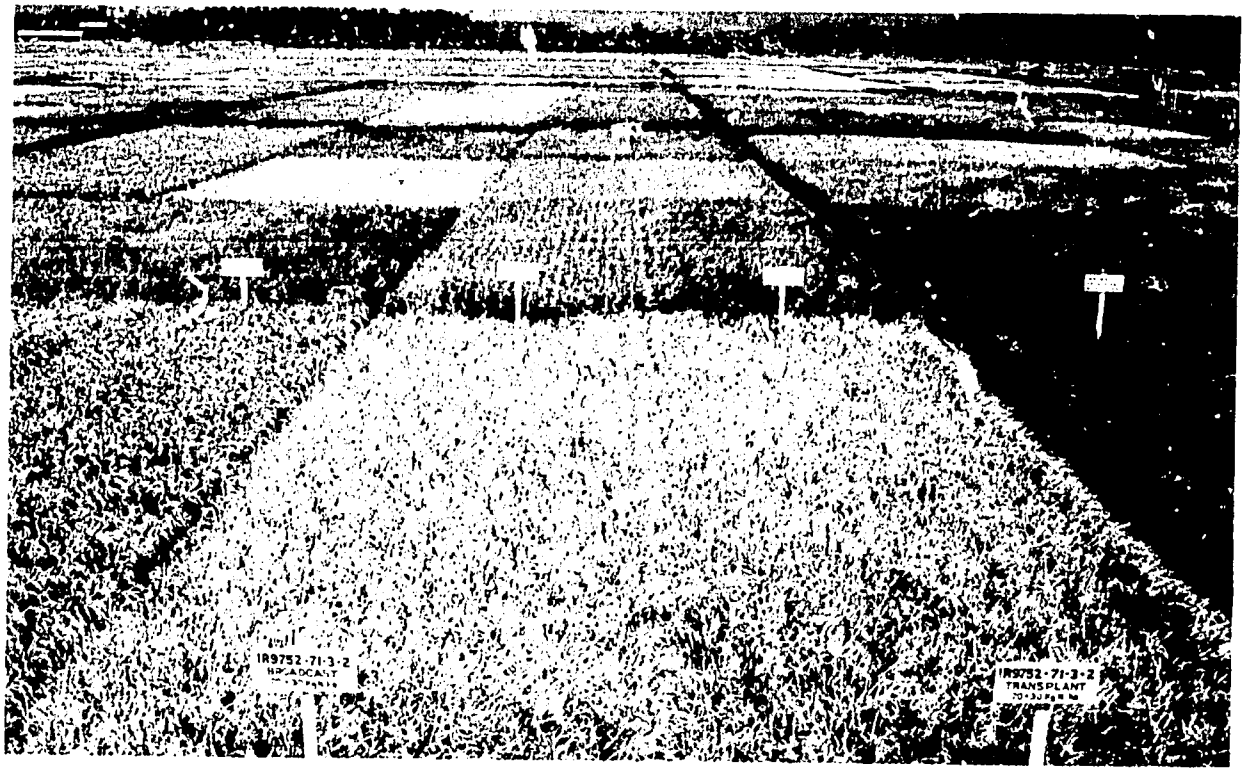
Members of the Genetic Evaluation and Utilization team check IR52 as a line in 1980 long-term trials.

modern IR varieties. IR52 (IR5853-118-5) was first reported in *Research Highlights for 1976* for its "excellent vegetative vigor"; later (in 1977) as "drought resistant with potential for rainfed and irrigated" areas, and (in 1979) for "consistently high resistance to drought" over 3 years of tests.

- RD17 and RD19, released in 1979 by Thailand's Department of Agriculture for farmers in areas with medium-deep water (0.5-1 m depth). These first high yielding modern varieties developed specially for flood-prone areas were the product of a Thailand-IRRI Collaborative Deepwater Rice Project. Their full impact is yet to be felt, but there are indications elsewhere in this report of their potential — they were the only rices to survive in a Philippine area subjected to deep flooding in 1980 and yields of RD19 were exceptionally high in deepwater fertilizer trials at IRRI.
- Varieties and lines with drought resistance and good yield in dryland fields. IR43 yielded 4.6 t/ha in a Filipino dryland farmer's field during the 1980 wet season; IR5931-110-1 had yields of 3.9 t/ha in the same field. Both rices held high ratings in 10 trials in 5 countries for the 1980 International

RD19 yields ran higher than 5 t/ha in these 1-m deep plots at IRRI in 1980.





Rices that mature in less than 100 days will make crop intensification easier. This plot of IR9752-71-3-2 is a good example of earliness. It matures in 99 days with dry season yields in the 5.5-6.0 t/ha range.

Upland Rice Yield Nursery of the International Rice Testing Program. A sister line to IR43 was released as IR1529 in several African and Latin American countries.

- IR cold-tolerant lines with yields higher than 6 t/ha. IR15889-32-1 yielded 7.9 t/ha in Korean cold tolerance tests. Several IR9202 lines had yields in the 5-7 t/ha range in cold areas of Korea and the Philippines.
- Several with tolerance for adverse soil conditions — salinity, alkalinity, iron toxicity, and boron, phosphorus, and zinc deficiency. A growing list of IR varieties and lines (see Table 7, page 27) shows these tolerances.

We do not cite the rices we note here as ones that will always give spectacular yields in fields with adverse conditions. Farmers who plant these rices, however, have an assurance of some yield in bad years and of high yield in good years. Contrast that with their previous expectation of crop failure in bad years and only low yields in their better years.

With the development of the new varieties, there has also been substantial progress in developing new cropping practices, and farmers in some rainfed areas now grow two rice crops where before they grew only one. Such farmers are found in areas of the Philippines, Sri Lanka, India, and Indonesia. A dry-seeded first crop gets off to a rapid start with the early rains. Using an early-maturing rice like IR36, a crop is ready for harvest within 4

These rice fields in South Cotabato, Philippines, are in an area where the traditional pattern of one rainfed rice crop per year is changing to use of a short duration variety direct-seeded as the first crop followed by a transplanted second crop. The first crop in the foreground was direct seeded at the onset of the rainy season and was heading while the single crop (background) was being transplanted. New short-duration varieties such as IR36 have led to substantial increase in cropping intensities and in many rainfed areas also had an important impact on the lives of many among "the other three."

months and a second crop can be transplanted while there is still plenty of water to complete its growth. Use of new drought-resistant varieties helps reduce risks in areas where rainfall is uncertain. In many areas farmers are getting their second rice crop off the fields in time to grow mungbean or another dryland crop on the residual moisture — three crops a year in a rainfed field!

Progress beyond varieties

We believe that it may well be time to start talking about the potential to hit "two out of three" rather than the "three out of four" that are missed by the new rice technology. Table 2 supports that belief.

Better life for more farmers

The technology that allows farmers to produce two or three crops where one was grown before — and do it without irrigation — has had dramatic effects on the incomes of many Asian

Table 2. Human support capacity of rice area in South and Southeast Asia, by character of cultivation in 1980.[a] Rices such as IR36, IR42, IR43, IR50, IR52, and RD17 and RD19 provide higher and more stable yield for farmers in the rainfed and dryland areas.

Rice land type	Area (000 ha)	Mean yield (t/ha)	Support capacity (no. of persons)
Deepwater (>1 m)	5,308	1.0	24,150,000
Irrigated	28,984	3.8	497,720,000
Shallow rainfed (0-30 cm)	30,248	1.8	247,930,000
Intermediate rainfed (30 cm-1 m)	11,547	1.2	63,100,000
Dryland	11,558	0.9	46,230,000
Total	87,645		879,130,000

[a]Adapted from a table prepared by Dr. R. E. Huke, IRRI visiting scientist, 1980.

farmers. In collaboration with national scientists, such intensification of rice cropping is being widely studied throughout Asia through the Asian Cropping Systems Network.

These developments of improved varieties for nonirrigated farms and of methods to intensify crop production in rainfed areas represent real achievements — ones that have already contributed significantly to a better life for many farmers among "the other three."

There has also been progress in other research areas that will make an impact on the lives of the less as well as the more advantaged farmers:

- Tissue and cell culture techniques were greatly improved in our laboratories in 1980. These techniques afford the possibility for further rapid advances in the development of varieties with salinity tolerance, disease and insect resistance, and other desirable characteristics. Through embryo culture we can revive irreplaceable stocks that have lost vitality.
- Continued screening of the world germplasm collection has identified new sources of tolerance for drought, flooding, low and high temperatures, and adverse soil conditions. Use of these materials in breeding programs provide hope for better rice worldwide (Table 3).
- More efficient ways of using nitrogen fertilizers have been identified. Work on biological fixation, especially on the association of the water fern Azolla with nitrogen fixing Anabaena, has shown that there is a great potential for increasing rice yields for the small farmer who may not use nitrogen fertilizer, and for saving money for the fertilizer user who buys less to get high yields.

Table 3. These promising improved varieties and lines from the Genetic Evaluation Utilization program were identified as tolerant of different stresses through worldwide testing in the International Rice Testing Program, 1980.

Excess or deficit moisture	
Rainfed dryland	IR43, IR45, IR9669 Sel., IR2061 522 6 9, IR3839 1, IR36
Rainfed wetland	IR46, IR52, IR4819 77 3 2, IR4829-89 2
Medium deepwater[a]	RD17, RD19
Problem soils	
Alkalinity	IR43, IR46, IR2053 436 1 2, IR4227 28 3 2, IR9846 256 3
Salinity	IR42, IR4595 4 1 15, IR2307 247 2 2 3, IR2153 26 3, IR4630 22 3 3 2, IR4563 52 1
Temperature	
Cold	IR8866 30 1 4, IR3941 25 1, IR13045 182 5, IR15924 265 3
Hot	IR2006-P12 12 2 2, IR1561 228 3 3

[a]From the Thailand IRRI Collaborative Deepwater Project.

Major research results

GENETIC EVALUATION AND UTILIZATION

Our Genetic Evaluation and Utilization (GEU) Program provides a multidisciplinary team approach to the improvement of the rice plant. Since the GEU teams were formed in 1974 there has been steady sharing of varietal development activities between IRRI and the national rice improvement programs. In 1980 we continued basic research aimed at supporting national programs worldwide.

- RD19, developed in the Thailand-IRRI Collaborative Deepwater Project and released to farmers in 1979, showed its potential to raise yields in farmers' fields during 1980. It yielded 3.9 t/ha in a Thai farmer's field, which was under 120 cm of water at the peak period. In a trial at IRRI with slow-release sulfur-coated urea RD19 yielded 5.2 t/ha in water 1 m deep.
- Several other deepwater lines with good elongation ability and good plant characteristics were identified in 1980. The importance of nodal roots in the nutrition of deepwater rice was shown.
- The International Rice Testing Program (IRTP) provided about 1,000 nursery sets to 60 countries in the IRTP network. There was solid evidence that IRTP monitoring tours provide an opportunity for discussion and observations by national rice scientists that help speed development of new varieties.
- Several hundred breeding lines with resistance to or tolerance for biological, environmental, and physical production constraints were developed. Ten were formally named as varieties in four countries. We now have advanced breeding lines that mature in less than 100 days — about 8-13 days earlier than IR36 but with similar yields and other desirable traits.
- More than 4,000 crosses were made in 1980, the majority for use by plant breeders in national programs.
- One thousand four hundred and twenty-two F_2 combinations and 109,657 pedigree lines were grown at IRRI. Twelve lines showed outstanding potential for irrigated, and rainfed wetland, and dryland farms. All have moderate to good resistance to a number of rice pests.

Rice breeders from five Asian countries look at hybrid rice production field in China. The breeders were in a joint China IRRI training course on hybrid rice during September October 1980.

• More than 500,000 plants from 287 cross combinations were grown in the rapid generation advance greenhouse at IRRI — double the number handled in 1979 — and again many for collaborators in other countries.

• Active collaboration with China to develop hybrid rices continued. Several restorer lines with multiple disease and insect resistance were identified. IRRI and the Chinese Academy of Agricultural Sciences collaborated on a first hybrid rice research training course offered in Changsha, China.

• In anther culture research, a culture media that increased plant regeneration efficiency from 3-10% to 73% was developed. Work started on development of salinity tolerance in rice through tissue culture techniques.

• New sources of insect resistance were identified. Studies on the extent and nature of moderate resistance of rices to brown planthopper showed tolerance for insect feeding as a component. Moderate resistance was also found compatible with use of biological control agents — predators killed more brown planthoppers on moderately resistant than on susceptible varieties.

• In tests for drought resistance in which 900 breeding lines were screened, the best yields were from three IR lines — from 3.9 to 4.6 t/ha in a farmer's field in Batangas province, Philippines.

• A cooperative nitrogen balance study with preschool children confirmed that brown rice is not superior to milled rice in protein quality.

GERMPLASM CONSERVATION AND DISSEMINATION

High yielding modern rice varieties continue to spread in the rice-growing world. To avoid the loss of gene-rich traditional rice varieties — also called land races — collection and preservation of these materials continued. As a result of selection by farmers and changes in natural genetic makeup, many varieties unique in pest resistance or ecologic tolerance have developed, and it is important to ensure the continued availability of such varieties.

It is impossible to reconstitute their characteristics if they become extinct. The careful categorizing of the attributes of these materials is therefore a major function of IRRI.

Germplasm collections

IRRI staff members continued to join national rice workers in the exploration and collection of land races. Our germplasm bank now holds 53,431 registered accessions of the Asian rices plus 3,288 unregistered samples. African rices, wild species, and genetic testers accounted for 3,900 samples.

Sharing the germplasm

During the year we had 198 requests from rice researchers worldwide; we sent them 4,142 seed samples. Our IRRI researchers used 30,467 samples from the germplasm bank.

Extension workers collect rice samples in farmers' fields on the island of Lombok, Indonesia. In 1980 the scope of collection work was broadened with funds from the International Board for Plant Genetic Resources. We channeled the funds into collection work in remote areas and improved storage in seven national programs.

Long-term seed packing and storage

During 1980 we perfected a system of drying and packing seeds for safe long-term storage in subfreezing conditions (−10° C, 25-35% relative humidity). By drying seeds at a moderate temperature (38° C) while dehumidified chilled air flows into the drying cabinets, seeds quickly reach 6% moisture content with a minimum effect of heating on seed longevity. From the ovens, seeds are cooled and packed in aluminum cans under partial vacuum.

We canned and stored 2,745 accessions (10 cans each) with the system. Our current estimate is that seed will remain viable at least 50 years in the new storage.

AGRONOMIC CHARACTERISTICS OF RICE

A major factor influencing rice farmers of Southeast Asia to grow more crops per year is the availability of short-growth-duration rices. IR36, for example, has allowed four crops a year and yields of more than 30 t/ha per year in continuous cropping systems. Highly popular cropping patterns for rainfed rice farmers have also been built around rices that will mature in 100-110 days. We believe that rices that mature in less than 100 days can be grown by farmers without compromising yield potential. During 1980, we had 368 short-duration lines in yield trials. A total of 97 in the dry season and 78 in the wet season matured in less than 100 days and many had yields as good as those of IR36. Productivity per day was considerably higher than that of IR36 (Table 1).

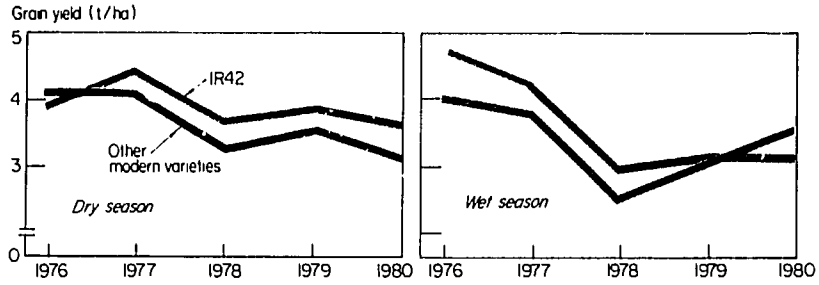
IR42 retains promise

IR42 has gained the confidence of many small farmers because of its ability to grow and produce high yields in a wide range of adverse soil conditions. It continued to look promising without fertilizer nitrogen. We compared IR42 with 4 other IR varieties with 7 years of yield data (Fig. 1). The data support the possibilities for identifying rices that are efficient users of soil nitrogen — a trait important for small farmers in South and Southeast Asia.

Table 1. Seven lines that matured in less than 100 days compared favorably with IR36 in 1980 replicated yield trials at IRRI.

Line	Growth duration (days)	Dry season[a]		Wet season[a]	
		Yield (t/ha)	Yield/field day (kg)	Yield (t/ha)	Yield/field day (kg)
IR9752-71-3-2	99	5.7	75.0	4.3	56.8
IR15429-268-1-2-1	99	5.3	69.1	4.5	59.3
IR19743-25-2-2-3	98	4.7	63.2	4.1	54.4
IR19743-46-2-3	99	5.0	65.4	3.8	50.1
IR19746-28-2-2-3	99	5.1	67.5	3.9	51.8
IR19774-23-2-2-1	95	4.6	63.2	4.2	58.7
IR19819-31-2-3-1	95	4.8	67.2	3.9	54.0
IR36 (as check entry)	108	5.4	63.9	4.0	47.5

[a]Yield rounded to nearest 0.1 t/ha; yield per field day of seedlings 23 days old when transplanted.



1. Yields of IR42 (tested as IR2071-586-5-6-3 before 1977) and other high yielding varieties without fertilizer nitrogen at 4 sites in the Philippines during 1976-80.

INSECT RESISTANCE

Our entomologists continue to search the IRRI germplasm collection for new sources of insect resistance. When rices with resistance are found, plant breeders check them as sources of new genes for resistance. With added genetic sources we can develop multilines as a means of meeting the problem of development of new biotypes among insects.

Identification of resistance sources

Since we began the varietal resistance program at IRRI, thousands of varieties have been screened and hundreds of sources of resistance identified (Table 2).

In 1980 almost 400 new varieties with green leafhopper resistance were identified. The relatively few sources identified for yellow stem borer resistance have only a low level of resistance. We screened more than 200 accessions from the wild rices in the germplasm collection and found several with resistance to the stem borer, biotypes 1, 2, and 3 of the brown planthopper, whitebacked planthopper, and green leafhopper.

Moderate resistance to the brown planthopper

Some varieties with a high level of brown planthopper resistance were grown commercially for only a few years before the evolution of a biotype that could overcome the resistance. In 1979 we

Table 2. More than 200,000 accessions in the IRRI germplasm collection have been screened and selected for resistance through 1980.

Insect	Germplasm bank screening		
	Accessions tested (no.)	Selected as resistant (no.)	For retesting (no.)
Brown planthopper			
Biotype 1	32,298	280	329
2	9,652	200	175
3	9,399	215	117
Whitebacked planthopper	36,833	267	414
Green leafhopper	35,290	1,155	386
Zigzag leafhopper	1,959	401	186
Yellow stem borer	18,000	39	23
Striped stem borer	15,000	21	0
Whorl maggot	40,000	5	0
Leaf folder	2,683	11	21

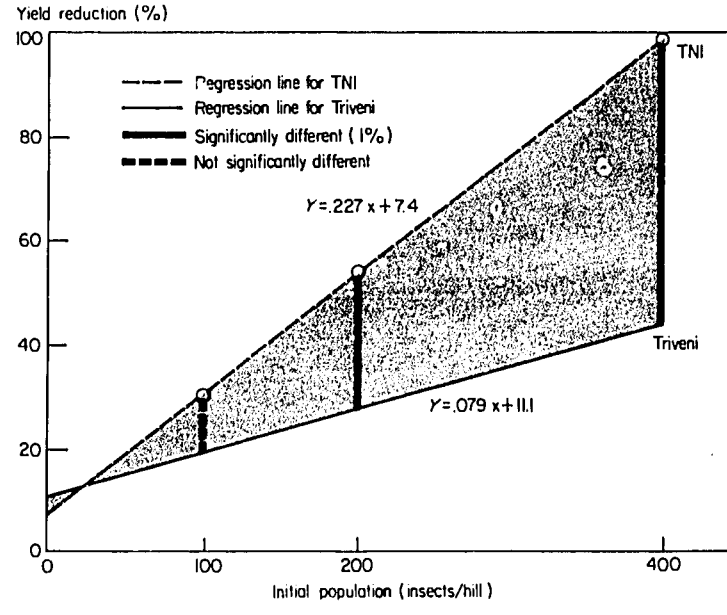
began the search for moderately resistant varieties with minor genes for resistance, which we believe would exert less pressure for biotype selection.

Nature of moderate resistance to the brown planthopper. Extensive 1980 studies on the nature of moderate brown planthopper resistance in Triveni indicated that tolerance is a component. Rate of feeding and population growth were comparatively high on Triveni, but the plants continued to grow and produced a crop. Yield reduction in Triveni was significantly less at initial insect populations of 200 and 400/hill (Fig. 2) than that in the susceptible TN1.

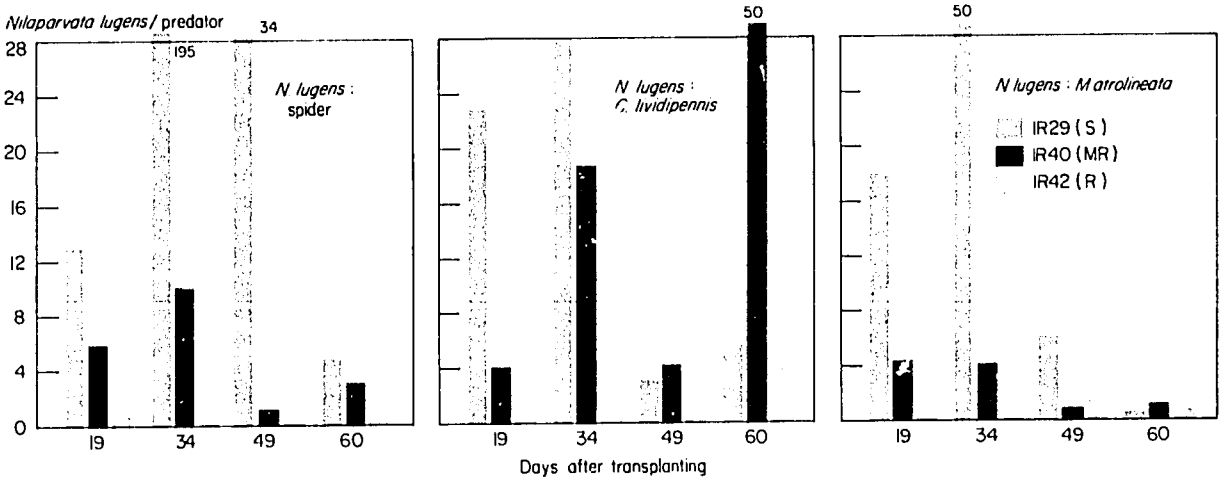
A field study showed that yield reduction in Triveni was generally one-half that in TN1 even at extremely high insect densities. Dry matter, total tiller number, and height at harvest were similar for the two varieties but the percentage of productive tillers was higher in Triveni. Triveni tolerated brown planthopper attack and produced panicles, but TN1 panicle production was severely reduced by the feeding of the brown planthoppers.

Moderate plant resistance and chemical and biological control of insects

Studies in 1980 showed that brown planthoppers and white-backed planthoppers feeding on a moderately resistant rice variety are much easier to kill with insecticides than those feeding on a susceptible variety. Moderate resistance is also compatible with biological control agents. The spider *Lycosa pseudoannulata* ate more brown planthoppers on a moderately resistant than on a susceptible variety.



2. Regression of yield reduction on different levels of brown planthopper infestation on TN1 and Triveni rice varieties. IRRI, 1979 dry season.



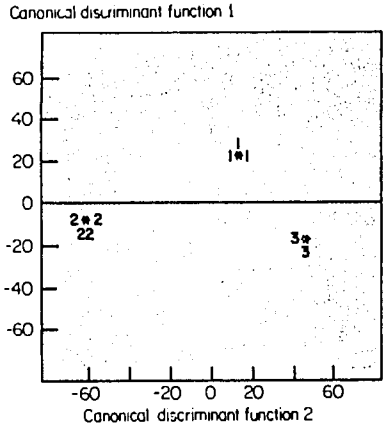
3. The resistance level of rice affected the brown planthopper-predator ratios on varieties in 1980 tests. IR29 is susceptible, IR40 is moderately resistant, and IR42 is resistant.

Field studies in 1980 compared varieties susceptible (IR29), moderately resistant (IR40), and resistant (IR42) to biotype 2 brown planthoppers. The prey-predator ratio was most favorable on moderately resistant and resistant varieties (Fig. 3).

Morphological variations among brown planthopper biotypes

Brown planthopper biotypes occurring within the Philippines and in other Asian countries pose a serious threat to the stability of resistant rice varieties now being cultivated. In 1980, we studied selected morphological characters of biotypes 1, 2, and 3, which have been maintained as stock cultures at IRRI for several years.

Multiple discriminant analysis using Wilks' Lambda method indicated distinct segregation of the biotypes. Rostral, antennal, and leg characters gave a significant degree of certainty in classifying the three biotypes (Fig. 4, 5, 6). The predicted biotype composition of populations formed separate clusters.



4. These discriminant scores show separation of 3 biotypes of *Nilaparvata lugens* based on rostral, leg, and antennal characters of brachypterous females. The numbers indicate biotype designation; the asterisk (*) indicates a group centroid. IRRI, 1980.

5. Scanning electron micrograph (200×) of antenna of *Nilaparvata lugens* (biotype 3). Number, relative position, and structure of sensoria on the pedicel can be useful criteria in differentiating biotypes (ICIPE, Nairobi).

6. Scanning electron micrograph (300×) of a sensorium on the antenna of *N. lugens* biotype 2 (ICIPE, Nairobi).

Green leafhopper resistance

Varieties with various genes for green leafhopper resistance were tested to determine relative levels of resistance. Pankhari 203, ASD7, and ASD8 with *Glh 1*, *Glh 2*, and *Glh 5* had the highest levels of resistance in seedling screening and in insect mortality studies.

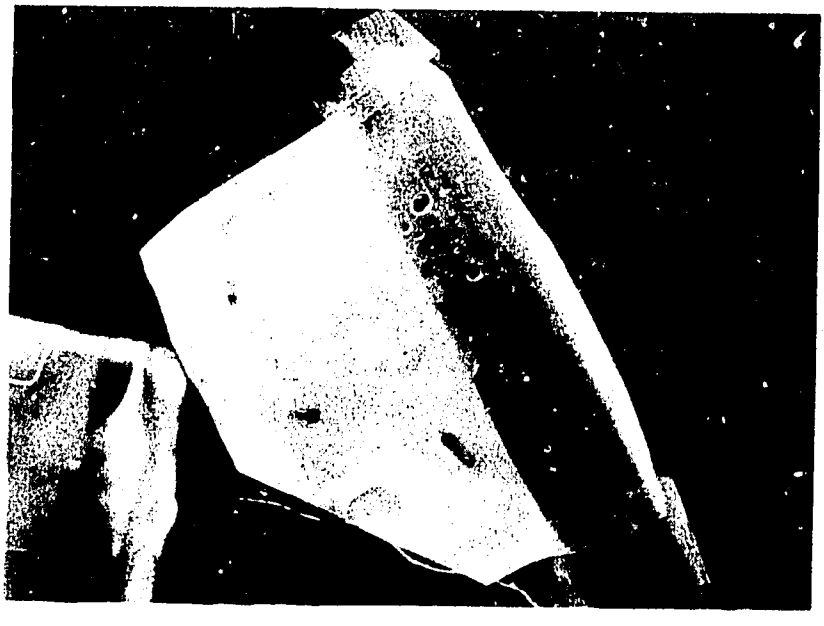
Feeding sites of the green leafhopper on susceptible and resistant rices

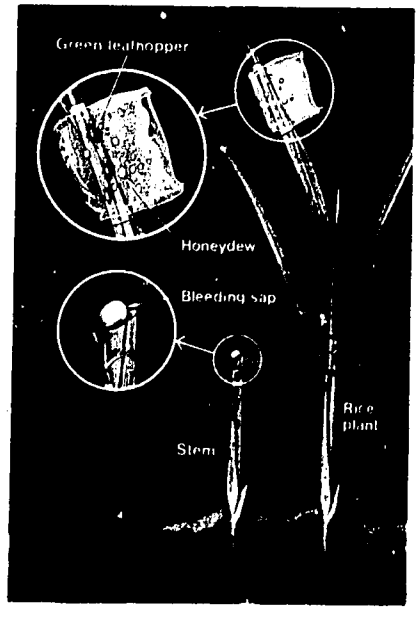
Analysis of honeydew excreted by the green leafhopper feeding on rice plants revealed a much higher free amino compound and sugar concentrations in honeydew excreted on susceptible TN1 than on resistant ASD7. We also found that sap exudates from those varieties — presumably mainly from the xylem — as well as honeydew excreted on ASD7 were acidic, whereas exudates and honeydew on TN1 were predominantly basic. Because phloem sap in herbaceous plants is usually alkaline whereas xylem sap is acidic, and because the phloem sap contains much higher concentrations of sugars and free amino acids than the xylem sap, we have strong biochemical evidence that the green leafhopper is primarily a xylem feeder on resistant ASD7, but feeds predominantly on phloem sap on susceptible TN1.

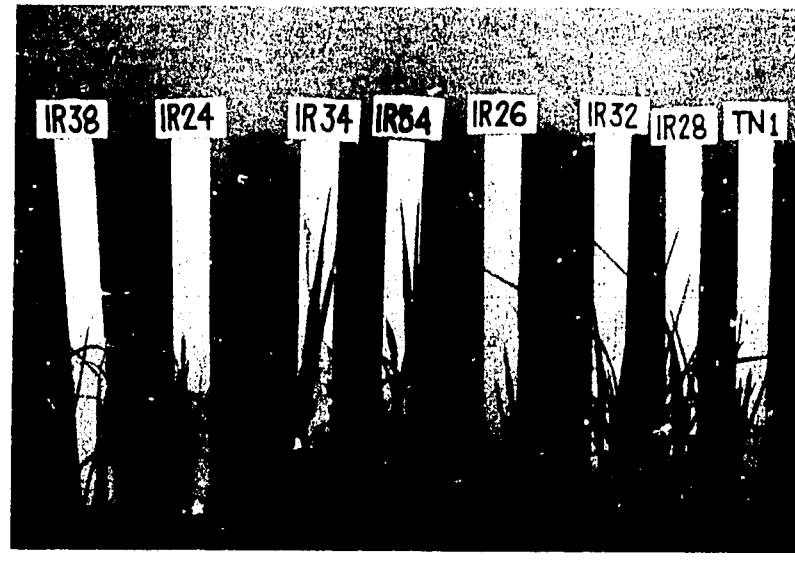
Whitebacked planthopper resistance

We tested varieties with genes for whitebacked planthopper resistance. IR2035-117-3 with *Wbph 1* + Wbph 2, and WC1240 with *Wbph 1* + one recessive gene had the highest levels of

Bleeding sap from a cut rice stem is from the xylem. Analysis of the sap and of the honeydew excreted by green leafhoppers feeding on rice leaves allows identification of feeding site. A close up of a sachet for collecting honeydew is on the left.







7. IR54, although not bred for whitebacked planthopper resistance, exhibited resistance in 1980 screening of IR varieties. TN1 (right) is susceptible to the whitebacked planthopper.

resistance. ARC10239 with *Wbph 2* and Colombo with *Wbph 2* + one recessive gene had the lowest levels of resistance.

Although the IR varieties were not bred for whitebacked planthopper resistance, we checked IR5 through IR54 by seedling screening and found distinct differences among them. IR54 was more resistant than IR26, which was equal to the susceptible check TN1 (Fig. 7).

Inheritance of resistance to whitebacked planthopper

Inheritance of resistance to whitebacked planthopper in 14 resistant varieties was investigated. We found 12 varieties with a single dominant gene for resistance, and 2 varieties whose resistance was governed by a single recessive gene.

DISEASE RESISTANCE

Rice pathologists maintain their constant search for new genetic sources of resistance. Diseases change and rice that the farmer accepted as disease resistant may suddenly be damaged in the field.

Screening rice germplasm for disease resistance

We identified several new sources of resistance among more than 22,000 rice varieties and lines checked for tungro, grassy stu and ragged stunt in mass screening. ARC11554 consistently showed resistance to tungro. Ptb 21 and seven other varieties had a consistently low percentage of ragged stunt infection after inoculation (Table 3).

Table 3. Among 4,961 varieties tested, 9 showed a low percentage of ragged stunt infection in mass screening. Reactions[a] to the brown planthopper (BPH) are from the Master List of the Germplasm Collection, IRRI.

Variety	Tests (no.)	Seedlings		Reaction to BPH biotype		
		Inoculated (no.)	Infected (%)	1	2	3
Balaratawee	14	287	20	R	R	S
Hathili	16	349	16	R	R	S
Hathili	14	307	13	R	R	S
Hondarawala 502	10	228	19	R	R	R
Molagu Samba	10	184	15	R	R	S
Murungakagan 101	10	248	19	R	R	S
Ptb 18	14	352	22	R	R	S
Ptb 21	76	1,476	16	R	R	R

[a]R = resistant, S = susceptible.

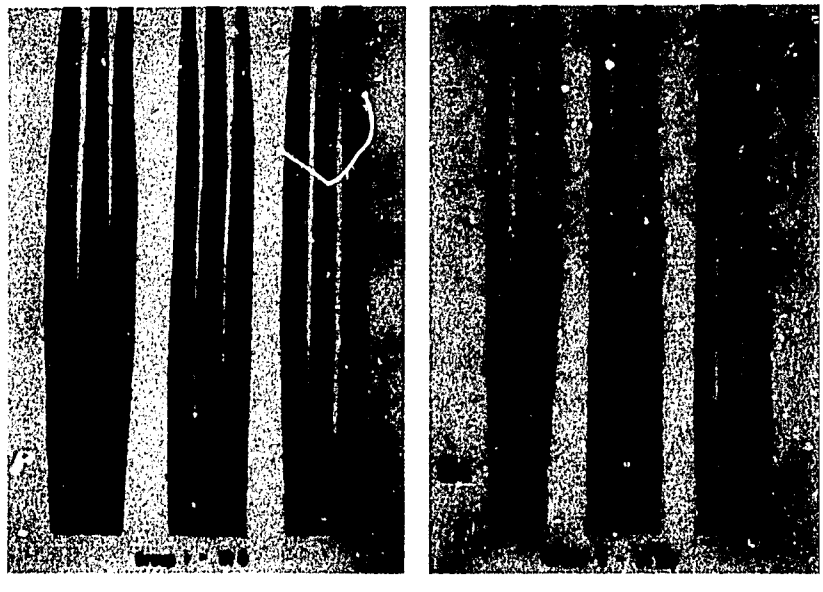
The reaction of 30,627 pedigree nursery entries for tungro disease was recorded in 1980. About 70% of the entries had a resistant reaction or low percentage of infection.

Resistance to bacterial blight

Seven known genes for resistance to bacterial blight from 60 varieties have been used in the IRRI breeding program. In addition, 84 other varieties — without known resistance genes — have been used. Many crosses are known to have more than one gene for resistance. Thirty-six of the resistance donors carried *Xa 4*, which is in about 55% of 33,898 crosses.

Virulence of pathotypes I and III of *Xanthomonas oryzae*

We used dose-response curves to compare the virulence of strains of the pathotypes of bacterial blight on IR8 and IR36. Pathotype I strains differed at the maximum tillering stage of IR8, but were similar at the flowering stage. In contrast, pathotype III



Bacterial blight lesions are seen here on IR8 and IR20 leaves from 1980 virulence tests. Within the same group there was no clear-cut difference in virulence, but a gradual change in lesion size was evident.

Table 4. The reaction of Japanese (I-V) and Philippine (I-IV) pathotypes of *Xanthomonas oryzae* to differential rice varieties of Japan and IRRI was tested in Japan and at IRRI in 1980. The reactions are scored on a scale where 0 = no incidence and 7 = 26-50% incidence.

Differential variety	Gene for resistance	Reaction								
		Japanese pathotype					Philippine pathotype			
		I	II	III	IV	V	I	II	III	IV
Japanese										
Kinmaze	None	7.0	7.0	6.8	7.0	6.6	6.7	6.4	6.7	6.9
Kogyoku	*Xa 1*	0.3	6.7	7.0	6.6	0.1	6.9	6.6	6.4	6.9
Tetep	*Xa 1, Xa 2*	0.0	0.2	6.6	6.6	0.0	4.8	6.3	6.0	4.9
Wase Aikoku 3	*Xa 3*	1.0	0.7	0.2	6.7	5.1	0.9	0.5	0.8	0.3
Java 14	*Xa 1, Xa 3, Xa kg*	0.0	2.0	1.3	6.1	0.1	0.7	0.4	2.0	1.2
IRRI										
IR8	?	6.3	1.2	1.9	6.5	1.1	6.6	6.4	6.2	5.9
IR20	*Xa 4*	0.0	2.3	3.9	4.5	0.0	1.9	6.3	7.0	3.0
IR1545-339	*xa 5*	1.5	2.0	2.0	1.4	1.8	1.9	2.0	1.7	5.6
DV85	*xa 5, Xa 7*	0.0	2.0	1.8	1.9	0.0	1.5	1.5	1.8	1.8
Cas 209	?	6.5	6.8	7.0	7.0	3.1	6.0	0.0	6.8	6.8
Cempo selak	?	1.7	1.2	0.1	6.0	6.1	1.6	1.2	2.6	3.1

strains differed at the flowering stage, but not at maximum tillering. The results confirmed earlier findings that the virulence of strains in each pathotype varied according to the rice susceptible to them.

Collaborative research on bacterial blight

Collaborative bacterial blight research with the Tropical Agriculture Research Center of Japan showed that pathotypes of *Xanthomonas oryzae* in Japan were distinct from those in the Philippines. Some rice varieties were more resistant to the Philippine strains than to the Japanese ones, and vice versa. DV85 was resistant to strains in both countries (Table 4).

GRAIN QUALITY AND NUTRIENT CONTENT

Consumer preferences and the nutritional value of rice remained important in our GEU research during 1980. Acceptability of the modern rices to consumers is a key to their acceptability to the farmer who grows and markets them.

Consumer preference tests

Consumer preference surveys and tests on raw and cooked milled rice continued. Villagers surveyed chose a nonwaxy uncooked rice because of its white, hard, and aromatic grains. Their criteria for boiled rice, in decreasing importance, were slightly strong aroma, slightly rich flavor, and moderately tough texture.

Actual rankings in two consumer tests showed a village preference for IR24 raw and cooked grains, and confirmed an earlier preference for low-amylose rices rather than for intermediate-amylose rices. Cooked IR24 rice was preferred to cooked IR43.

8. Participants in the 1980 Genetic Evaluation and Utilization training ranked raw and cooked rices as part of their course. The consumer preference test was the one used for village tests.

Short and white-belly grains were less preferred in raw form, but the short-grain Korean rices Milyang 23 and Tongil ranked as well as IR24 when cooked.

The consumers' preference criteria — in decreasing importance — for waxy milled rice were aroma, whole big grains, and rich flavor for raw rice, and cohesiveness, aroma, and rich flavor for rice cake. Malagkit Sungsong in both raw and cooked form was preferred. IR29 was ranked low in raw form probably because of its more slender grain.

We asked GEU trainees from various countries and IRRI employees to rank five IR milled rices (IR43, IR48, IR9129-209-2, IR32, and IR42) differing in amylose content (17-29%) as raw and cooked rice (Fig. 8). The shorter-grained IR42 in raw form was less preferred than IR43, but ranking of the five cooked rices was similar. The test indicated diverse rice eating qualities preferred by different people.

Minor constituents affecting starch gel viscosity

Minor grain constituents are known to complex with amylose and, thus, affect starch gel viscosity and consistency. Our 1980 studies showed that rice amylopectin (waxy starch) can also complex well with water-extractable lipids and nonstarch polysaccharides of milled rice through its short linear outer chains.

We developed a modified gel consistency test using defatted waxy rice starch gel in water to measure this complexing activity of minor rice fractions.

Nutritional value of rice protein

Chemical analyses of brown and milled rice give the false impression that brown rice may be more nutritious because of its higher protein content and the higher lysine content of its protein. But in cooperative nitrogen-balance studies of IR32 as brown, undermilled, and milled rices for preschool children, we confirmed that milled rice is comparable to brown rice in protein quality (Table 5). Earlier studies of preschool children fed a lower protein level (200 mg N/kg body wt daily, 1/2 from rice and 1/2 from milk) showed lower digestibility for brown rice than for milled rice. These results confirmed information obtained from feeding trials with rats conducted in collaboration with the National Institute of Animal Science, Copenhagen (Table 6). No advantages were observed for brown rice compared to milled rice.

Table 5. The properties and nitrogen balance of IR32 brown, undermilled, and milled rices in preschool children in cooperative studies with the Nutritional Evaluation Laboratory, Food and Nutrition Research Institute, Manila, Philippines, 1980.

	Brown rice	Undermilled rice	Milled rice
Property			
Protein (% N × 6.25)	8.7	8.5	8.3
Lysine (g/16 g N)	3.8	3.6	3.6
Crude fiber (%)	0.7	0.5	0.2
Dietary fiber (%)	2.6	1.8	0.8
Phytin P (%)	0.06	0.05	0.02
Balance in 6 preschool children[a]			
Apparent N absorption (% of intake)	67.4 ± 3.9	70.0 ± 3.2	70.4 ± 4.9
Apparent N retention (% of intake)	36.1 ± 3.7	37.3 ± 6.2	36.9 ± 5.1

[a]Mean ± standard deviation; 250 mg N/kg body weight, 2/3 from rice and 1/3 from casein.

Table 6. Nitrogen balance[a] in 5 growing rats fed IR32 as brown, undermilled, and milled rices at the National Institute of Animal Science, Copenhagen, Denmark, 1980. Rice properties are in Table 5.

	Brown rice	Undermilled rice	Milled rice
True N digestibility (% of dietary N)	96.9 ± 0.5	97.2 ± 0.9	98.4 ± 1.0
Biological value (%)	68.9 ± 1.4	69.7 ± 1.1	67.5 ± 1.3
Net protein utilization (%)	66.8 ± 1.3	67.7 ± 1.1	66.4 ± 1.2

[a]Mean ± standard deviation.

DROUGHT RESISTANCE

The droughts that damage the rice crop most often are not the kind that make news headlines. The headline drought story presents an image of disaster — vast parched areas, cracked

earth, dead crops and animals, and people on the move in search of food and water.

The drought that causes serious drops in rice yield may last only a few days. A shortage of water at critical stages of crop growth, even the temporary cessation of water supply in an irrigated crop, can reduce yields by as much as 50%.

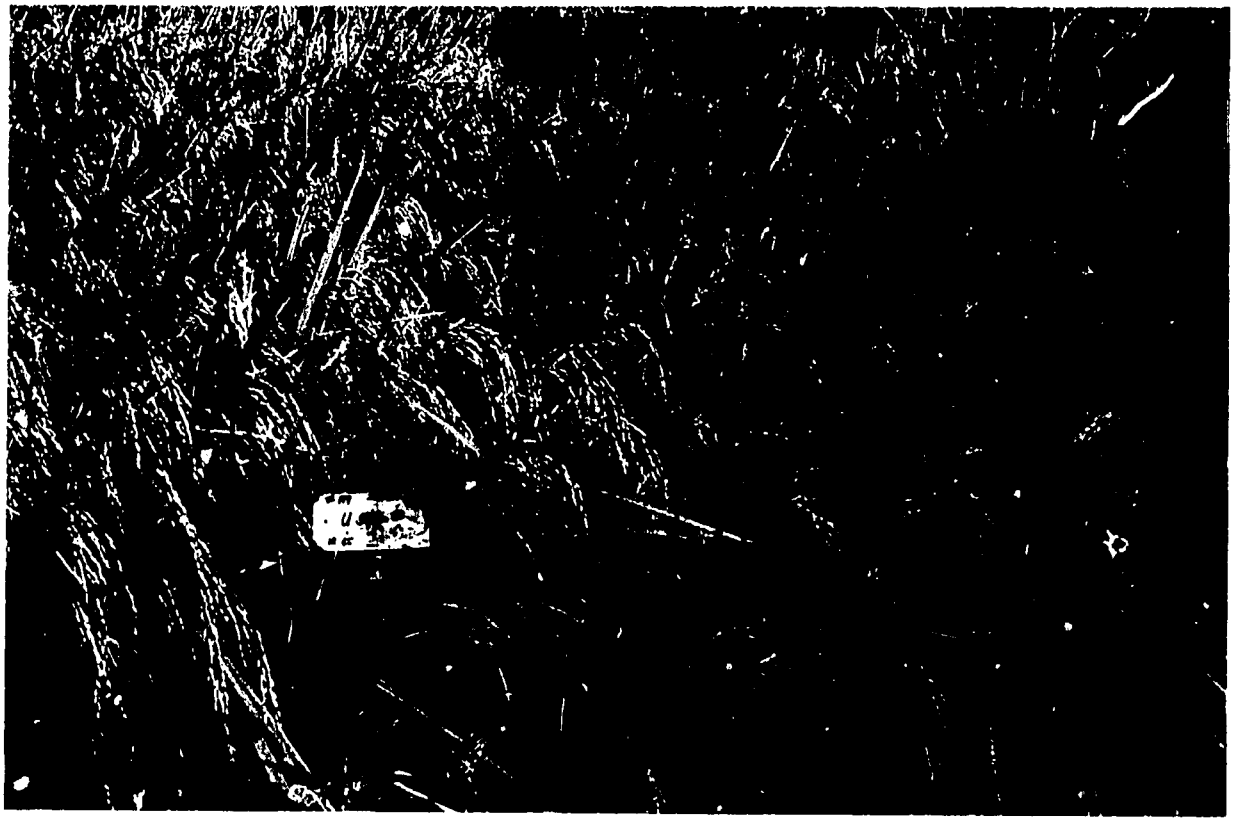
Our GEU scientists continue to study drought and the drought resistance of the rice plant. The objective is to reduce — for the 70% of rice farmers who grow their crops on rainfed fields — the risk of yield reduction when drought strikes.

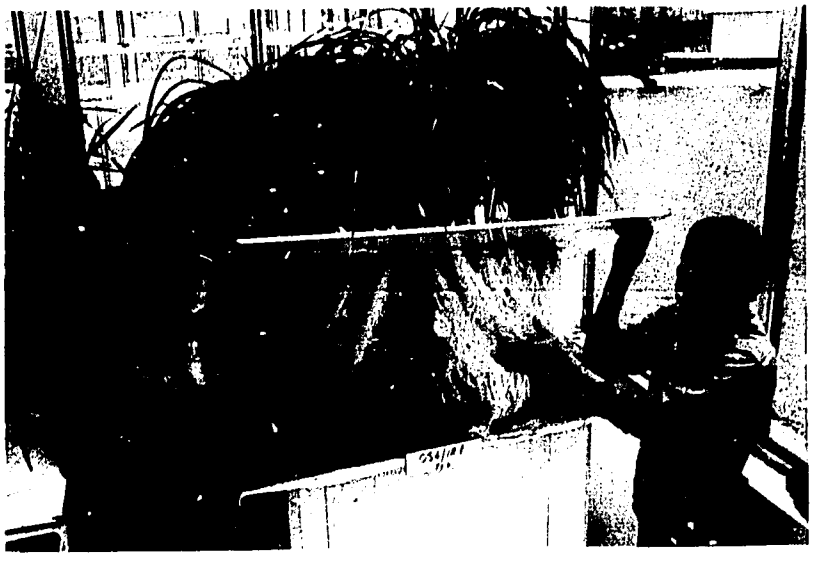
Screening and testing for drought resistance

Screening of rices for drought resistance continued. More than 4,000 varieties and lines were evaluated in a dryland nursery and rainfed-wetland plots. Eighty entries were field-tested at three sites — a farmer's field in Batangas province (Fig. 9), the IRRI upland farm, and a well-drained low-fertility site at IRRI. The farmer's field yields were 3.9-4.6 t/ha from IR5931-110-1, IR6115-1-1-1, and IR43. The drought-resistant line IR6115-1-1-1 gave a high yield of 2.5 t/ha at the well-drained low-fertility site at IRRI.

Several promising rainfed-wetland lines were tested in Central Luzon, where drought occurred at the vegetative and reproduc-

9. This plot of intermediate-stature IR5931-81-1 in 1980 wet season trials in a farmer's dryland field, Batangas, produced 3.5 t/ha. IR45 on the right yielded 2.4 t/ha.





Research fellows Jorge Soto Armenta (Mexico) and Jorge Jonas (Panama) lift seedlings from an OS4/IR8 cross from an aeroponics tank in the IRRI phytotron. The study gave basic information on root characteristics.

tive growth stages. The best performers were IR46, IR5853-118-5, IR13426-19-2, B1141C-KN-43-1-8, KKN7409-SRN-245-2, SPR7421-3-1-2, and KKN7205-39-3-SKN-1-1.

IRRI-India collaborative drought resistance trials

We continued to evaluate materials coming from different breeding programs of India for resistance to drought. Early-maturing varieties that were not affected by a 9-day dry spell at the reproductive phase were Black Gora, Brown Gora, IAC 25, Kalakari, Bala, and N22. Some of the drought-resistant varieties in the trial were used in 125 single crosses made for Indian breeders.

Hybridization and selection for drought resistance

We made 104 single crosses and 86 multiple crosses to incorporate insect and disease resistance into dryland breeding lines with high levels of drought resistance and good yield potential. Bulk populations were grown in dryland fields and 5,451 F_2 plants selected. Another 452 plants in the F_3 to F_5 generations were selected from pedigree nurseries.

Inheritance of root characteristics for drought resistance

Earlier studies have indicated that deep and thick roots are associated with high levels of field resistance to drought. The root systems of different varieties and their hybrid progenies were studied in the phytotron with an aeroponic technique, by which the rice plants were supplied with water and nutrient by a uniform mist. The study provided basic information on the heritability of desirable root characteristics for drought resistance.

Shallow and thin roots generally showed overdominance in

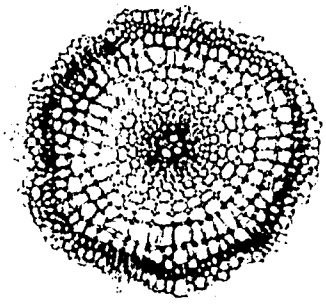
the parental arrays. Among the dryland varieties, OS4 has a combination of deep and thick roots governed by dominant alleles. Moroberekan and 20A have a combination of deep roots controlled by dominant alleles and thick roots governed by recessive alleles.

Root length was positively correlated with plant height and root thickness. Root thickness was positively correlated with plant height, dry weight of the roots, and root-to-shoot-weight ratio. Root number was positively correlated with tiller number, and the dry weight of roots and shoots. But there was no correlation between root number and root length, root number and plant height, and root number and thickness.

The fact that deep and thick roots are controlled by various combinations of dominant and recessive alleles in different parents partly explains the difficulty in recombining deep and thick roots with a moderate number of roots in semidwarf-dryland crosses. Association of traits appears to be mostly in undesired directions. We also experience F_1 partial sterility, restricted F_2 segregation, and aberrant recombination of other traits in such wide crosses. Nevertheless the technique offers a much-needed procedure in the difficult task of producing varieties with desired root characteristics.

Diagnosis of aluminum toxicity

Aluminum toxicity is important in large areas where dryland rice is grown — in Latin America, and also some parts of Africa and Asia. We reported in 1979 that aluminum toxicity affects the drought resistance of rice by reducing root growth. A typical, consistent symptom of aluminum toxicity is roots characterized by shortened root axis, less branching, and brittleness. Leaves do not normally show any specific symptoms.

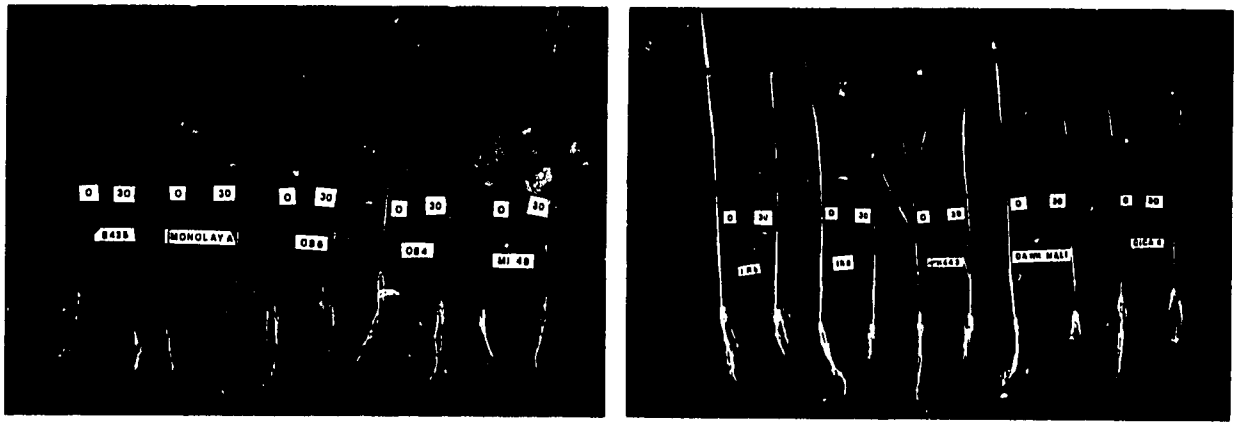


10. The blue stains in this microscopic cross section of a rice root indicate aluminum deposits. The staining serves as part of a technique to diagnose aluminum toxicity in a rice crop.

In 1980 we found that examination of the root tip region provides a convenient and reliable means for diagnosing aluminum toxicity. A root cross-section near a tip was stained with 0.2% hematoxylin solution and examined under a microscope. Blue stains in the cortical cells indicated aluminum deposition (Fig. 10). Deposits of high levels of aluminum coincided with significant reductions in root growth. The technique can be used in combination with soil exchangeable aluminum or percentage aluminum saturation for diagnosis of aluminum toxicity in growing crops.

Screening rices for aluminum toxicity tolerance

Relative root length, root regrowth, and hematoxylin staining can be used in screening rices for aluminum toxicity. Among those, relative root length — ratio of length at 0 ppm aluminum to



11. The roots of 2 groups of rices grown in culture solution show the simplicity of screening rices for aluminum toxicity by relative root length. The group on the left is tolerant; the group on the right is intermediate or susceptible.

that at 30 ppm aluminum — was found simplest and most reliable.

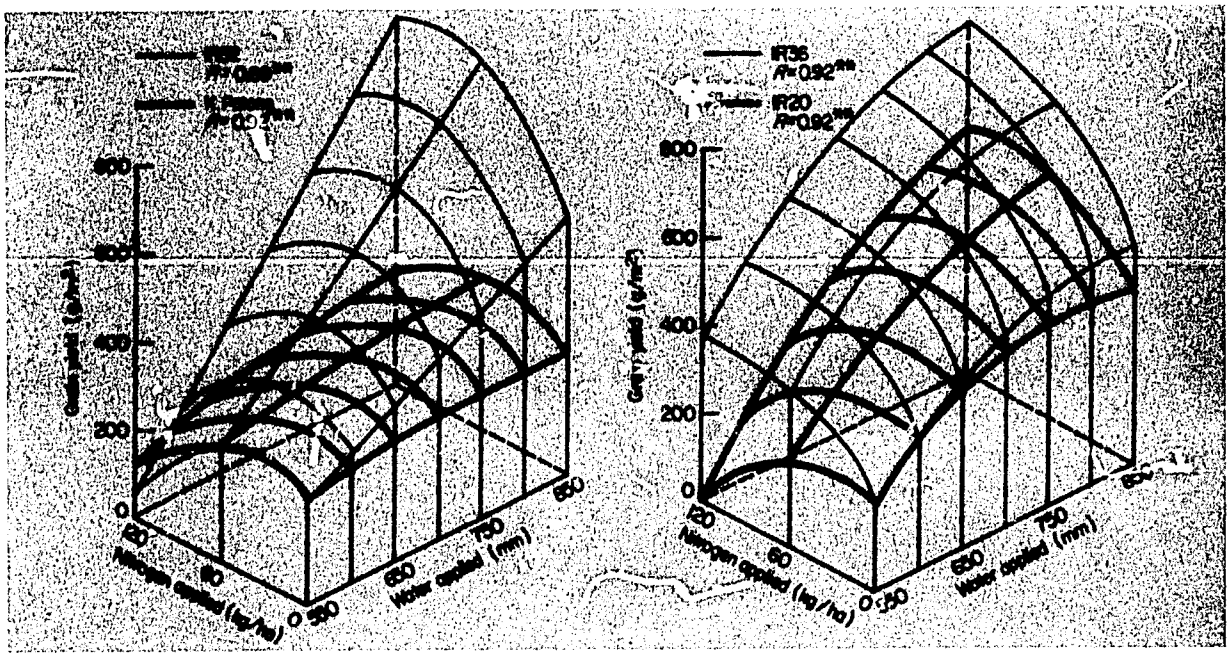
Tolerant varieties have relative root length ratios greater than 0.85; susceptible varieties less than 0.60; and intermediate varieties between 0.60 and 0.85. When tolerant varieties are to be screened, visual comparison of roots facilitates screening (Fig. 11).

Drought response at different nitrogen fertility levels

Nitrogen enters the rice plants' conduction systems chiefly through water uptake. When the soil moisture supply is low, nitrogen supply to the rice plant is also low.

During the 1980 dry season, we assessed the effects of combinations of water applications and fertility levels on rices of various plant types. Moisture and nitrogen regimes that gave the highest grain yield for a given variety were plotted.

The effects of drought and nitrogen are seen in these 1980 trials with IR20. The plot at the bottom (seen partially) had 60 kg N/ha, the next plot had 120 kg N/ha, and the green plot had no N. Moisture level was the same in all plots.



12. A line source sprinkler system was used to study drought effect on nitrogen fertility. Early maturing IR52 had the highest grain yield at 120 kg N/ha with maximum water application. A traditional variety, Kinandang Patong, had the highest yield of 255 g/m² with 550 mm of water applied and no nitrogen fertilizer. That yield, however, was about the same as yields of the other cultivars with the same treatment. At 120 kg N/ha and 550 mm of water, IR36 was superior to the other rices tested.

IR20, IR36, IR52, and Kinandang Patong showed different yield-water-fertilizer nitrogen relationships (Fig. 12). The effect of drought stress was least on Kinandang Patong and greatest on IR20. The application of 120 kg N/ha decreased leaf water potential when total water applied was at a minimum. There was a curvilinear increase in the number of days to heading and linear decrease in plant height and dry matter production with decrease in total water applied.

The 1980 results suggest that in areas of uncertain moisture supply, nitrogen application for rainfed rice should be less than that normally used for irrigated rice.

ADVERSE SOILS TOLERANCE

There are two main approaches to increasing the rice yields on millions of hectares of adverse soils. One approach is amending the soil, but this may be too expensive for the individual farmer. The other approach is to make available to the farmer rice that tolerates the specific adverse soil conditions he experiences. Tolerant germplasm has first to be identified, and then used to breed modern rices for farms on adverse soils. Our GEU adverse soils team has made good progress in this area.

In 1980 we screened 11,827 rices from the germplasm collection, the general breeding program, and the salt tolerance hybridization project. Rices with outstanding tolerance for adverse soils are listed in Table 7.

Table 7. Screening for adverse soils tolerance in 1980 identified 25 rices with outstanding tolerance.

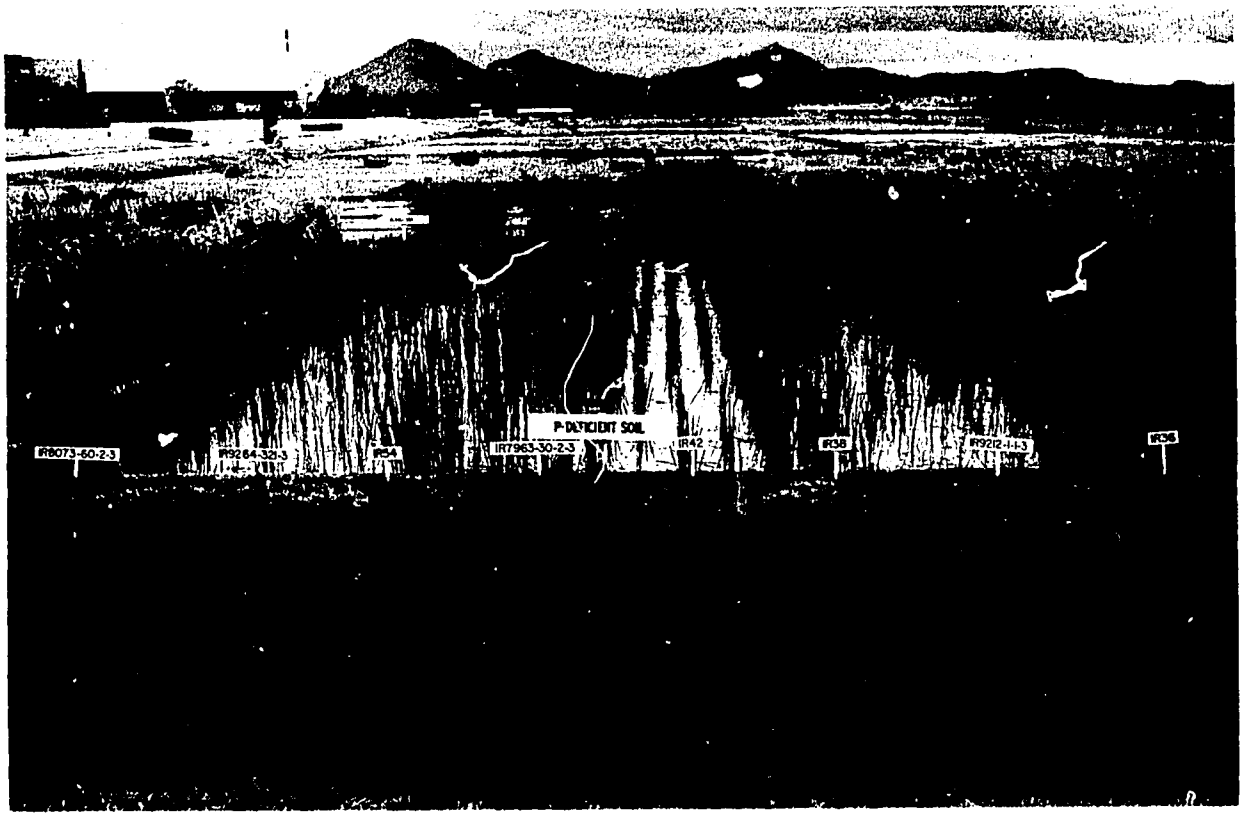
Adverse soil condition	Tolerant line or variety
Salinity	IR46, IR52, IR54, IR4563-52-1
Alkalinity	IR36, IR38, IR52, IR9715-7-2
Iron toxicity	IR36, IR46, IR52, IR54, IR4683-54-2
Peat soil	IR34, IR42, IR54, IR8192-31-2, Kuatik Putih
Boron toxicity	IR50, IR54, IR8608-298-3, IR9129-209-2, IR9764-45-2
Phosphorus deficiency	IR32, IR48, IR52, IR54, IR9732-119-3
Zinc deficiency	IR34, IR46, IR54, IR8192-31-2, IR13168-143-1, IR7790-18-1
Aerobic neutral soil	IR36, IR43, IR52, IR1754-F5B-22, IR19759-29-2
Aerobic acid soil	IR30, IR43, IR52, IR1754-F5B-22.

New rices with wide adaptability

IR52 and IR54, named as varieties in the Philippines in 1980, have marked tolerance for multiple soil stresses. Such tolerance can give them a yield advantage of about 2 t/ha over modern rices that lack tolerance. The two varieties also have disease and insect resistance and should be popular among small farmers of South and Southeast Asia.

IR9884-54-3, which we identified as a salt-tolerant hybrid in 1978 tests, yielded 3.6 t/ha in a farmer's saline field. Eleven modern rices in the same field averaged 1.9 t/ha. IR9884-54-3 is suited to several millions of hectares of coastal saline soils in South and Southeast Asia.

The reaction of IR lines and varieties to adverse soils is seen in these demonstration test tanks at IRRI.



Dr. Benito S. Vergara, IRRI plant physiologist, points to a dead entry in a screening trial for submergence tolerance at Huntra, Thailand. The plots were submerged for 10 days.

DEEPWATER AND FLOOD TOLERANCE

Real breakthroughs in the world of rice science are rare, but the 1979 release of RD19 as a modern deepwater variety may well be called a breakthrough by Thailand's deepwater rice farmers.

RD19 was developed in the Thailand-IRRI Collaborative Deepwater Project, with IRRI core program support. The new rice showed its potential in 14 yield trials in Thailand — yields were 3.9 t/ha in a farmer's field with 120 cm of water at the peak period.

Internode elongation is the most important character for survival of deepwater rice in areas where floodwaters reach more than 50 cm. In RD19, elongation occurs only if necessary for survival. The variety's superior plant type above the water level is evident when it is compared with Leb Mue Nahng 111. Leb Mue Nahng has excellent elongation ability but elongation occurs even when the plants are way above the water level.

The yield potential of RD19 in deep water (maximum water depth 100 cm) was tested at IRRI. In one trial RD19 had a maximum plant height of 200 cm, suggesting that it can withstand 150-cm-deep water without any difficulty if the increase in water depth is gradual. It produced a maximum yield of 3.7 t/ha with no fertilizer nitrogen (Table 8).

Table 8. Yield and some agronomic characteristics of RD19 as affected by fertilizer nitrogen application in deep water (100 cm deep) at IRRI, 1980.[a]

Treatment	Grain yield (t/ha)	Plant ht (cm) at harvest	Tillers (no./m^2) at harvest	Panicles (no./m^2) at harvest	Unfilled spikelets (%)
No fertilizer nitrogen	3.7 ab	200 a	300 ab	235 bc	21 a
		58 kg N/ha			
Prilled urea[b]	3.9 a	197 a	325 a	300 a	22 a
2/3 prilled urea[b] + 1/3 urea foliar sprayed at 5-7 DBPI[c]	3.9 a	196 a	308 ab	261 ab	25 a

[a]In a column means followed by a common letter are not significantly different at the 5% level.
[b]Broadcast and incorporated. [c]Days before panicle initiation. Urea solution was applied 73 days after transplanting.

Table 9. Grain yield of RD19 in deep water as affected by nitrogen sources. The maximum water depth was 100 cm. IRRI, 1980 wet season.

Nitrogen rate (kg/ha)	Grain yield[a] (t/ha)		
	Prilled	Sulfur-coated	Supergranules
0	3.0 a	3.5 b	3.5 a
29	3.3 a	4.0 b	3.5 a
58	3.3 a	5.2 a	4.0 a

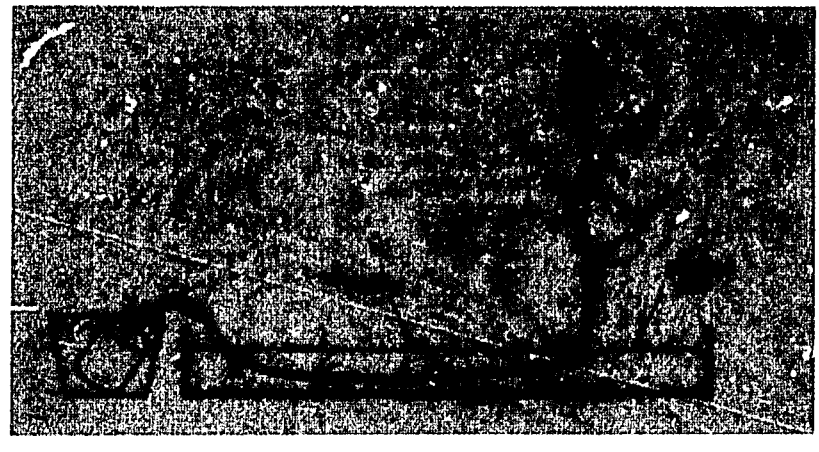
[a]In a column, means followed by a common letter are not significantly different at the 5% level.

RD19 also gave evidence of its high yield potential in a comparison of basal fertilizer applications, where it yielded 5.2 t/ha with slow-release sulfur-coated urea at 58 kg N/ha (Table 9).

Studies with RD19 outside Thailand indicate the plant type will be of wide value, but that some adaptation for insect and disease problems may be needed.

Deepwater rice nutrition through nodal roots

The importance of upper nodal roots in the nutrition of the deepwater rice plant was shown when the activity of basal roots was separated from that of upper nodal roots. We allowed an elongated deepwater rice plant to "knee-up" on a tray in such a way that the upper nodal root region could be fully submerged in ^{15}N-tagged solution (Fig. 13). A high activity of nodal roots in the



13. The uptake of tagged ^{15}N by nodal roots was measured by allowing the plant to elongate and then inducing "kneeing." The ^{15}N uptake was calculated from later analysis of the plant.

absorption of nitrogen from the solution was indicated by the high proportion of tagged nitrogen to the total nitrogen uptake and by the considerable reduction in tagged nitrogen uptake when most of the nodal roots were excised.

When tagged nitrogen was applied before flowering, it became the major component of grain nitrogen. The nitrogen absorbed through the nodal roots markedly increased the dry matter weight of the rice plant.

TEMPERATURE TOLERANCE

Farmers in Korea and Japan had a drastic decrease in rice yields in 1980, much of it because of low temperatures. These setbacks emphasize the importance of increasing the tolerance of rice for extreme temperatures.

Low-temperature tolerance

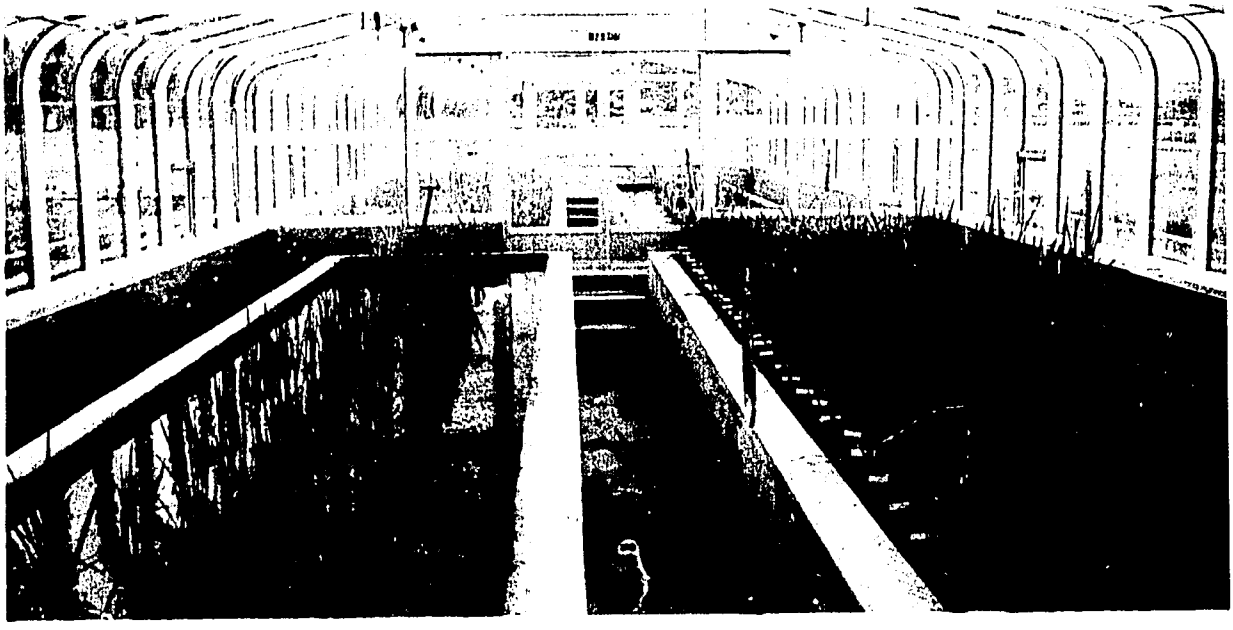
We continued collaborative studies on cold tolerance in Korea and started cooperative research with China and Russia. About 1,500 entries were screened for cold tolerance by the Korea-IRRI team at the Office of Rural Development's special station at Chuncheon, Korea. In the first observation yield trial, the seven entries listed below had high yields despite the unusually cold weather. IRRI crosses were predominant among the top yielders.

Entry	*Yield (t/ha)*
IR15889-32-1	7.9
IR15636-8-3	7.3
SR3044-78-3	7.3
IR9202-10-2-1-11	6.9
China 988	6.8
IR9202-5-2-2	6.6
IR9202-6-1-1	6.5

The use of three planting dates at Chuncheon allowed excellent selection of entries with tolerance for low air temperature at the flowering stage. Of the entries that flowered late, the most tolerant were Anna, Silewah, and Suweon 258. They flowered 12—14 September at an average minimum temperature of 11.9° C.

Cold-tolerant varieties from China

Varieties with the best cold tolerance at 4 growth stages were selected from 1,474 Chinese varieties in the IRRI germplasm bank. Tests were for early seedling stage tolerance at 5° C, seedling stage tolerance at 12° C, and panicle development stage



This glasshouse at the Office of Rural Development's (ORD) Chuncheon Station, Korea, was inaugurated in 1980. It uses cold water to keep the air temperature low during ORD IRRI collaborative research on cold tolerance.

and flowering stage tolerance at 15° C. Eleven varieties selected for use in the breeding program to increase tolerance of rice for low temperature were:

Chiang Tsenf Tau Ju	Chu Cheng
Hung Chao Lu Yu	Fi-Lai-Feng
Y Chang Ju	Ai Yeh Lu (PI 160965)
Ta Chong Kong	Hsing-Yo 613
Fang Chi	Ching-Hsi 15
	Ching-Hsi 17

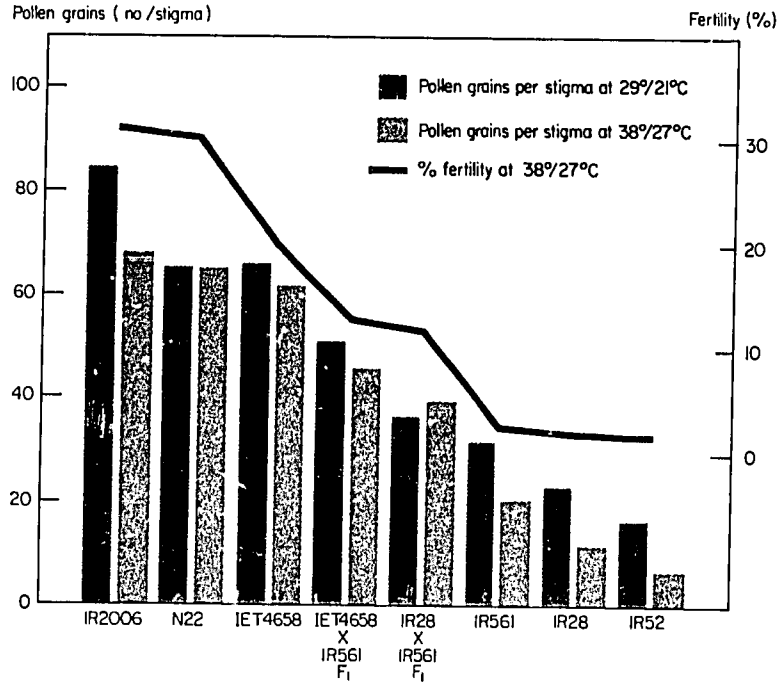
All entries are sinica varieties except Hung Chao Lu Yu and Ai Yeh Lu.

High-temperature tolerance of IR varieties

Spikelet fertility of 21 IR varieties was tested at 35° C in the IRRI phytotron. Fertility ranged from 17% for IR46 to 74% for IR36. Next to IR36 in heat tolerance are IR8, IR20, IR24, and IR50.

We found that IRRI phytotron testing provides an efficient means to screen rice varieties for heat tolerance.

In phytotron screening for high temperature tolerance, we normally use 35° C or 38° C for 8 hours — 0900 to 1700. Such temperatures are lower than the maximum day temperature in the heat-prone areas but correspond to the critical temperature at 1000 to 1100 hours, which disturbs anthesis and fertilization. Comparison of our phytotron data and those from heat-prone rice-growing areas indicates that varieties screened at 35° C in the phytotron are also heat tolerant in the hot areas.



14. The number of pollen grains per stigma affects the heat tolerance of a rice variety. Use of heat-tolerant lines IR2006, N22, and IET4658 as parents increased pollens per stigma in the F_1 progeny. IRRI, 1980.

Genetics of high-temperature tolerance

A diallel cross experiment of six rice lines in 1979 showed that general and specific combining abilities for heat tolerance are highly significant. The heat-tolerant lines N22, IR2006-P12-12-2-2, and IET4658 (UPR96-1-1-1) had good general combining ability for heat tolerance. N22, however, would be difficult to use in the breeding program because of poor plant type and genetic sterility in its hybrid progeny.

A study of the amount of pollen shed on the stigma for the six parental lines and two of their F_1 hybrids showed that heat tolerance is closely associated with the number of pollen grains on the stigma (Fig. 14).

INTERNATIONAL RICE TESTING PROGRAM

Our International Rice Testing Program (IRTP) is an effective force in global rice improvement through linkages among national programs and between IRRI and the national programs. Emphasis during 1980 was on strengthening those linkages through national monitoring tours. During the tours, national and IRTP scientists observed the major rice-growing areas in a given country and the national and IRTP trials for the areas.

There is solid evidence that discussion and observations during the tour help speed the development of improved varieties.

Table 10. These entries in the 1979-80 IRTP trials showed promising yield performance across many sites.

Nursery	Promising entries
Yield (good yield performance across many environments)	
IRYN (Early)	IR36, IR50, IR52, B1014b-Pn-18-1-4, B2360-6-7-1-4, BR51-54-2
IRYN (Medium)	BR51-282-8, RP825-24-7039-236, IR4422-98-3-6-1, IR42, IR54, Cica 8
IRYN (Late)	CR1006, CR1009, RP1064-14-2-2, IET5656
IURYN	UPL Ri-5, IR9669 Sel., IR45, BG35-2, IR2061-522-6-9
Observational (high acceptability in target environments)	
IRON (irrigated)	IR9859-45-2, IR7963-87-3-3, IR4422-480-2, IR8073-231-3-3, IR13415-[illegible]
IURON (dryland)	C894-21, C[illegible]2-14, C424-2, KN96, MRC172-9, Salumpikit, C22, Gama 318, IR3880-29, IR9575 Sel., BPI76 (NS), BG35-2, IR5929-12-3
IRLRON (rainfed wetland)	IR4215-301-2-2-6, IR4819-77-3-2, IR14632-181-1, IR14753-49-2, IR14753-66-3, IR14753-133-2, Nam Sagui
IRDWON (deepwater)	BKN7022-6-4, BKN6986-147-2, BKN6986-173-5, BKN6986-108-3, BP118-3P-17, Chenab Sel. 64-117, CN539, Sitpwa, Saran Krahan
Stress (resistance to specific stresses)	
IRCTN (cold)	JC99, Jo[illegible], Stejaree 45, China 1039, Ahgukdo, Dadajo, Fuji 102, Shin-ei, IR579 ES38-PLP1B, IR2298 PLPB-3-19, K31-163-3, K332, Eiko
IRSATON (salinity & alkalinity)	
• Salinity	IR4595-4-1-15, IR43
• Alkalinity	IR11418-19-2-3
• Both salinity and alkalinity	Getu, CSR1, CSR2, CSR3, Pokkali
IRBN (blast)	Carreon, Tetep, IR1416-128-5-8, 5458 (Colombia), 5470 (Colombia)
IRTN (tungro)	ARC10342, DWA8, ARC13804, BKNBR1031-7-5-4, Utri Rajapan, Utri Merah
IRBPHN (brown planthopper)	IR13427-45-2, IR13427-60-1, IR17496-2-25-1
IRGMN (gall midge)	BG12-1, BKNBR1008-21, CR199-1, W1263, BG275

International nurseries

During 1980 we sent about 1,000 nursery sets to 60 countries in the IRTP network. We also analyzed 1979-80 trial results from more than 500 sites and published nursery reports. Several entries continued their good performance. In addition, some promising new entries were identified in various trials (Table 10).

Focus on national monitoring tours

IRRI scientists participated in national varietal improvement tours in Sri Lanka and India. They also participated in Indonesian tours that focused on GEU activities. Two tours in China looked at the early and late season crops.

Two regional monitoring programs were held — one for Guatemala, Honduras, Nicaragua, Costa Rica, and Panama; and the other for Sierra Leone, Ivory Coast, and Nigeria. In Asia, two problem-area monitoring tours looked at rainfed rice and the cold and blast problems of the hill areas of India and Nepal. After the scientists observed the vast rainfed areas of Northeast Thai-

Turkish and IRRI scientists inspect short-duration, cold-tolerant rices in an International Rice Cold Tolerance Nursery in Turkey. IRRI Pathologist J. P. Crill is on the right.

Indonesian rice scientists look at an improved variety in an IRTP nursery during a national monitoring tour.

Dr. S. C. Modgal (left), rice research agronomist, UNDP/IITA Sierra Leone project and Dr. M. D. Thomas (right), plant pathologist, Rice Research Station, Rokupr, Sierra Leone, discuss IRTP dryland entries in trials at Masorie, Sierra Leone, with Dr. Seshu V. Durvasula, IRRI plant breeder and IRTP joint coordinator.

land and Burma, they unanimously agreed that the breeding effort on rainfed rice must be intensified.

INTEGRATION FOR WIDE USAGE

Ten varieties from nine IRRI lines were named in four countries in 1980 (Table 11), which brought to 85 the number of named national varieties from IRRI sources.

- IR52, released in the Philippines, is a drought-tolerant rainfed variety that matures in 115 days.
- IR54, released in the Philippines for irrigated wetland, has multiple disease and insect resistance and matures in 120 days.
- Semeru, a 110-day variety released in Indonesia, is resistant to brown planthopper biotype 2 in Indonesia.
- NN6A, released in Vietnam, is identical to Semeru.
- NN3B, released in Vietnam, is a medium-growth-duration variety suitable for farms in the Mekong Delta.
- NN2B, released in Vietnam, is tolerant of acid sulfate soils and also has multiple disease and insect resistance.
- NN7A, released in Vietnam, is a 105-day variety recommended for Mekong Delta farmers.
- IR26, identical to its Philippine counterpart, is grown in the single-crop areas of northern Kiangsu, Hupeh, and Anhwei provinces in China. It is also the restorer parent of the F_1 hybrid varieties planted on about 5 million hectares in China.
- IR28 is recommended for the second rice crop in Hunan province, China. It is identical to its Philippine counterpart.

Table 11. IRRI lines named as varieties in different countries in 1980.

Variety name given	IRRI line	Where named
IR52	IR5853-118-5	Philippines
IR54	IR5853-162-1-2-3	Philippines
Semeru	IR2307-247-2-2-3	Indonesia
NN6A	IR2307-247-2-2-3	Vietnam
NN3B	IR2797-115-3	Vietnam
NN2B	IR2823-399-5-6	Vietnam
NN7A	IR9129-192-2-3-5	Vietnam
IR26	IR1541-102-7	China
IR28	IR2061-214-3-8-2	China
32 Xuan 5	IR1561-228-3-3	China

• 32 Xuan 5 is a line with multiple disease and insect resistance recommended for the second rice crop in Hunan province, China.

In response to special requests 8,240 packets with seed of improved breeding lines and varieties were distributed in 1980. The germplasm bank furnished 4,142 samples to 156 rice researchers in foreign countries. The International Rice Testing Program sent another 68,769 seed packets to national programs.

New lines with multiple attributes

Trials during 1980 identified several promising lines for different growing conditions. Outstanding lines for irrigated fields are listed in Table 12.

• IR9752-71-3-2, IR19743-25-2-2-3, and IR19746-28-2-2-3 with a growth duration of less than 100 days are especially promising. Their yield potential is close to that of IR36.

• IR9129-209-2-2-2 is an early-maturing line with high yield potential, intermediate amylose content, and intermediate gelatinization temperature.

• IR13429-109-2-2-1 and IR13429-299-2-1-3, with multiple disease and insect resistance, are resistant to three biotypes of brown planthopper in the Philippines.

• IR13525-43-2-3-1 and IR17494-32-1-1-3 are also resistant to three biotypes in the Philippines.

• IR15314-43-2-3-3 inherits resistance to three biotypes of brown planthopper from Babawee.

• IR13423-10-2-3 and IR13423-17-1-2-1 are two multiple-resistance lines with tungro resistance inherited from Pankhari 2033.

Lines that did well in rainfed fields are IR13149-19-1, IR13149-

Table 12. Some promising breeding lines with multiple attributes suitable for irrigated fields.

Designation	Growth duration (days)	Amylose content (%)	Reaction[a] to Blast	Bacterial blight	Tungro	Grassy stunt	Green leafhopper	Brown planthopper biotypes 1	2	3
IR8192-200-3-3-1	120	26	6	1	3	1	3	3	3	7
IR9752-71-3-2	99	25	2	1	3	1	3	3	3	7
IR9129-209-2-2-2	108	22	7	1	3	1	3	3	3	7
IR13429-109-2-2-1	108	25	2	1	3	1	3	3	3	3
IR13429-299-2-1-3	107	26	4	1	3	1	3	3	3	3
IR13423-10-2-3	118	27	4	1	3	1	1	3	3	7
IR13423-17-1-2-1	121	27	6	1	3	1	1	3	3	9
IR13525-43-2-3-1	118	27	4	1	3	1	1	1	1	3
IR15314-43-2-3-3	122	26	3	1	3	1	3	3	3	3
IR17494-32-1-1-3	125	25	5	1	3	1	1	1	3	3
IR19743-25-2-2-3	99	25	5	1	3	1	3	3	3	9
IR19746-28-2-2-3	99	25	1	1	3	1	1	3	3	9

[a]Reactions are scored by a standard system scale — 1 indicates resistance and 9 indicates no resistance.

The 1980 hybridization blocks and the IRRI Rice Genetic Resources Laboratory are seen in this aerial view.

71-3-2, IR13365-253-2-2, IR13358-85-1-3, and IR13365-253-3-2. They are already in rainfed trials in several countries.

For the rainfed dryland, several breeding lines that have moderate to high levels of drought tolerance, improved yielding ability, and a moderate degree of pest resistance were identified.

- IR6115-1-1 performed well in farmers' field trials for 4 years.
- IR5931-110 is early maturing and has good recovery from drought stress.
- IR6023-10-1 also has good drought recovery.
- IR3880-13-7 is another promising rainfed dryland line.

Breeding operations

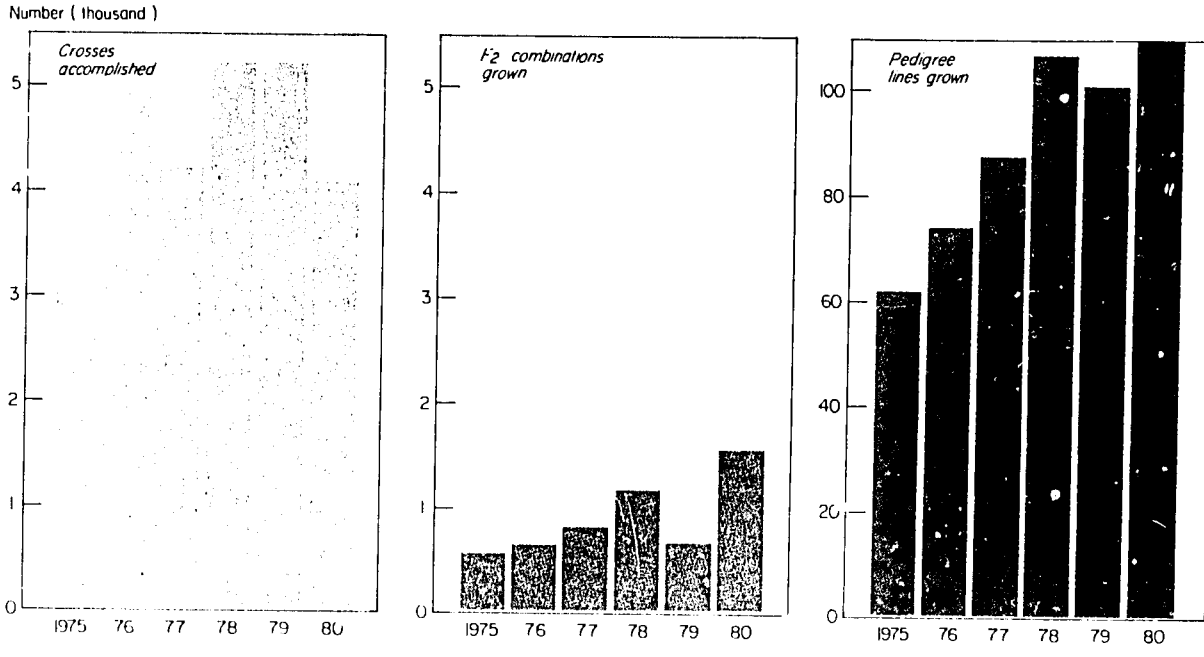
In 1980 breeding operations, we made 4,018 crosses and grew 1,422 F_2 combinations. Pedigree lines grown totaled 109,675 (Fig. 15).

Mutation breeding. In 1979 we reported treating the Indonesian varieties Siyam Halus and Siyam Kuning with chemicals to produce mutants that would provide higher yields in tidal swamp areas.

Ethyleneimine-derived mutants were grown for the first time in tidal-swamp fields in South Kalimantan, Indonesia, the origin of the parent cultivars. Preliminary results were promising, but most of the mutants were unexpectedly later maturing than the check Siyam Kuning (Fig. 16).

Rapid generation advance. The number of rice plants handled in our rapid generation advance greenhouse was double the 1979

15. The 1980 volume of breeding operations in the IRRI GEU Program.



16. Contrasting height and leaf habit of Siyam Kuning and several of its mutant derivatives in a field in South Kalimantan, Indonesia, 1980.

figure. In 1980 we grew 500,000 plants from 287 cross-combinations in rapid generation advance. Countries that sent materials to cross and grow or that received the rapid generation advance materials were Thailand, India, Sri Lanka, Japan, Bangladesh, Nigeria, Korea, Burma, Malaysia, and Indonesia.

We experimented to see if we could select plants with cold tolerance, early maturity, and appropriate plant height during rapid generation advance. Selection was successful for cold tolerance and earliness, but not for plant height.

Hybrid rice. China is acknowledged as the leading country in hybrid rice production on a commercial scale. We believe hybrid rice may have much to offer farmers outside China. In 1980 IRRI trials, hybrids outyielded conventionally bred varieties by 20-25%. The hybrids' yield advantage was attributed primarily to the increase in number of spikelets per panicle and spikelets per unit area even though tiller number was reduced. Grain weight was either the same or slightly higher.

During 1980 we worked in close collaboration with Chinese scientists to help them identify from among IRRI breeding materials effective restorer lines possessing multiple disease and insect resistance. Several such lines were identified. They include IR54, which is already used in China for developing experimental hybrids.

Outcrossing studies in 1980 indicated that bulk quantities of hybrid seed can be produced in the tropics through natural cross-pollination on male sterile lines.

To teach Asian rice breeders the techniques of hybrid rice research, we collaborated with the Chinese Academy of Agricultural Sciences in offering Asia's first hybrid rice research training

Active collaboration between China and IRRI in hybrid rice is in progress. Mr. Yuan Long Ping, father of China's hybrid rice, and Dr. S. S. Virmani (left), IRRI plant breeder, examine an experimental hybrid derived from Chinese cytosterile line V20A and IR54, a restorer line.

Participants in Hybrid Rice Research training at Hunan Academy of Agricultural Sciences, Changsha, Hunan, China.

at the Hunan Academy of Agricultural Sciences, Changsha, Hunan, China, in late 1980.

Anther culture. Rice varieties differ greatly in their ability to produce callus and regenerate green plants on the same culture medium.

In 1980 we cultured 85 rice varieties and classified them as high, medium, or low callus producers. We then tested 16 common rice tissue culture media to determine essential components and the optimal amounts of each for callus production and green plant regeneration. Two improved media had a green plant regeneration efficiency of 73%, compared to the 3-10% efficiency in our initial studies.

Many inbred rice lines that had appeared genetically uniform and homozygous are not so. We found that plants regenerated from fixed-line varieties by anther culture exhibited one or more characteristics not seen in the seed-maintained population. The differences became apparent through the haploid-diploidization process that occurs with anther and pollen culture.

Work started on development of salinity tolerance in rice through tissue culture techniques.

International rice genetic survey

Work continued on adding the genetic ancestry of about 38,000 rices to information in the *History of IRRI Crosses*. We included data on 36,000 crosses made in national rice improvement programs, 500 post-IR8 varieties, and 1,100 older varieties. This work will make the *History of IRRI Crosses* an international rice genetic ancestry program, which will serve rice scientists everywhere.

Semidwarfism was traced in a sample of 370 improved rice varieties released in 35 countries since 1966. We found 274 of the new varieties were semidwarfs; 91 of them were IRRI lines or varieties released in national programs. IRRI germplasm is in the ancestry of 85% of the 183 varieties that were locally developed.

Dr. M. S. Balal, Egyptian plant breeder, checks the height of dwarf progeny in an M_3 population derived from gamma radiation of Giza 172, a popular Egyptian japonica variety. The seeds were irradiated at the University of California, Davis, in November 1979; the M_1 generation was immediately grown at IRRI and M_2 seed was sent to Egypt in time for the 1980 planting season. This cooperative work is expected to provide Egypt with short stature japonica varieties in 3 to 5 years.

Dr. R. Feuer, IRRI Philippines, checks a foundation seed field of IR52, the first improved IR variety to be named for rainfed, drought prone areas.

Of all the semidwarf varieties released, including IR lines named locally, 89% are IR progeny. Of all varieties released, 66% are IR progeny.

We found that although Dee-geo-woo-gen is four generations removed in some local semidwarfs, it is the ultimate dwarfism source of almost all semidwarf rice varieties outside China.

COMPUTERIZED DATA MANAGEMENT

In 1980, we continued to improve the existing computer programs and to develop new ones to handle the growing needs of IRRI scientists.

We added 6,797 registered accessions of *O. sativa* to the IRRI germplasm computer data bank, bringing to 47,565 the total bank accessions as of 31 December 1980. A separate data bank for the wild species of *Oryza* was created with the initial data of 85 traits for 3,793 accessions. An inventory system for seed storage, distribution, and rejuvenation was implemented.

Computer data files on the parentage of the 33,698 crosses made at IRRI and for the system tracing parental history were extended to include information on crosses made in national programs. Parentage records of more than 17,000 crosses made in 16 national programs are now in our computer files.

All data from 15 IRTP nurseries for crop years 1973 to 1979 are stored in computer files. The information retrieval system that has been developed can accurately and rapidly search for desired information pertaining to the prescribed test sites, type of nurseries, varieties or lines tested, crop years, and characters measured.

CONTROL AND MANAGEMENT OF PESTS

The increasing extent to which a single variety — IR36 — is being grown worldwide emphasizes the potential vulnerability of the world's rice crop to attack by insects and diseases. In addition to our efforts to build a high degree of resistance to many pests into this and other varieties, we have continued efforts to develop simple, low-cost, and safe pest-control techniques that will serve the rice farmers.

DISEASES

Modern rice varieties with multiple disease resistance have contributed greatly to removing the risk of disease striking the rice crop, but the resistant varieties are best used in programs where they combine with cultural practices, chemical pesticides, and biological control as well.

The effectiveness of fungicides on sprouted seed for control of bakanae disease is seen in these IR42 plots at IRRI. Treatment costs at P15.30/ha gave 12.20% yield increases.

Chemical control of blast disease

Research on chemical control of blast covered seed, soil, and crop treatments. In continuing seed treatment tests with systemic fungicides, CGA49104 (50% W.P.) at the rate of 8 and 4 g/kg seed and PP389 JF5816 (50% W.P.) at 40 and 20 g/kg seed remained outstanding against leaf blast.

In soil treatment, effective control of leaf blast with a 5% granular formulation of CGA49104 broadcast at 50 kg/ha was obtained. We had excellent control of leaf blast, even at a high nitrogen level of 480 kg/ha.

As a foliar spray, CGA49104 at 1 kg/ha appeared most effective for leaf blast control. Tricyclazole at 0.7 kg/ha and PP389 JF5816 and benomyl at 1 kg/ha were also effective.

Sheath blight control

Benomyl at the rate of 40 g/kg seed was an effective seed-treatment fungicide for sheath blight control on seedlings.

A laboratory bioassay technique that uses detached leaves for evaluating the efficacy of fungicides for sheath blight control was developed. Preliminary results with the technique confirmed previous greenhouse and field test results on the efficacies of Iprodione, Validamycin A, NTN19701, Hoe 00662, and Triphenyltin acetate.

Control of bakanae disease

Soaking sprouted seed in benomyl at 2, 1, and 0.5 g/liter of solution for 18-24 hours gave effective control of bakanae. Other fungicides effective on sprouted seed were benomyl-thiram (40% W.P.), thiophanate-methyl-thiram (30% W.P.), thiophanate-methyl, TCMBT (65% W.P.), and thiobendazole (45% W.P.) each at 1 g/liter concentration.

Ecology of *Thanatephorus cucumeris* and cultural control of sheath blight

The basidial stage of the sheath blight pathogen *Thanatephorus cucumeris* was observed frequently on rice in rainfed wetland and dryland fields at IRRI. It was also noted on the weed *Paspalum distichum*. We did not find the basidial stage on irrigated wetland rice.

Three species of *Cyperus* — *C. compactus*, *C. ferax*, and *C. kyllingia* — in a field left fallow after rainfed wetland rice were found infected with *T. cucumeris*. This could be the first time these weeds were observed to be naturally infected by the rice sheath blight pathogen.

When we controlled grassy weeds in a fallow field with preemergence herbicides, the number of sclerotia of *T. cucumeris* was

Table 1. In 1980 experiments recovery of the rice sheath blight pathogen *(Thanatephorus cucumeris)* **from plant residues (<5 mm in size) was lowest in an irrigated field where fallow and preemergence herbicides were applied before planting of IR36.**

Treatment	Recovery (%) at		Sclerotia[a] (no.)	
	Harvest	One wk after harvest	Counted	Viable
No herbicide	6.4	11.7	24	11
Herbicide				
Fallow (no herbicide) Preemergence (X 150)	5.4	9.7	19	9
Fallow (glyphosate) Preemergence (none)	3.5	7.4	5	0
Fallow (glyphosate) Preemergence (X 150)	4.4	5.8	2	2

[a]Per liter of surface soil.

reduced (Table 1). Recovery of the fungus from rice debris a week after harvest was also less. Sheath blight incidence was lower in fields where land was prepared 4 weeks before transplanting than in fields prepared 2 weeks before transplanting.

Rice tungro epidemiology

The incidence of rice tungro disease is a function of vector insects, virus sources, susceptibility of rice to the vectors and virus, environment, and time. We have studied the field epidemiology of rice tungro in 37 farmers' fields in Luzon since 1973. The tungro vectors *(Nephotettix virescens, N. nigropictus,* and *Recilia dorsalis),* infective insects, and tungro incidence varied from place to place and from time to time. However, the incidence of tungro in the wet-season crop was correlated to vector population and percentage of infective insects (an indication of virus sources) in April to June (Table 2).

The period from April to June covered the time before and after seedbed and field preparation, seedbeds with rice seedlings, and fields with newly transplanted rice plants. Therefore, the data collected in the early stages of the crop could be used as criteria for forecasting the incidence of tungro disease.

Table 2. Eight years of biweekly surveys of 37 Philippine farmers' fields for tungro vectors from April to June and the incidence of rice tungro disease from June to October provides a basis for the prediction of tungro outbreaks.

Year	Tungro vectors (Apr-Jun)		Tungro (Jun-Oct)	
	Av no./10 sweeps	Infective (%)	Fields (%)	Incidence (%)
1973	5.8	0	1	0.60
1974	11.0	1.77	45[a]	2.38[a]
1975	9.8	0.69	72	3.32
1976	3.9	0.18	25	0.33
1977	3.0	0	15	0.03
1978	2.3	0	0	0
1979	3.3	0.34	18	0.02
1980	5.8	0.17	11	0.06

[a]The Philippine Government launched a green leafhopper control program in the area in July and August.

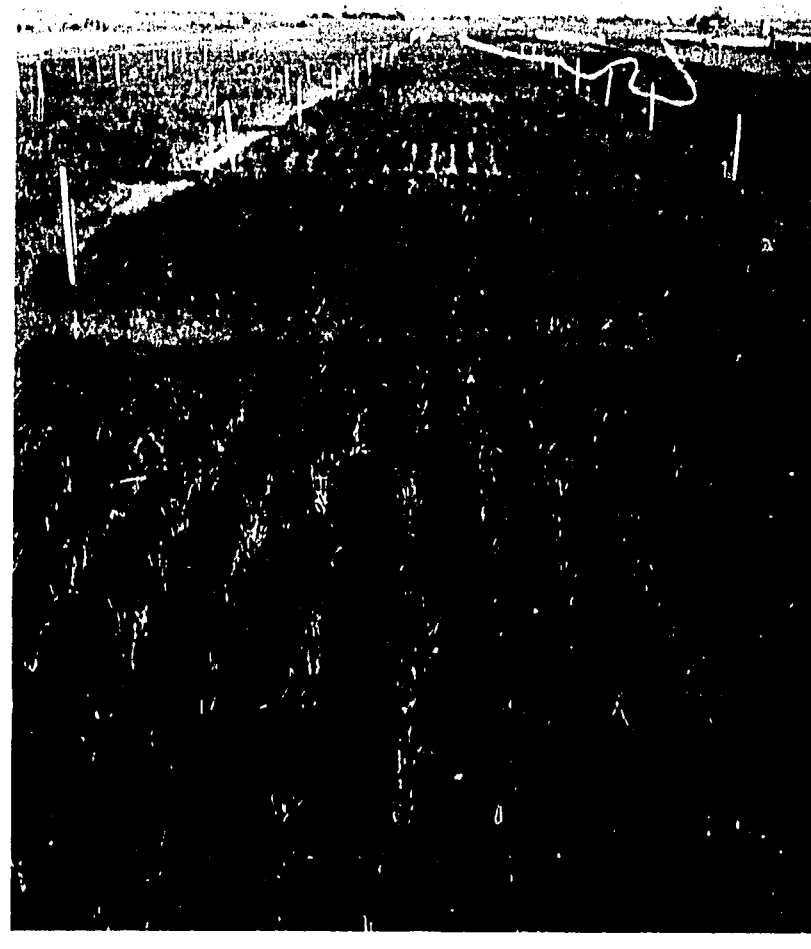
Rice tungro virus collaboration

Rice varieties differ in their reaction to rice tungro virus from place to place and from time to time. To study the variation, a Rice Tungro Virus Collaborative project was started in 1978 by scientists from IRRI, Bangladesh, India, Indonesia, and Thailand. Project work in 1980 concentrated on identifying varieties that could differentiate biotypes of the green leafhopper (the tungro vector) and strains of the tungro virus. Varieties that could do both were identified and possible causes of variation in varietal reaction were identified.

INSECTS

Timely use of the right insecticide can still make the difference between profit or loss for the rice farmer. Continuous field testing of insecticides is needed because several insecticides giving poor insect control are currently recommended for use in various countries.

Field evaluation of insecticides for yellow stem borer control on IR29 at the Maligaya Rice Research and Training Center. The untreated plot in the foreground is severely damaged, but the treated plot in the background has little stem borer damage.



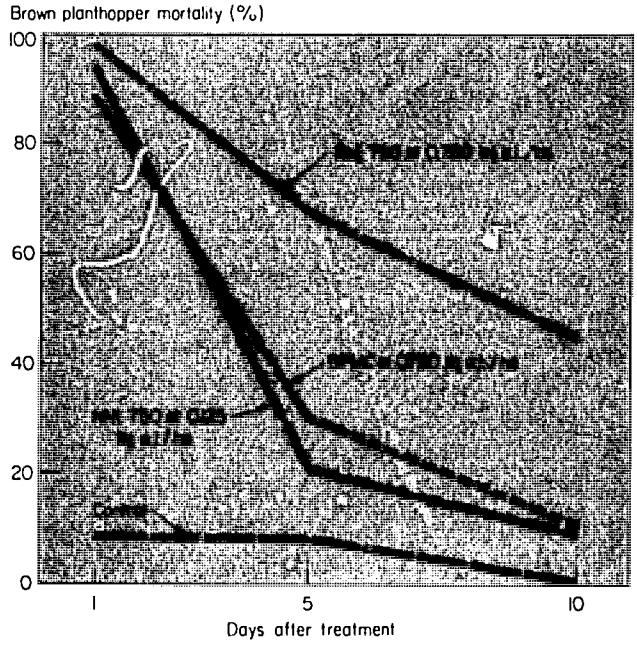
Evaluation of insecticides

Tests to determine the effectiveness of insecticides in controlling major insect pests, to measure their impact on natural enemies, and to identify those causing resurgence of the brown planthopper continued.

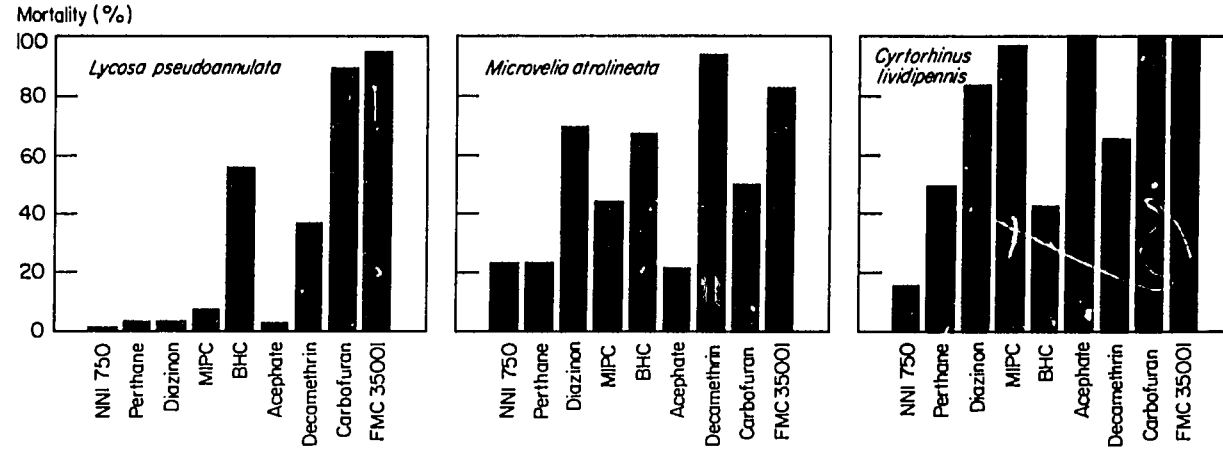
NNI 750, an insect growth regulator, was identified as an effective hopper insecticide that is not destructive to natural enemies. It is effective only against the nymphal stage of hoppers by causing a disruption in the molting process. Unlike carbofuran, NNI 750 did not have a rapid knockdown effect. But at 0.25 kg a.i./ha, within 6 days it provided control of the brown planthopper and green leafhopper equal to that by carbofuran at 0.75 kg a.i./ha. In field studies NNI 750 had a longer residual activity than BPMC, a commonly used hopper insecticide (Fig. 1).

In tests against three major natural enemies of hoppers NNI 750 was relatively safe to the three predators (Fig. 2). No other insecticide tested was safe to all three.

In a search for additional insecticides that control brown planthopper without causing high mortality to natural enemies, 10 insecticides were tested. Decamethrin was selectively more toxic to the spider *Lycosa pseudoannulata* and the mirid bug *Cyrtorhinus lividipennis* than to the brown planthopper. Endosulfan was more toxic to *L. pseudoannulata* but less toxic to *C. lividipennis* than to the brown planthopper. Perthane, an effective insecticide for brown planthopper control, had low toxicity to both predators.



1. Mortality of caged brown planthopper nymphs at 1, 5, and 10 days after treatment in IRRI field plots sprayed with 2 rates of NNI 750 and BPMC at 40 days after transplanting. A fresh group of nymphs was caged on the plants at 1, 5, and 10 days after treatment and mortality readings were taken 5 days later.

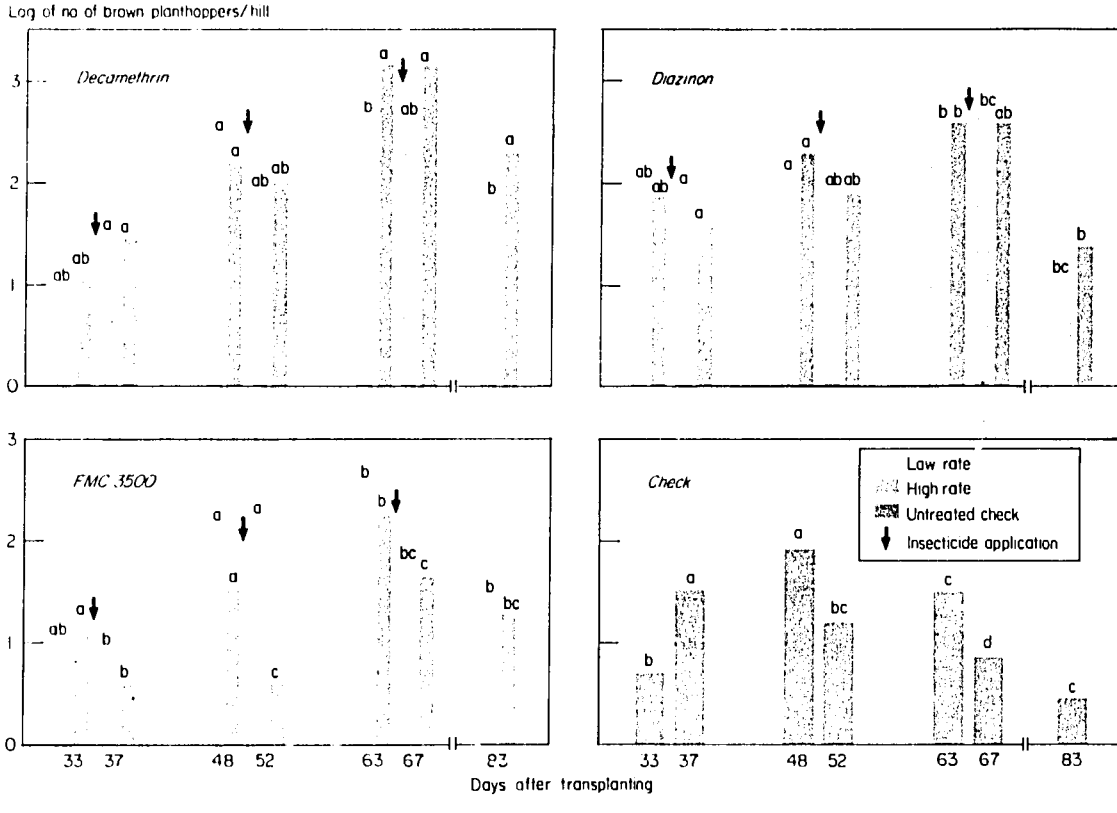


2. The mortality rate of predators 48 hours after treatment with insecticides at 0.75 kg a.i./ha — except decamethrin, which was applied at 0.013 kg a.i./ha.

3. Field tests in 1980 examined resurgence of the brown planthopper at 3 rates of insecticides applied at 35, 50, and 65 days after transplanting. Low and high rates of decamethrin were 0.002 and 0.04 g a.i./ha; those for diazinon and FMC 35001 were 0.2 and 1.0 kg a.i./ha. Within each sampling date, bars with the same letter are not significantly different at the 5% level.

Brown planthopper resurgence

Thirty-five insecticides used on rice in Asia were tested in the field to determine their effect on populations of the brown planthopper. Ten insecticides significantly reduced the brown planthopper number, but propoxur and perthane gave the most consistent effective control. Sprays of 12 insecticides and granules of 3 insecticides caused significant increases in numbers of the brown planthopper.



The use of some insecticides causes a rapid increase in the brown planthopper population — commonly called resurgence — resulting in hopperburn of the rice crop as seen in the field on the right. Insect population has not built up on the younger plants (left).

Three resurgence-inducing insecticides, decamethrin, diazinon, and FMC 35001 were tested to determine the effect of insecticide rates on degree of resurgence. Brown planthopper populations were significantly larger in all the insecticide-treated plots than in the untreated checks 63—83 days after transplanting (Fig. 3). The tests showed that it does not appear possible to avoid resurgence by changing rates when a resurgence-inducing insecticide is used.

The importance of brown planthopper resurgence

How important is it to avoid resurgence-inducing insecticides on farms growing a brown-planthopper-resistant variety? To answer the question, we grew IR29, IR40, and IR42 — respectively susceptible, moderately resistant, and resistant to brown planthopper biotype 2 in the Philippines — and treated the field with decamethrin.

Brown planthopper populations increased to a significantly higher level in the treated plots than in the untreated checks, but the degree of resurgence varied among varieties. The maximum population increases (x) in the treated plots were 74x for IR29, 50x for IR40, and 5x for IR42. Although brown planthopper populations on the highly resistant variety IR42 were below the economic injury level, the 5x increase offers the danger of inducing more rapid natural selection for a biotype of hopper that can overcome the resistance. In addition, most commercial rice varieties are susceptible to the whitebacked planthopper, which also resurges.

The causes of brown planthopper resurgence

Resurgence of brown planthopper populations on certain insecticide-treated susceptible rice varieties has been attributed primarily to increased insect feeding and reproduction, enhanced adult life, and death of predators. To understand the basic causes of resurgence better, we investigated biochemical

Table 3. Carbohydrate and nitrogen levels in leaf sheath of insecticide-treated TN1 plants.

Treatment	Starch (%)	Soluble sugars (as % glucose)	Nitrogen (%)	Free amino nitrogen (as % leucine N)	Carbohydrate-nitrogen ratio
Methyl parathion	5.97 a	1.67 a	1.77 ab	0.115 ab	14.52
Decamethrin	6.65 a	1.02 a	1.88 a	0.134 a	7.61
Perthane	4.70 a	1.44 a	1.57 b	0.076 b	18.95
Water (control)	4.40 a	1.80 a	1.90 a	0.106 a	16.98

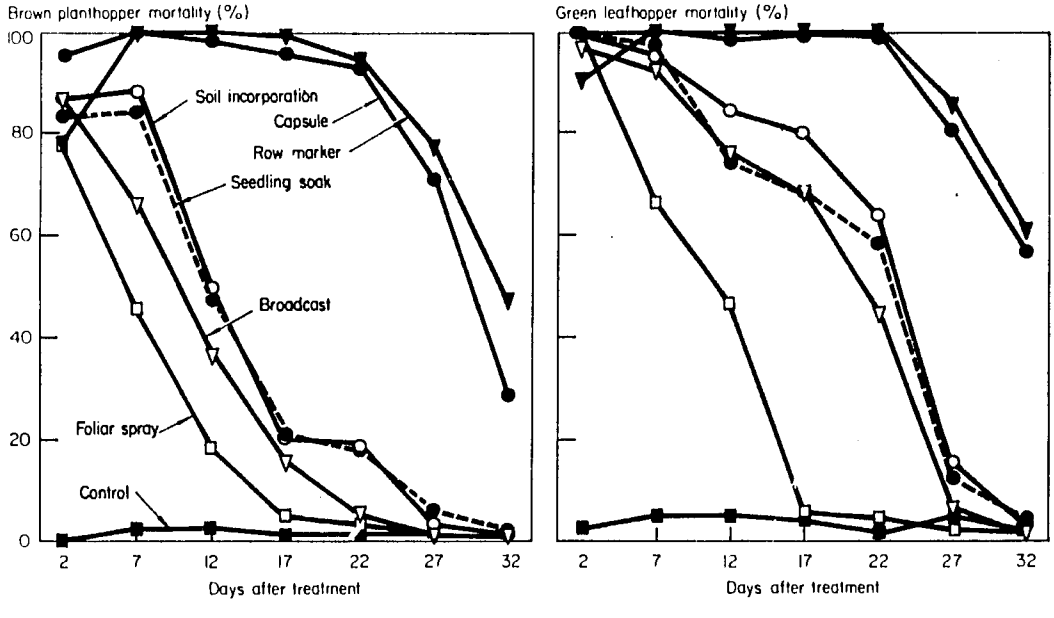
This injector row marker, developed by IRRI entomologists and engineers, applies insecticides to the plant root zone.

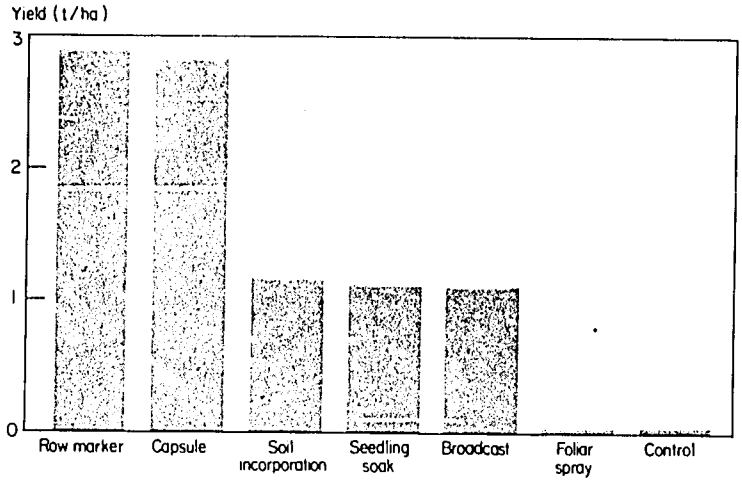
changes in insecticide-treated plants because the chemistry of the plant has a profound effect on insect growth and development. The resurgence-inducing insecticides decamethrin and methyl parathion, and the nonresurgence-inducing insecticide perthane were compared (Table 3). The carbohydrate-nitrogen ratio in decamethrin-treated TN1 plants was lower than in the other treatments and may be responsible for enhanced insect feeding.

Methods of insecticide application

Application of carbofuran into the rice root zone gives long residual activity. In 1980 IRRI engineers and entomologists continued testing equipment for applying insecticides into the root zone. Application of carbofuran with an injector, which also marked rows as a guide for transplanters, provided much longer residual activity against both the brown planthopper and green leafhopper than the commonly used foliar spray and granular broadcast methods (Fig. 4). Despite severe attack by tungro and ragged stunt virus, the row marker plots yielded about 3 t/ha (Fig. 5).

4. Effectiveness of a single application of carbofuran on brown planthopper and green leafhopper mortality as influenced by different application methods.





5. Yield response of IR22 as affected by different methods of a single application of insecticide. Carbofuran at the rate of 0.75 kg a.i./ha was applied as a preplanting treatment — soil incorporation, seedling soak, and with the row marker — and postplanting treatment —foliar spray, broadcast and capsule.

We also tested the new IRRI mechanical transplanter in farmers' fields as a means of getting insecticide into the root zone. Carbofuran granules applied to the seedlings 1 day before transplanting provided control of green leafhoppers, whorl maggot, and stem borers throughout the vegetative stage (Fig. 6) and increased yields more than 2 t/ha.

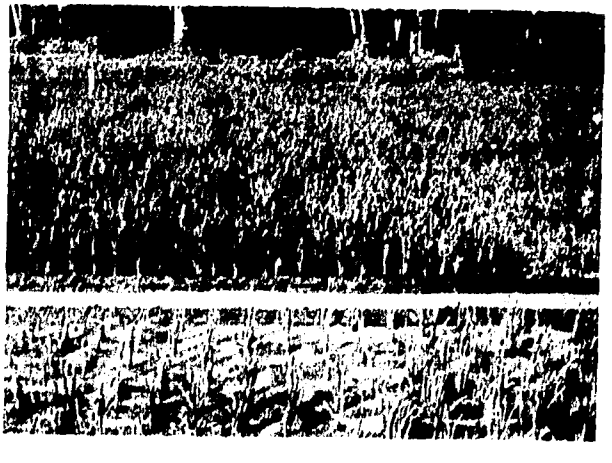
Sex pheromone traps and pest control

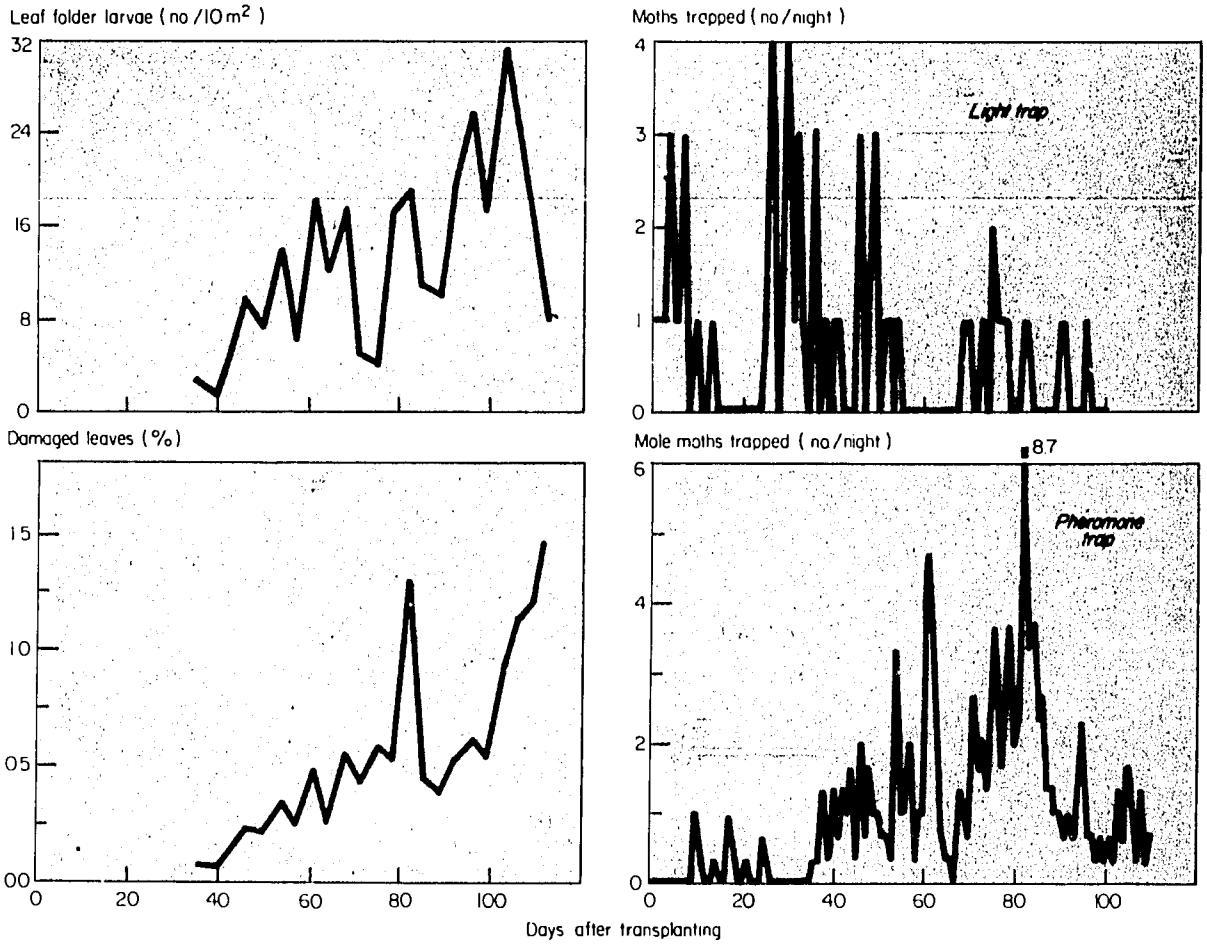
In tests of insect traps, the trend in sex-pheromone trap catches of rice leaf folder matched leaf folder infestation and damage. Light trap catches did not (Fig. 7). Thus pheromone traps may be helpful in timing insecticide treatment efficiently — for example, right after a peak in the trap catch.

Similar trap-infestation data were obtained for the striped rice borer *Chilo suppressalis*, using pheromone traps unique to the

6. The photo on the left shows the mechanical transplanter in action. Granular formulations of systemic insecticide can be broadcast on the seedlings one day before transplanting and injected into the soil along with the seedlings at transplanting time.

In the photo on the right, the plot in the background has been treated with 0.5 kg a.i. carbofuran/ha with the mechanical transplanter, and the plot in the foreground has received no insecticide.





7. Leaf folder infestation and damage on IR29 followed the trend in pheromone trap catches, but not that in fluorescent light trap catches in the 1980 wet season. Pheromone trap catches may be useful indicators of the right time to apply insecticides for leaf folder control.

species. In a field trial we achieved as good striped borer control with one spray a week after the peak in trap catches, as with two prophylactic granular-insecticide applications.

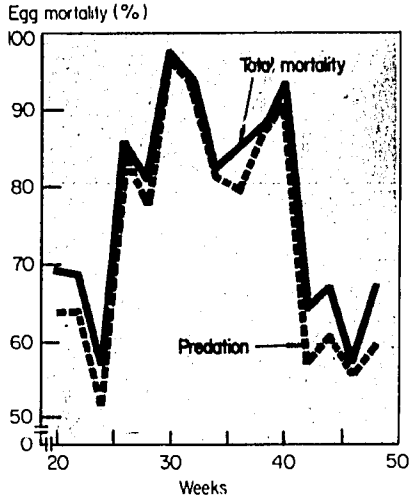
Spiders as enemies of rice insect pests

Little is known about the role of spiders (Fig. 8) as natural enemies of rice insect pests. To date, only a wolf spider species has been studied in detail. A 2-year survey in the Philippines revealed 51 spider species inhabiting rice fields in dryland, rainfed wetland, and irrigated environments. Nine species were sufficiently abundant and were prime candidates for further study to determine their prey preference and predatory capabilities.

8. As predators, spiders are highly effective natural enemies of rice insect pests because they are long lived, abundant, able to survive between rice crops, and have few natural enemies of their own. IRRI, 1980

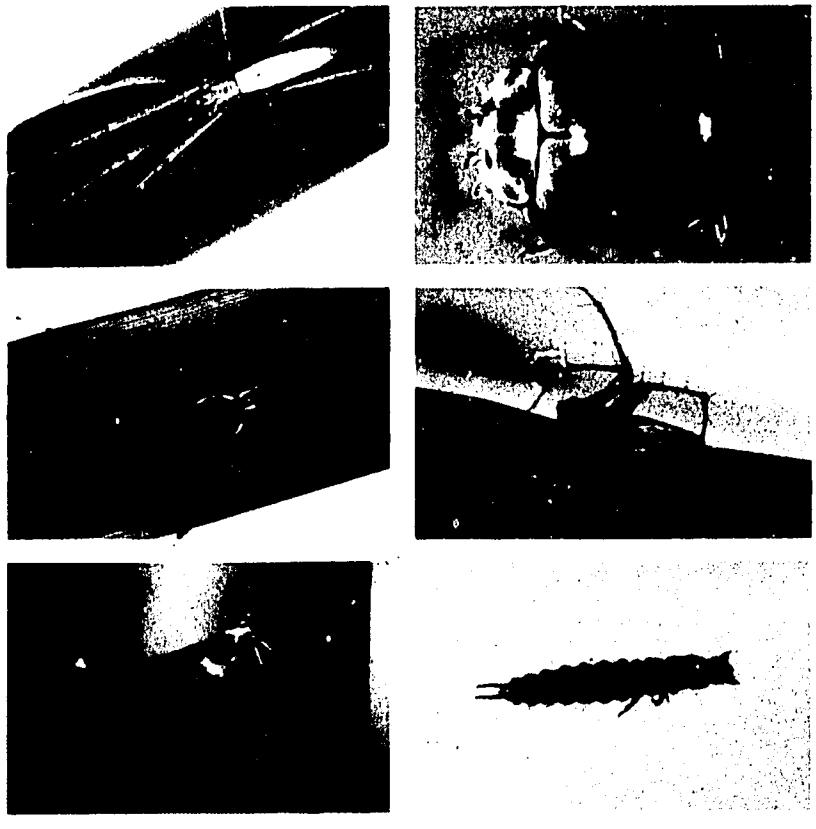
Natural control of whitebacked planthopper and rice leaf folder

Extensive field observations were made on the survival of the rice leaf folder and the whitebacked planthopper. Planthopper egg predation caused by *C. lividipennis* ranged from 20% to 50%.

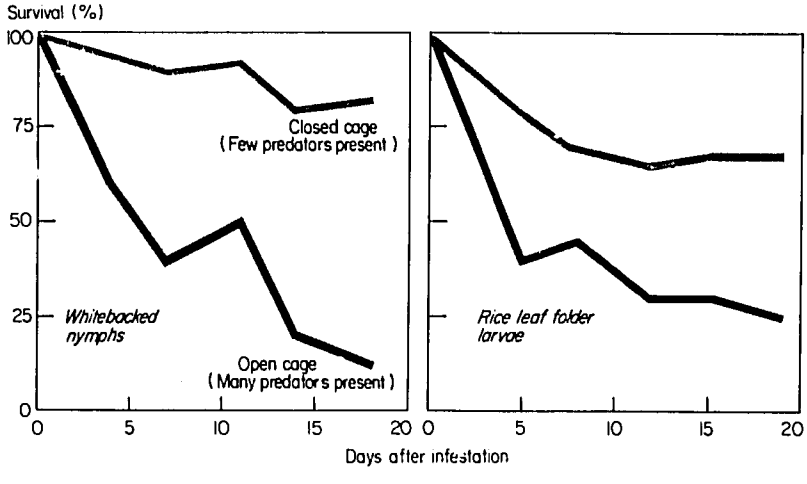


9. On many occasions when rice leaf folder eggs were exposed in dryland rice fields, predation was shown to be high. Most of the eggs disappeared in only 1 day. IRRI, 1980.

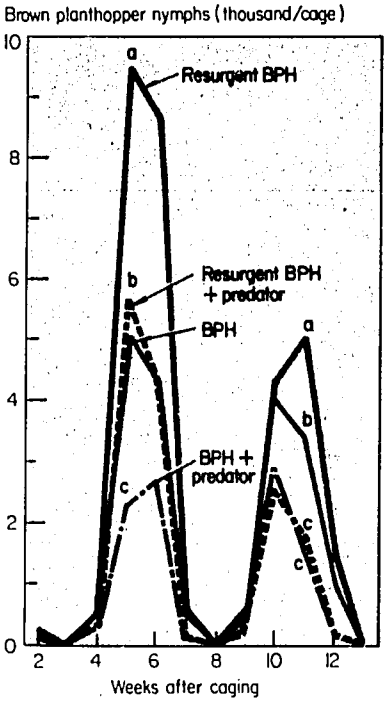
Each bug could kill 5 eggs a day. A high average of 70% of leaf folder eggs were killed (Fig. 9) by predaceous ants, spiders such as *Tetragnatha* sp., and ladybird beetles (Fig. 10). Each predator could kill more than 10 eggs daily. Nymph-larval predation was estimated at 80%, which was a significant discovery (Fig. 11). Important predators of planthopper nymphs were damseflies and spiders, for example, *L. pseudoannulata* and *Oxyopes*



10. Predation is the major mortality factor for whitebacked planthoppers and rice leaf folders. Common predators in the field were spiders — *Tetragnatha* (upper left), *Lycosa* (middle left), and *Oxyopes* (middle right) — ladybird beetles (upper right), damselflies (lower left), and carabid beetles (lower right). These valuable predators must be conserved to maintain the good natural biological control of pests.



11. Predators naturally present in wetland rice fields severely reduced the survival of whitebacked planthopper nymphs and rice leaf folder larvae in these dry season experiments.



12. The predatory bug *Microvelia atrolineata* suppressed the brown planthopper (BPH) population even when this resurged because of the insecticide methyl parathion sprayed on rice plants. Densities at 5 or 11 weeks having a common letter are not significantly different at the 5% level.

javanus. Predators of leaf folder larvae were *L. pseudoannulata*, a ladybird beetle, and a larval carabid beetle *Chalaenius* sp.

When the measured field densities and predation capacities of the predators were multiplied, it was evident that predators could easily cause high pest mortality rates.

Brown planthopper control by small water striders

A predaceous small water strider, *M. atrolineata*, is commonly found on the water surface of IRRI's wetland rice fields. Its capability to reduce a caged brown planthopper population significantly was demonstrated for the first time in 1980. After 5 female planthoppers had laid eggs on plants, 100 *Microvelia* adults were released in a greenhouse cage as the eggs were hatching. When the next-generation nymphs hatched, the predator had substantially suppressed the pest density, and the suppression continued to the third generation (Fig. 12).

Control of planthoppers with fungal pathogens

In collaboration with the Boyce Thompson Institute for Plant Research, Ithaca, N.Y., we initiated a new project on the fungal diseases of planthoppers. It is rather common to find diseased insects in fields infested with hoppers (Fig. 13). Diseased specimens were collected in three tropical countries. The fungi were

13. The warm humid environment of rice fields is conducive to fungal infection. Planthoppers infected by fungal pathogens may stick to the plant. The white or grey colored fungus is seen growing out of dead insects.

Rice leaf folders damage the leaves of plants by chewing on leaf blades. It is easy to control them with insecticides because they ingest the chemical as they feed. Rice leaf folders can be killed with a very selective biological insecticide made from the bacterium Bacillus thuringiensis, commonly known as B. T. Treated larvae stop feeding a few hours after ingesting the chemical, turn black, and soon die.

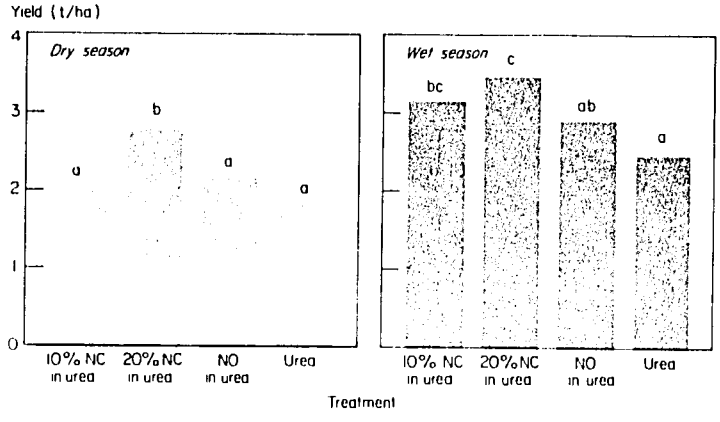
cultured and then bioassayed in the laboratory for pathogenicity against a range of planthopper-leafhopper species.

Preliminary field tests using laboratory-produced fungi suggest that the pathogens could be developed for use in pest control. When imported species or strains of fungi (*Entomophthora virulenta* and *Metarrhizium anisopliae*) were applied with regular sprayers on a rice crop, initially more than 50% of the brown planthoppers in the plots were infected.

Neem cake and urea for brown planthopper management

The seed cake of neem tree *Azadirachta indica* is known as an insect repellent, antifeedant, and nitrification inhibitor. Those properties prompted us to explore its potential for brown planthopper management.

In 1980 field trials, plots treated with a blend, by weight, of 20% neem cake and 80% urea (120 kg N) gave a significantly higher yield than the control plots treated with urea only (Fig. 14).



14. Neem cake (NC) mixed with urea significantly increased rice yields in IRRI plots, 1980. NC was added as a percentage of urea (120 kg N/ha). Neem oil (NO) was mixed with urea at a rate of 133 ml/kg urea; NC was added as a percentage of urea (120 kg N/ha). The control received only 120 kg N/ha as urea

WEEDS

Dry seeding of rice has become common in areas where farmers have taken advantage of modern early maturing rices to shift to a 2-3 crop system. But because the dry-seeded rice must grow as a dryland crop until rains provide enough to flood fields, weed problems increase.

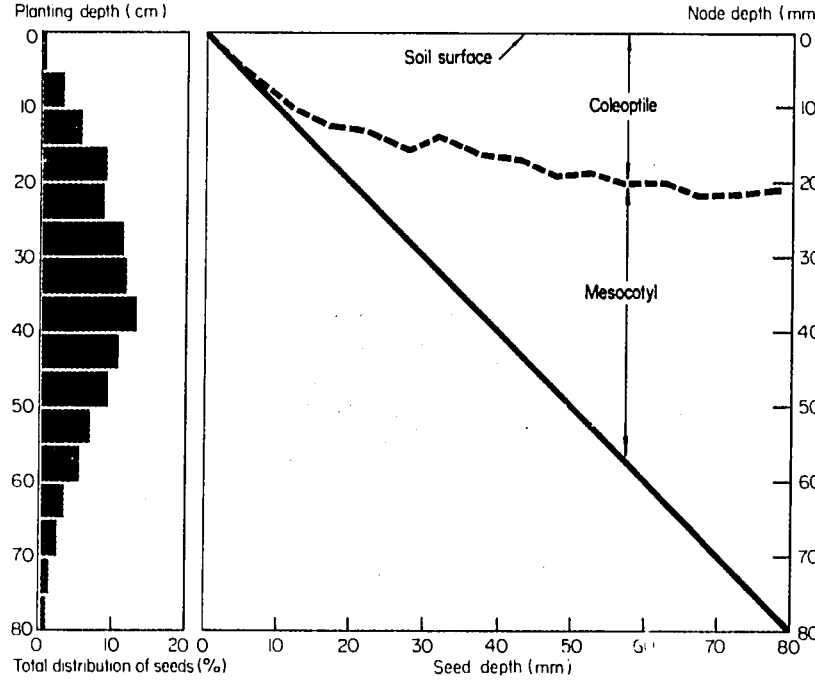
Weed control in dry-seeded paddies

A single application of a preemergence herbicide has generally not controlled weeds in dry-seeded rice. In 1979 and 1980 we tested herbicide combinations. Pendimethalin + oxidiazon applied before seedling emergence gave good weed control. So did propanil + butachlor, thiobencarb, or pendimethalin applied early postemergence. Applications of the preemergence herbicides followed by either propanil or 2,4-D at postemergence also gave promising results.

Cultivar tolerance for herbicides

Farmers who dry seed rice cover the seed at various depths depending on tillage system and implements used. In a study in a farmer's dryland field in Batangas province, we found a high proportion of seed planted between 20 and 50 mm deep. We also found that node depths varied with seeding depth (Fig. 15).

In simultaneous herbicide tests with dryland rice cultivars node depth was related to differences in herbicide tolerance. The



15. In a check of 1,000 seedlings of CV171 120, a dryland rice cultivar in a Batangas farmer's field, seeding depth range was 0 to 80 mm, but coleoptile node depth was never greater than 22 mm

Table 4. The 1979 International Upland Rice Observational Nursery was dry-seeded 4 cm deep and treated with herbicides. Correlation of herbicide injury and node depths showed that butachlor gave less injury than pendimethalin and thiobencarb.

Herbicide	Correlation coefficient[a]
Butachlor	-.60**
Pendimethalin	-.71**
Thiobencarb	-.72**

[a]**Significant at the 1% level.

Research Assistant Eduardo Castin checks dry seeded plots for herbicide damage to rice seedlings in IRRI plots. Nodal depth is an important factor in seedling survival where butachlor is used as a preemergence spray.

tests also showed that nodal depth was more important for pendimethalin and thiobencarb than for butachlor (Table 4). This implies that some seedlings have greater biochemical and physiological tolerance for butachlor than for the two other herbicides. Screening for specific tolerance for butachlor — and herbicides of its type — has potential for finding cultivars that rice farmers can treat with herbicides with less risk of yield reduction.

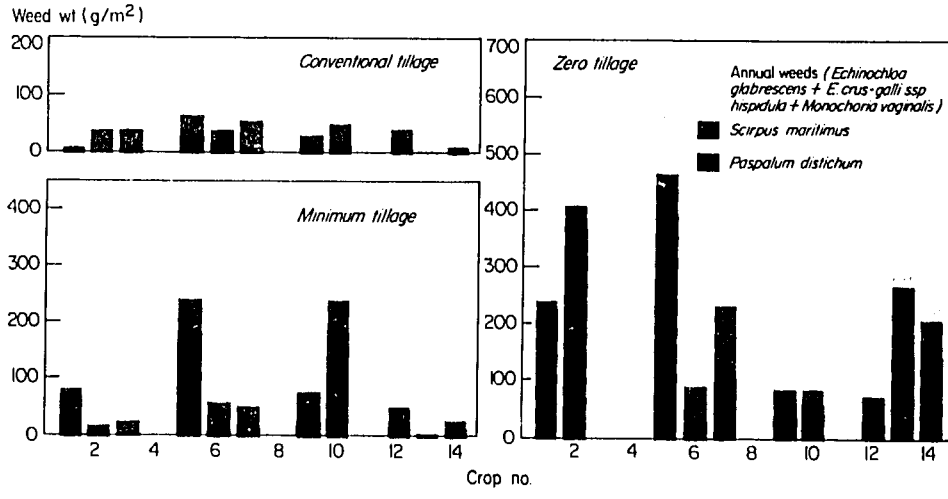
Reduced tillage and weeds

Minimum and zero tillage have potential for replacing conventional tillage. They offer considerable savings in time, labor, capital, and power without any loss in yield, but they may increase weed problems.

We made tests with 14 successive crops of 3 rice varieties to measure the weed shift in wetland rice. Generally, as conventional tillage was reduced to zero tillage, weed populations shifted from annuals to perennials (Fig. 16). We also noted that the perennials tended to increase where minimum and zero cultivation continued for two or more successive crops.

It appears that where *P. distichum* is a problem, minimum and zero tillage may not be feasible for more than two successive crops.

16. In long-term tillage-weed trials at IRRI (14 successive crops), the stand of *P. distichum* was minimal in conventional and in recently recultivated minimum- and zero-tillage plots, suggesting that tillage is a practical way to control that weed. *S. maritimus*, on the other hand, generally appeared to increase or decrease with *P. distichum* density rather than to be directly affected by tillage level.



IRRIGATION WATER MANAGEMENT

Small communal gravity irrigation systems, such as this one in Calatagan, Batangas, Philippines, have low capital investment and low operation and maintenance costs per hectare.

Policy makers are often faced with questions about the appropriate mix of irrigation investments. Should limited funds be used to build, to rehabilitate, or to improve irrigation facilities?

We studied 12 Philippine irrigation projects of different types and sizes to develop procedures for calculation of investment cost. With the data, we made comparisons among irrigation investments and costs of operation, and maintenance for different types of irrigation systems.

In the case of systems built at different points in time, a deflator for irrigation construction cost was developed and used to eliminate the effects of inflation. The study showed that investment cost for gravity systems varied from as low as US$118/ha to as high as US$683/ha, depending on the type and size of structures, service area, and other physical attributes. The capital investment cost was generally higher among pump systems with deep well pumps; surface pumps were intermediate (Table 1).

National and communal gravity systems had the lowest annualized cost per hectare.

Table 1. Costs for various irrigation systems in Central Luzon, Philippines, at 1978 prices. Data on costs were obtained from the National Irrigation Administration, whenever possible. Where cost records either were not available or lacked details, a complete inventory of the structure was undertaken. The replacement cost for each structure was then calculated by applying the 1979 prices to the material and labor components.

	Service area (ha)	Capital investment cost ($/ha)	Operation and maintenance cost ($/ha)	Annualized total cost[a] (US$) at interest rate of	
				6%	18%
Gravity systems					
National system					
San Fabian River Irrigation System	2698	451	21	52	103
Communal system					
Prenza	551	683	8	51	131
Salapungan	378	387	5	29	74
Caingin	30	118	45	53	66
Sibul	16	156	3	12	31
Pump systems					
Surface pumps					
BPIP	297	543	85	133	188
Safari	121	229	42	62	85
Halina	22	393	135	174	211
Small pump	2.7	562	43	127	180
Deep well pumps					
GP-3	55	1836	96	236	431
GP-4	56	1255	94	192	324
GP-19	46	1564	122	249	412

[a]Computation based on 60 years life span for dams, 30 years for canals, and 15 years for pumps and engines. US$1 = ₱7.38.

Irrigation system management research

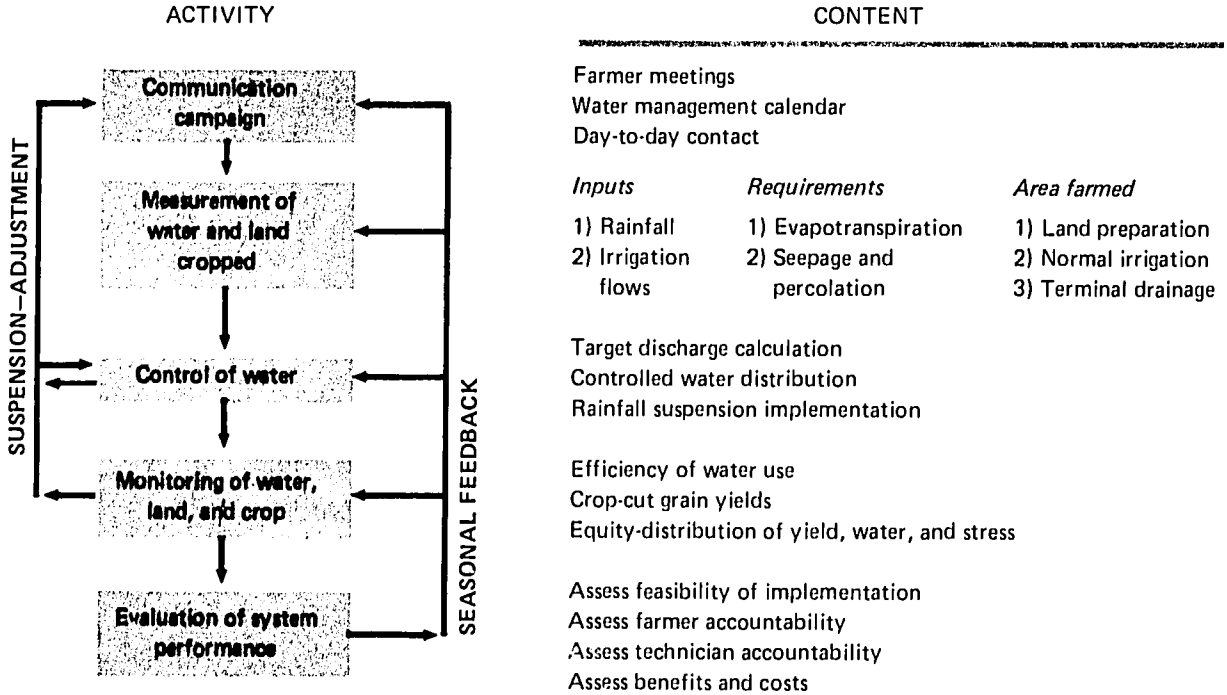
We continue to place major emphasis on irrigation systems, particularly on gaining a better understanding of their operational efficiency and organization problems. We tested new management techniques, and continued monitoring large-scale national systems to determine the extent to which the previously developed improved management techniques continued to be implemented by irrigation personnel.

Large-scale reservoir-supplied irrigation system management

Our efforts in developing irrigation management techniques for large-scale, reservoir-supplied irrigation systems continued in cooperation with the Philippine National Irrigation Authority (NIA). The major focus was in the refinement of management techniques that could be implemented by technicians assigned to each 500-ha block in the Upper Pampanga River Integrated Irrigation System (UPRIIS). We refined the techniques into a methodology that will be applied successively to 13,500- and 24,000-ha blocks of the UPRIIS (Fig. 1).

Our original work in the Lower Talavera River Irrigation System (LTRIS) component of UPRIIS continued as a major research and training area. Our annual irrigation water management training course used the system for actual management

1. Methodology for implementation by management of reservoir supported gravity irrigation system.



experience to gain an understanding of intensive system measurement, control, and monitoring. The major finding was that a considerable portion of the technique remained in day-to-day practice and became part of new management behavior. The items adopted were primarily those concerned with the calculation of target deliveries and water allocation to achieve the targets.

Of particular interest is the analysis of the yields in the formerly disadvantaged tail end of LTRIS. The management of water to avoid maldistribution resulted in tail-end farmers moving consistently into the forefront of the cropping schedule, achieving a cropping intensity exceeding 200%, and getting annual (wet + dry season) rice yields exceeding 8 t/ha in 1980.

IRRI research on irrigation system management implementation in Central Luzon has led to two specific types of management intervention methodologies for more equitable water distribution throughout the systems:

- Diversion type or run-of-the-river systems require management based on scheduled water checking along the system, accompanied by rotation of water deliveries, preferably from the tail end of the system first.
- Systems that are supported by a storage reservoir require more detailed allocation procedures including:
  1. measurement of the water inputs and requirements, and the areas in various rice-farming activities;
  2. control and allocation of water, with irrigation suspension when rainfall is abundant; and
  3. monitoring the water, land, and crop with regard to three performance parameters — equity, efficiency, and productivity.

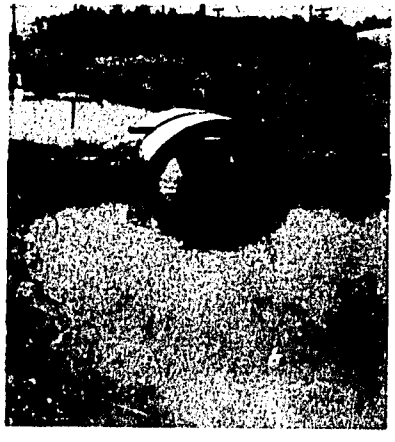
Farmer participation in irrigation design

In addition to intervening with management, we tried a technique of farmer involvement in design, layout, and construction of their own terminal irrigation facilities in two communal irrigation systems in Bicol. The *custom-fit design technique* replaced the traditional contour map with a farmer-prepared paddy map with elevations added by the survey team, and used a backward calculation from field to source to verify water availability to the individual farmer.

With simple charts to guide the calculations, the farmers and design engineer worked together in the field to determine the extent of the irrigated service area, the direction of water flow, the feasible layout of farm ditches, and the location of tertiary turnouts. The method had good response from farmers — who normally used the trial and error method of selecting turnout

Filipino farmers and engineers from IRRI and the National Irrigation Authority worked together in the field to put new communal irrigation systems into operation.

In the custom-fit design technique tried in 1980, farmers got a chance to see and discuss low-cost flow structures before they were put in the irrigation ditches.



Low-cost measuring instruments designed in 1978 supported the irrigation management methods developed in 1979-80. This vane in a reinforced concrete pipe has a flow-measuring capacity of 270 liters/second and can be made for only $60. If a culvert is already in place, the vane costs only $30 to install.

sites and ditch layout. The design engineers found the method useful in preliminary layout of laterals and main canal and the more precise delineation of the expected service area.

Water requirements and use in deep tube well systems

Deep tube wells are generally the most expensive kind of irrigation to develop, yet they are important in India and Bangladesh where suitable aquifers exist. In the Philippines, use of deep tube wells for irrigation has steadily increased in Central Luzon.

During 1980 we studied the water requirements and water use patterns of two deep tube well irrigation systems in the Philippines. Particular focus was on rainfall use in the wet season and efficiency of use of pumped water.

Table 2. Water requirement for land soaking until the end of transplanting and total water used during land preparation in the San Manuel Groundwater Pilot Project, Philippines, 1979 wet season.

Tube well system	Service area (ha)	Land soaking requirement (mm) for top 30 cm soil	Water (mm) supplied for land preparation	Duration of land preparation (days)
T-2	61	91	630	56
T-6	52	102	747	54
Av		96	688	55

- As in other types of systems, major water losses occurred during land preparation. Only 14% of total water supplied by rainfall and pump was used for land soaking (Table 2). Although the individual farmer did not take more than 28 days to complete transplanting his farm once land soaking started, about 55 days elapsed between the first supply of water and completion of transplanting in the system area. Faster land preparation would save the water lost by percolation and seepage, evaporation, and surface runoff.
- Effective use of rainfall is a key to maintaining high efficiency in management of pump systems. We used two methods to estimate effective rainfall use in the 1980 wet season. One, the freeboard model, was based on daily water requirements for evapotranspiration and seepage and percolation, and

A flow measuring device is checked on a farm in Central Luzon, Philippines. The water is from a deep tube well system, which was part of the 1980 research on water requirements and use efficiency.

field measurements of water level and spillway height to determine the capacity of the sample paddies to store further water. The other method used the ratio of water requirements to rainfall amounts for consecutive blocks of time — the length of which depends on the textural classification of the soil — to determine the proportion of rainfall to be considered effective. The advantage of this demand-supply ratio method is its simplicity for use. It does not consider farmer's spillway management and the stored water in the field, which vary and influence the effectivity of rainfall.

The freeboard model gave an effective rainfall of 87% for the period 2 July to 30 August; the demand-supply ratio method gave 86% effective rainfall for the same period. A high proportion of rainfall was effective during July-August because rainfall was low, and its distribution uniform. We will compare the methods in different rainfall patterns to assess the practical usefulness of the simpler technique.

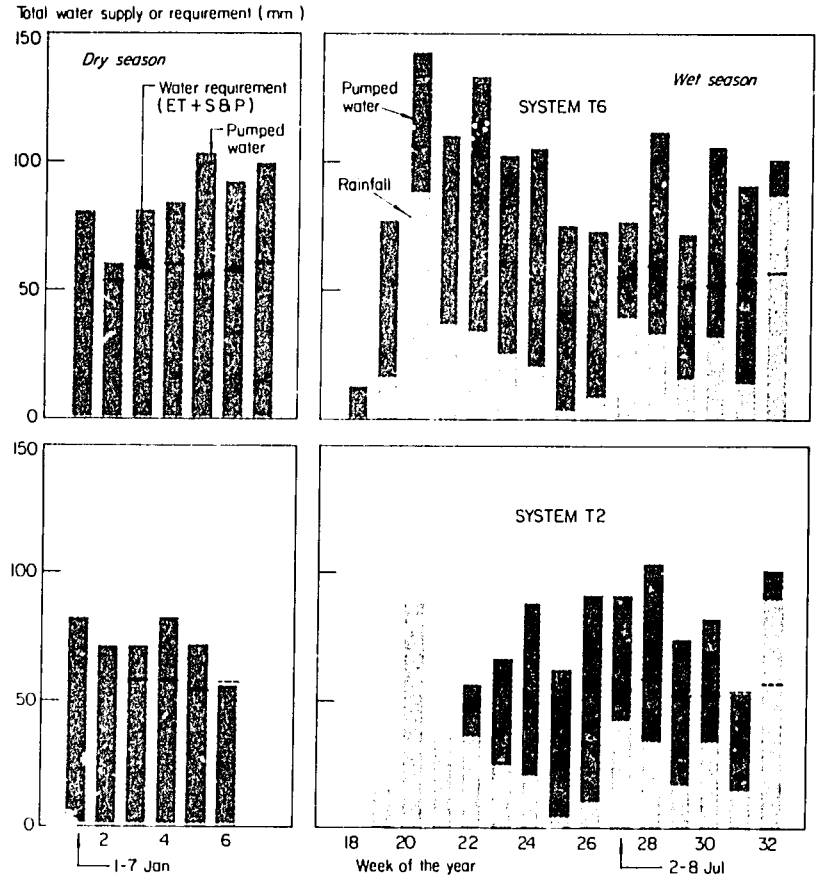
- Irrigation efficiency (IE) — the efficiency with which irrigation water (I_r) was supplied in response to its demand — was calculated for the two pump systems using the formula:

$$IE = \frac{E_t + S\&P - R_e}{I_r}$$

where E_t and $S\&P$ are the requirements for evapotranspiration and seepage and percolation, and R_e is the effective rainfall. Table 3 shows the weekly IE values estimated for two consecutive seasons. Figure 2 shows the weekly total water requirements for E_t plus $S\&P$, rainfall, and pumped water for the two systems.

Table 3. Irigation efficiency values for the two tube well systems of the San Manuel Groundwater Pilot Project, Philippines, 1979.

Period	Irrigation efficiency (%)		
	Tube well system T_2	Tube well system T_6	Both systems
Dry season			
Week no. 2	72.8	90.6	
3	81.2	72.4	
4	71.2	72.3	
5	75.7	54.1	
6	100.0	62.4	
7	–	61.3	
Av	80.2	68.8	74.9
Wet season			
Week no. 27 (2-8 July)	–	65.4	
28	47.9	42.1	
29	61.9	65.4	
30	38.6	26.4	
31	98.2	51.4	
32	0.0	0.0	
Av	49.3	41.8	45.5



2. Weekly total water requirement, rainfall and pumped water supplies for two tube well systems in San Manuel Groundwater Pilot Project, Philippines, 1979. In both systems, irrigation efficiency in the wet season was lower than in the dry because the supply of pumped water exceeded the actual requirement by a greater margin than in the dry season. It is evident that more restrained use of the pump in system T_2 enabled it to achieve a higher irrigation efficiency in both seasons. ET = evapotranspiration, S&P = seepage and percolation.

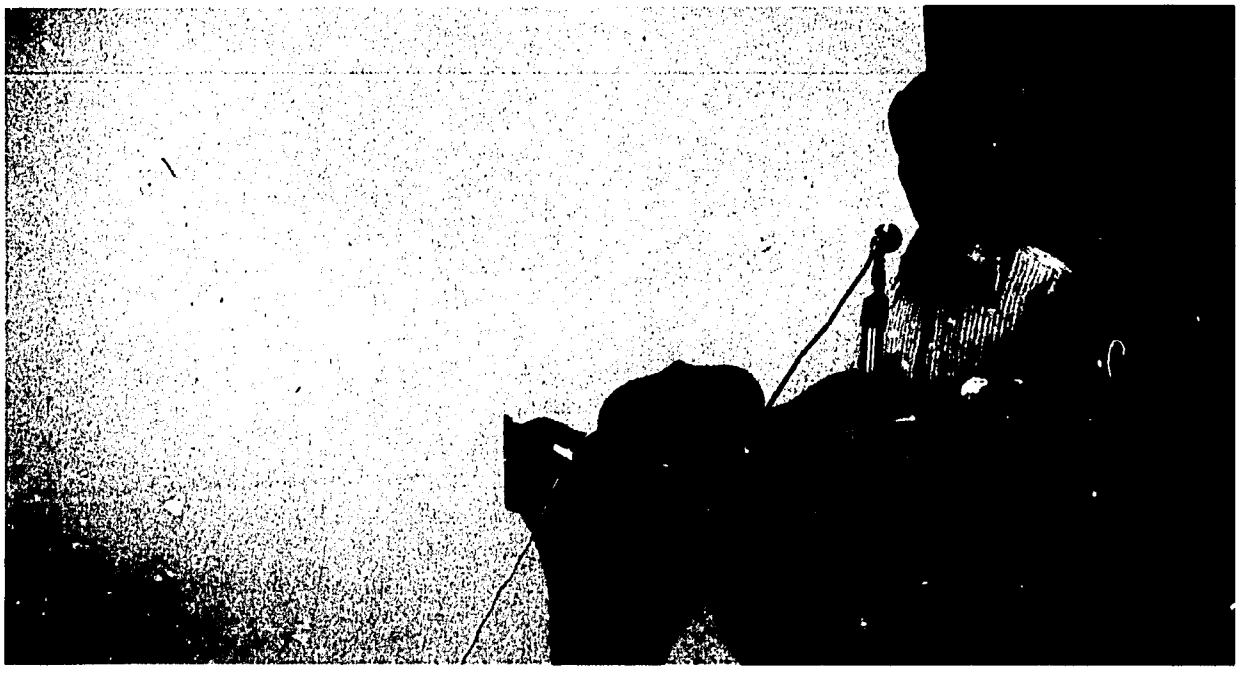
Problem identification in Northeast Thailand

We concluded a joint field study on irrigation water management with the Royal Irrigation Department in Thailand. One component of the research was the analysis of 16 factors influencing the degree of farmer participation in water-user association activities and system maintenance in small-scale gravity irrigation systems.

All factors were positively correlated with farmers' increased participation in irrigation association activities and maintenance. Two sets of factors showed the highest correlation with participation in association activities:

- those related directly to the effectiveness of the association in educating its membership and the extension of water management information by government agencies; and
- those related to contacts with irrigation agency personnel.

Both sets have important policy implications for irrigation and extension agency programs — contacts with farmers provide them with up-to-date irrigation recommendations and influence their participation in small-scale irrigation.



Extension Agronomist Wiraphol Chachalwalwong, Agricultural Extension Department, Thailand, lectures at a workshop on Irrigation Water Management Research. The workshop brought together the field workers at the end of a joint Thai-IRRI study. Wiraphal was an IRRI scholar in 1978-79.

For participation in system maintenance, an additional significant factor was dissemination of information through the mass media.

Cooperation among members of the association was significantly related to 7 factors (Table 4) and conflict over water was significantly related to 11 factors.

At the end of the joint study, we sponsored a workshop on Irrigation Water Management Research in Khon Kaen, Northeast Thailand.

Table 4. Field studies of irrigation water management in Thailand indicated a wide range of factors that affect farmer conflicts over water supply and use.

Factor	Relationship[a]	
	Cooperation among members	Conflict over water
Size of household membership		*
Rice production income		**
Gross family income		**
Training exposure		**
Perceived benefits from channel maintenance	**	
Knowledge of recommended irigation practices		*
Agreement with a proposed set of rules and regulation for water management		*
Degree of adoption of recommended farm practices		**
Rating of irrigation service	**	*
Degree of satisfaction with association officer performance	**(-)	* (-)
Degree of satisfaction with work of irrigation agent	*	
Frequency of farmers' approach to irrigation agent	**	
Frequency of irrigation agent approach to farmers	*	**
Discussion with irrigation agent		**
Exposure to communications media	*	

[a]Significant at 1% (**), at 5% (*).

SOIL AND CROP MANAGEMENT

Conserving and increasing the natural supply of the major soil nutrients for rice, and increasing the efficiency of fertilizers by improved land and water management are essential to farmers seeking the highest payoff from planting modern varieties. Our research emphasis remains on increasing the efficiency of applied nutrients and on determining the role of soil microorganisms in providing additional nitrogen for the rice plant.

INCREASING FERTILIZER NITROGEN EFFICIENCY

Many rice farmers fail to derive the full benefits from the fertilizer they use because they apply it inefficiently. In collaboration with the International Fertilizer Development Center (IFDC), new fertilizer materials, developed at IFDC and by commercial organizations, were tested with various cultural practices.

Nitrogen fertilizer trials for deepwater rice are checked in IRRI's special deepwater research tonks by E. V. Laureles, Agronomy Department research assistant.

Modified urea fertilizers

Most of the nitrogen used on rice in Asia is, and will continue to be, in the form of urea. Efficiency of its use in wetland rice is, however, low. Two concepts can lead to increased fertilizer nitrogen efficiency in wetland rice:

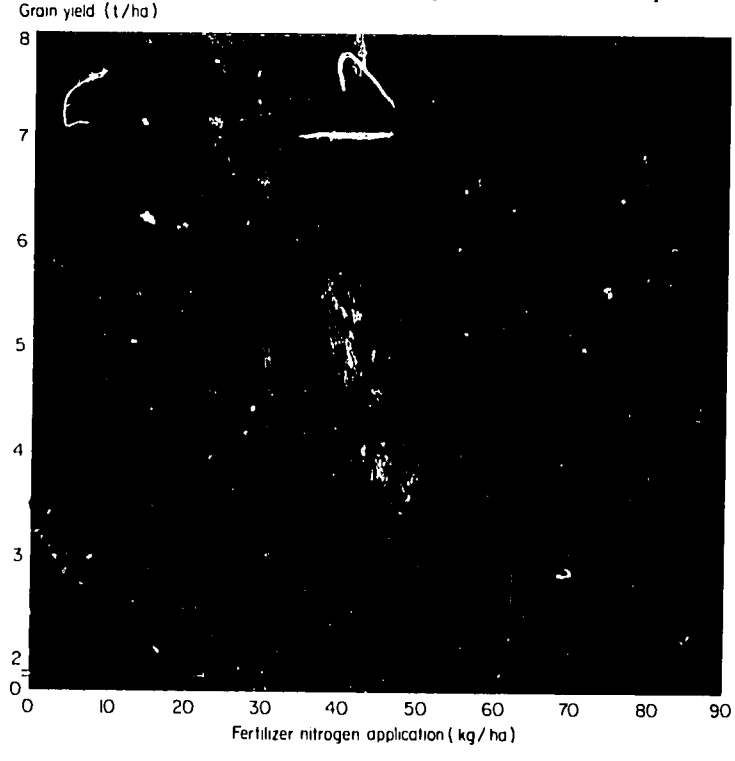
- use of controlled-release nitrogen fertilizers, and
- deep placement of nitrogen fertilizer.

IFDC recently developed a silica-polymer-coated urea for controlled release of nitrogen for wetland rice. We tested both sulfur-coated urea and silica-polymer-coated urea at IRRI during the 1980 crop season.

When grain yields for the dry season were averaged for three rates of nitrogen application, the controlled-release materials and deep-placed urea did not significantly differ (Fig. 1). Both types gave significantly higher grain yields than the so-called best-split application — one-half broadcast and incorporated before transplanting and one-half broadcast at panicle initiation. During the wet season, yields from controlled-release and deep-placed urea were not significantly different from those from the split application.

Depth of fertilizer placement

We know that deep placement of nitrogen fertilizer improves its efficiency in wetland rice. A question often raised, however, is how deep the fertilizer should be placed. In 1980 experiments we



1. Yield response to different modified urea fertilizers, IRRI, 1980 dry season (De Datta et al 1980, unpubl.).

Table 1. Effect of depth of placement of supergranule on the yield of IR50 and IR48. IRRI, 1980 dry and wet seasons.

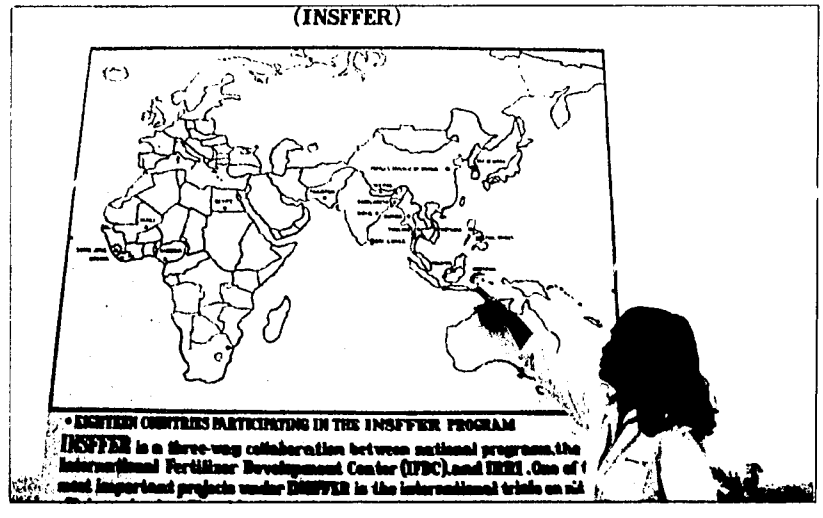
Treatment	Depth of placement (cm)	Yield[a] (t/ha)					
		Dry season[b]			Wet season[b]		
		IR50	IR48	Mean	IR50	IR48	Mean
No fertilizer nitrogen		4.4	4.5	4.5 c	4.0	4.1	4.0 c
Urea supergranule	10	7.7	7.8	7.8 a	5.6	5.2	5.4 a
Ammonium sulfate supergranule	5	8.0	7.5	7.8 a	5.6	5.1	5.4 a
Ammonium sulfate supergranule	7.5	7.7	7.6	7.7 a	5.6	5.2	5.4 a
Ammonium sulfate supergranule	10	8.1	7.8	7.9 a	5.6	5.2	5.4 a
Ammonium sulfate supergranule	15	8.0	7.8	7.9 a	5.7	5.3	5.5 a
Split application of ammonium sulfate[c]	—	7.3	7.2	7.2 b	5.1	4.9	5.0 b

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]Nitrogen levels were 100 kg/ha in the dry season and 50 kg/ha in the wet. [c]Two-thirds basal plus one-third 5-7 days before panicle initiation.

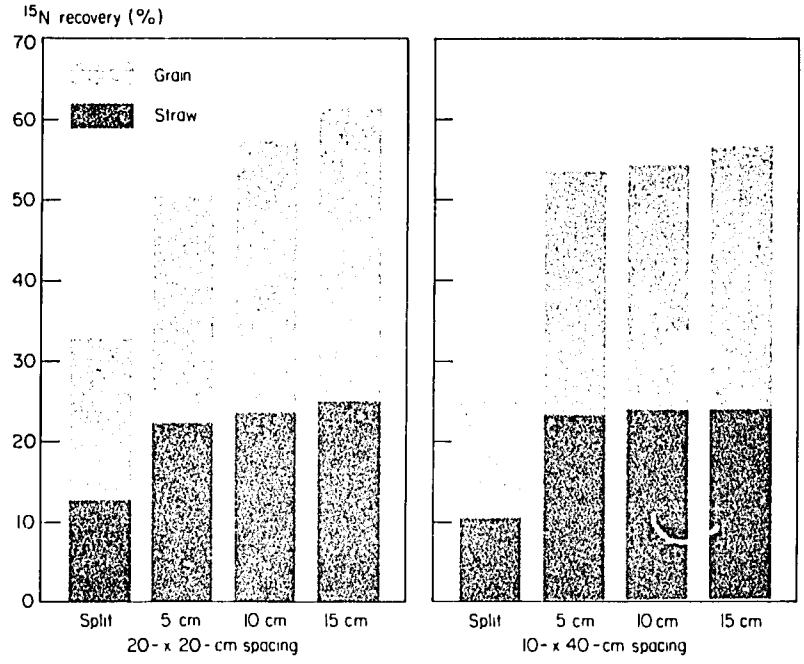
monitored the movement and distribution of ammonium-N from supergranules placed at depths of 5, 7.5, 10, and 15 cm.

In both crop seasons there were no significant differences in grain yields with nitrogen placed 5 and 15 cm deep (Table 1). However, grain yields were significantly higher with deep placement of nitrogen as ammonium sulfate and urea than with split application of ammonium sulfate. The lower yields with split application than with deep-placed urea were due to higher losses of nitrogen from the floodwater. The floodwater with the split-applied nitrogen had 78-98 μg N/ml; that with deep-placed nitrogen had a negligible concentration.

These results suggest that nitrogen placement at a 5-cm soil depth is adequate for high rice yields in a clayey soil with good water control. However, in farmers' fields where soil and water conditions are often less than ideal, it is better to place nitrogen fertilizers at greater depths and minimize ammonium in flood-



Activities in the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) are explained to IRRI visitors by Wilma Obcemea, Agronomy Department research assistant. IRRI, International Fertilizer Development Center, and 18 countries collaborated in the network during 1980.



2. Fertilizer nitrogen recovery by wetland rice (IR42) as influenced by placement depth of urea supergranules and transplanting geometry. IRRI, 1979 dry season.

water. Nitrogen uptake by grain was higher with deep-placed (10 cm and deeper) urea than with urea placed at 5-cm depth (Fig. 2).

We grew IR36 and IR42 as rainfed crops during the 1980 wet season to evaluate broadcast and incorporated sulfur-coated urea (SCU), supergranule urea placed in the soil, and broadcast and incorporated prilled urea. Highest grain yields in both varieties were about 5.5 t/ha despite some plant moisture stress during the tillering stage (Table 2). With IR36, all the treatments with fertilizer nitrogen performed similarly and yields were significantly higher than those of the unfertilized control. With IR42, SCU and urea supergranules yielded significantly higher than prilled urea, basal and incorporated.

Nitrification in the paddy

A 1980 experiment presented the first data on the rate of nitrification in a paddy. We developed a ^{15}N-nitrate dilution technique to measure field nitrification. Nitrate formation from unlabeled

Table 2. Yield of IR36 and IR42 as rainfed crops at IRRI in the 1980 wet season.

Forms of urea[a]	Yield[b] (t/ha)			
	IR36		IR42	
	29 kg N/ha	58 kg N/ha	29 kg N/ha	58 kg N/ha
Prilled	5.4 a	5.4 a	4.5 d	5.0 bc
Sulfur-coated	5.5 a	5.6 a	4.9 c	5.4 a
Supergranule	5.4 a	5.6 a	4.9 c	5.4 a
Unfertilized control	3.8 b		4.4 d	

[a]Prilled and sulfur-coated urea were broadcast and incorporated, and supergranule was deep placed. [b]In a column, means followed by a common letter are not significantly different at the 5% level.

A field worker places supergranules at different depths in a puddled soil at IRRI. Placement of the granules 5 cm or deeper in the soil greatly reduced nitrogen losses.

ammonia was measured by comparing it to the dilution of ^{15}N-labeled nitrate added to the soil surface of undisturbed cores. A significant but low rate of nitrification was found to occur on the paddy soil surface.

The changes in nitrification rate were monitored after surface application of urea to the paddy. A peak occurred 12 days after urea application.

Nitrogen loss studies

Early and rapid loss of tagged (^{15}N) nitrogen in 1980 trials indicated that ammonia volatilization is an important loss mechanism where nitrogen is applied to floodwater, a common farmer practice.

Nitrogen loss in the field through nitrification and denitrification was determined by comparing the loss of nitrogen from microplots amended with ^{15}N with and without nitrapyrin, a nitrification inhibitor.

Substantial nitrogen loss followed topdressing of urea and ammonium sulfate to the floodwater (Table 3). Nitrapyrin had no effect on the recovery of ^{15}N, indicating that nitrification-denitrification was not accounting for the loss.

Table 3. Nitrogen losses by nitrification were not evident when labeled ^{15}N and nitrapyrin, a nitrification inhibitor, were used to measure recovery of nitrogen added as ammonium sulfate and urea (100 kg N/ha).

Weeks after flooding	Nitrogen recovery (%) from			
	Ammonium sulfate	Ammonium sulfate + nitrapyrin	Urea	Urea + nitrapyrin
1	39.4	42.8	62.4	62.8
2	36.0	35.0	—	—
4	38.1	35.0	44.3	47.3

Table 4. Form and method of nitrogen fertilizer application influence yield of brown rice protein. Slow-release fertilizers significantly increased the brown rice protein of an early-maturing line, IR9729-67-3.[a]

Treatment	Brown rice protein (%)	Grain yield (t/ha)
No fertilizer nitrogen	8.4 c	4.6 b
	108 kg N/ha	
Urea, split application[b]	9.5 b	6.9 a
SCU,[c] broadcast and incorporated	10.6 a	7.0 a
Urea supergranule, placed 10-12 cm deep	10.5 ab	7.1 a
	150 kg N/ha	
Urea split application	9.8 ab	7.3 a

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]Two-thirds basal and incorporated plus one-third topdressed at 5-7 days before panicle initiation. [c]Ordinary sulfur coated urea.

Increasing protein with basal nitrogen fertilizers

Research has shown that nitrogen application, particularly in split doses, can increase rice protein content by at least one percentage point over rice getting no fertilizer. A 1980 test at IRRI confirmed that, but suggested that use of a slow-release nitrogen fertilizer, such as sulfur-coated urea, could increase protein more.

A basal application of sulfur-coated urea during final harrowing and placement of urea supergranules 10-12 cm deep significantly increased protein content in IR9729-67-3 rice at a high yield level (Table 4).

BIOLOGICAL NITROGEN FIXATION

Collection of azolla from all parts of the world continued in the search for strains adapted to different environments and with the capacity to provide high rates of nitrogen fixation in those environments. More than 30 strains of *A. pinnata*, *A. mexicana*, *A. filiculoides*, and *A. caroliniana* were collected from Asia, Africa, Europe, and America.

Azolla growth and temperature

The azolla strains in the IRRI collections were tested for growth at 3 temperature ranges — 33°C average (37°C day/29°C night), 29°C average (33°/25°), and 22°C average (26°/18°). For most strains, growth was maximum at 22°C. At 33°C, the highest maximum biomass was one-third of that at 22°C, indicating azolla's poor tolerance for high temperature. Some strains of *A. pinnata* grew reasonably well at 33° C. *A. caroliniana* produced the most biomass nitrogen — nitrogen taken from the atmosphere by blue-green algae in the fern — at 29° C. It produced 14 g N/m^2 in 41 days.

Research Assistant Nilda Berja, Soil Microbiology Department, removes azolla from laboratory dishes for weighing. Growth of azolla was tested at three temperatures in the IRRI phytotron.

We found that phosphorus deficiency stimulated sporulation at low temperature (25°C), but iron deficiency and the addition of ammonium salt inhibited sporulation. Sporulation was often observed in the crowded azolla populations, indicating a factor or factors stimulating sporulation in the plant itself.

Nitrogen-fixing bacteria associated with rice root

We continued to study nitrogen-fixing bacteria that live on the roots of rice. The percentage of aerobic nitrogen-fixing bacteria among heterotrophic bacteria isolated from rice roots was much higher in wetland soils than in dryland soils. Among three nitrogen-fixing bacteria — *Pseudomonas*, *Klebsiella*, and *Azospirillum* — *Azospirillum* was most active when inoculated onto sterile rice roots.

Role of subsoil in the nutrition of rice

In IRRI plots receiving no nitrogen fertilizer, rice yields of 4-5 t/ha have been obtained for many years. Biological nitrogen fixation may contribute to nitrogen gain in every crop, but because soil organic matter is distributed to considerable depth in IRRI fields, a contribution of nitrogen from beneath the plow layer was suspected.

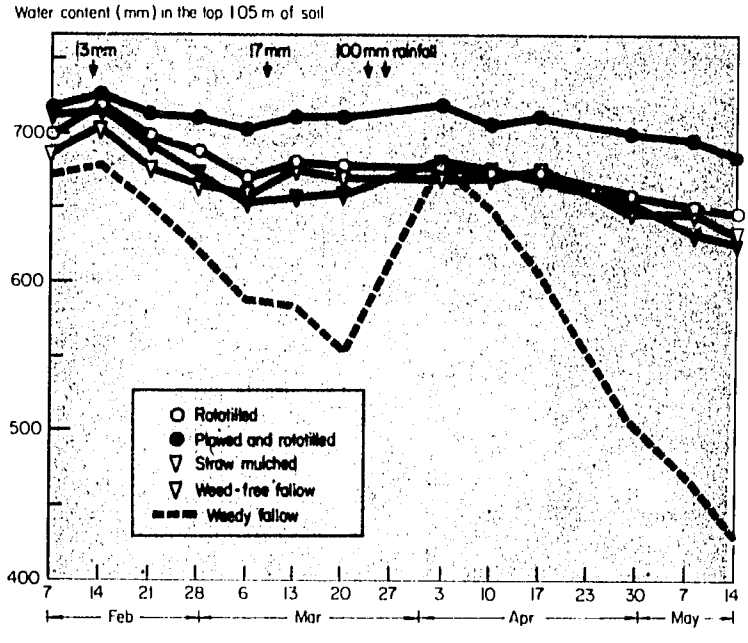
Of total nitrogen in the IRRI soil (0-70 cm), 54% is between the 20-cm and 70-cm depths. Biologically active soil is distributed to 55-cm depth. A plastic film was placed at 20-cm depth to cut nutrient supply from beneath the plow layer and rice growth was compared with that in plots without a film. Rice plants absorbed 40 kg N/ha from 0-20 cm and 40 kg N/ha from below 20 cm. Yields where the plastic film prevented root growth and access to water and nutrients below 20 cm were 2.7 t/ha. Where no plastic was used yields were 4.3 t/ha.

CROP CULTURE

Early establishment of dry-seeded rice depends largely on soil moisture availability and the seedbed's condition. Better control of weeds during the dry season can conserve soil moisture as well as provide a weed-free seedbed.

Soil water conservation during dry-season fallow

During the 1980 dry season, we compared the soil-moisture conservation effect of a soil mulch (Maahas clay), a fallow field kept weed free by herbicide use (with and without rice straw mulch), and the conventional practice of weedy fallow. Weed control by tillage (soil mulch), or herbicide spray alone or in combination with straw mulch all conserved significant amounts of soil moisture (Fig. 3). Soil drying reached to only the 15-cm



3. Four land management treatments in 1980 dry season trials on a clay soil at IRRI conserved significant amounts of soil moisture.

depth in tilled treatments, to 30-cm depth in straw-mulched plots, to 45-cm depth in herbicide-treated bare fallow plots, and throughout the 105-cm depth in the conventional weedy fallow plots.

Our results indicated that a rainfall of 20-50 mm would provide enough moisture in the seedbed of weed-free treatments to allow germination and establishment of the first crop of dry-seeded rice. In weedy fallow plots, however, extensive weed growth and severe soil drying and cracking inhibited dry-seeded rice establishment.

Moisture conservation during the dry season fallow also has implications for rainfed wet-seeded or transplanted rice cultures. Significantly less rain will be required for initial land soaking and seedbed preparation if soil moisture is conserved during the dry season.

Minimum tillage for dry-seeded rice

At the onset of the wet season rice was dry-seeded in plots kept weed free during the previous dry season. Tillage before seeding was either minimum (one rototilling) or no tillage.

Tillage for seedbed preparation showed no advantage in grain yield or weed control where the soil had been tilled during the preceding dry season (Table 5). A significant yield increase was obtained, however, by minimum tillage when the soil was not tilled during the dry season and weeds were controlled by herbicide.

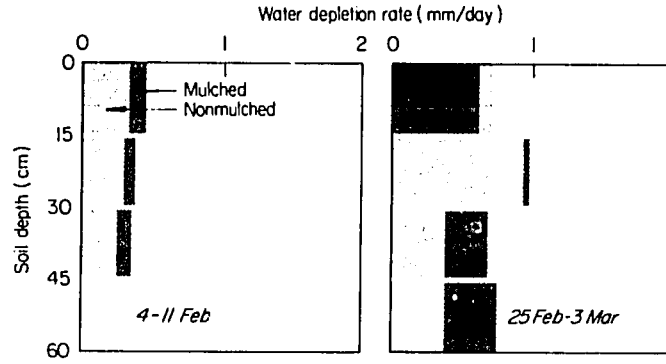
Mulching and soil water extraction

Water availability is often a critical factor for profitable yields from upland crops grown in rainfed environments. With maize planted in a clay soil at IRRI, we found that a rice straw mulch

Table 5. A dry-season fallow with herbicides for weed control, followed by minimum tillage for a seedbed, produced highest wet-season grain yields in a 1980 land management study at IRRI.[a]

Dry-season management treatment for fallow land	Grain yield (t/ha)		Weed wt (t/ha) at first weeding	
	Minimum	No-till	Minimum	No-till
Dry season, untilled				
Herbicide weed control	6.40 a	5.51 a	1.64 a	1.51 a
Herbicide weed control + rice straw mulch	6.07 a	5.52 a	1.36 a	1.36 a
Dry season, tilled				
3 rototillings in January + 1 rototilling in April	5.98 a	5.88 a	1.63 a	1.95 a
1 plowing + 2 rototillings in January + 1 rototilling in April	5.50 a	5.64 a	1.74 a	1.42 a
$LSD_{.05}$ (minimum vs no-till)[b]	0.68*		ns	

[a]In a column, means followed by a common letter are not significantly different at the 5% level. Minimum = one rototilling before seeding, no-till = no seedbed preparation. [b]*means significant at the 5% level, ns = not significant.



4. Mulch increased soil water removed by plant roots as seen during 2 rainless periods in maize plots. The data are averaged from 5 tillage treatments at IRRI, 1980.

increased the ability of maize roots to extract soil water (Fig. 4). Greater soil water extraction resulted in significantly higher maize yields.

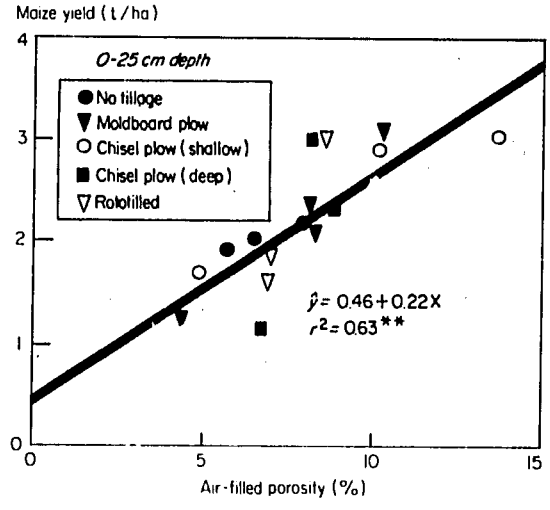
Soil aeration in a previously puddled soil

Puddling of soil for wetland rice leaves a poor physical environment for dryland crops that follow rice. Soil aeration and root development are adversely affected, especially where soils are relatively wet.

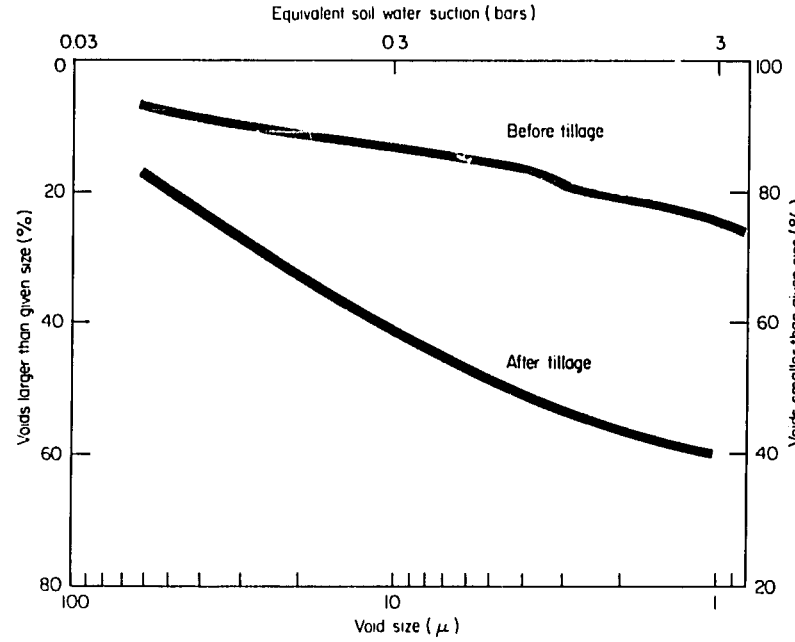
At IRRI we found a linear relationship between air-filled porosity and maize yield on a clay soil that had been puddled for the preceding rice crop (Fig. 5).

Techniques to evaluate tillage properties of soils

In most of South and Southeast Asia, farmers grow dryland crops in rotation with wetland rice. Characterization of the tillage properties of rice soils is needed for identifying soils suitable for such wetland-dryland cropping patterns, but no appropriate techniques for the characterization have been established.



5. A linear relationship between soil air-filled porosity and maize yields was found when a range of air-filled porosity was obtained by different degrees of primary and secondary tillage of a clay soil puddled for wetland rice the previous season. IRRI, 1980.



6. A technique to determine void size distribution in a puddled clay soil before and after simulated tillage was tested in 1980.

In 1980, we tested a technique to determine change in pore size distribution in a puddled soil before and after simulated tillage (Fig. 6). Preliminary indications are that the shift in pore size distribution and its structural stability to water may provide an index that can be used to characterize tillage properties.

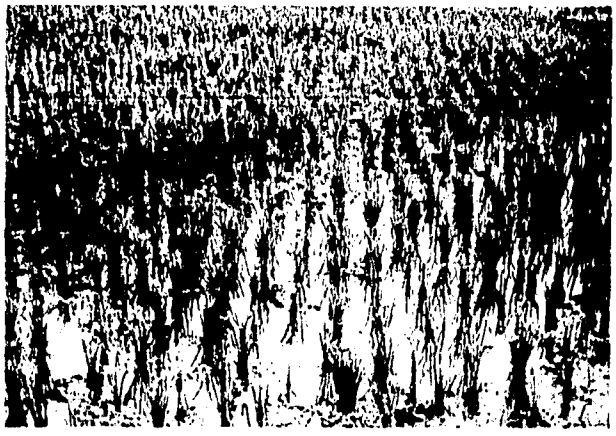
SOIL CHARACTERIZATION

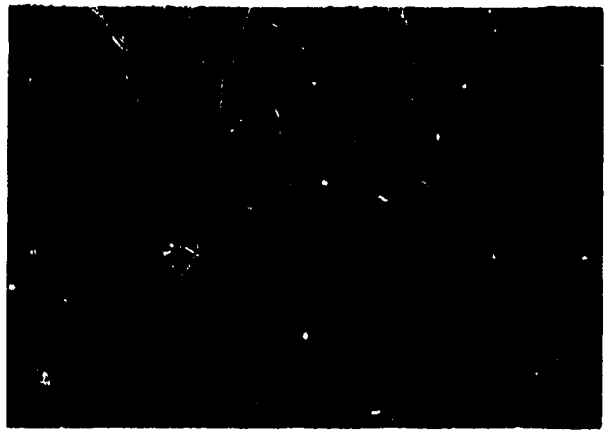
Minimizing zinc deficiency

Strong zinc fixation keeps the efficiency of applied zinc fertilizers low on very poorly drained soils. Methods to minimize zinc deficiency of transplanted wetland rice were tested on very poorly drained soils. Ridging the land and transplanting rice along the lower edges of the ridges reduced zinc deficiency and increased dry matter yield in the dry season; in the wet season planting on the top of the ridges was better than planting on the lower edges. Neither planting method gave results equal to those of high zinc applications (4-16 kg Zn/ha as oxide). Use of old (40-day) seedlings from seedbeds outside the zinc-deficient area also gave promising results.

Chromium in poorly drained soils

Some Philippine soils contain relatively high levels of chromium. Chromium uptake in rice grown in nutrient solutions is proportional to solution concentration, and toxicity symptoms develop between 1 and 10 mg Cr/liter. However, chromium in wetland soils does not seem to be toxic even at 1,000 mg/kg.



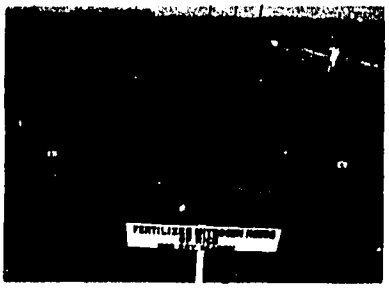


7. Irrigation with high-boron water caused boron toxicity in this farmer's field in Laguna province, Philippines. Toxicity symptoms are seen in the close-up of rice hills.

Boron and zinc problems in wetland rice

Zinc deficiency is increasingly recognized as a widespread nutritional disorder of wetland rice farms. It was seen in 1980 on alkali, calcareous, peat, and poorly drained soils, and on soils high in water-soluble silica. We found dilute hydrochloric acid to be a simple, efficient, inexpensive, extractant for available zinc — and also boron, and copper — in tests of wetland rice soils.

Boron toxicity of wetland rice was recognized in farmers' fields irrigated with high-boron water (Fig. 7). We established the critical toxicity limits as 5 ppm available boron in the soil, 2 ppm boron in the soil solution, and 35 ppm boron in the rice plant.



Differences in response to nitrogen are seen in these IRRI trials on fertilizer nitrogen needs. Yields from the plots verified that nitrogen application could be tailored to crop needs.

Soil nitrogen levels

Over a 7-year period, growing 2 wetland rice crops per year combined with straw incorporation and flood fallow increased the nitrogen content of the soil at the rate of 317 kg/ha per year. In 1980 we used a model for tailoring fertilizer nitrogen dressings for wetland rice to soil and crop needs. The model worked satisfactorily for crops in IRRI soils (Fig. 8).

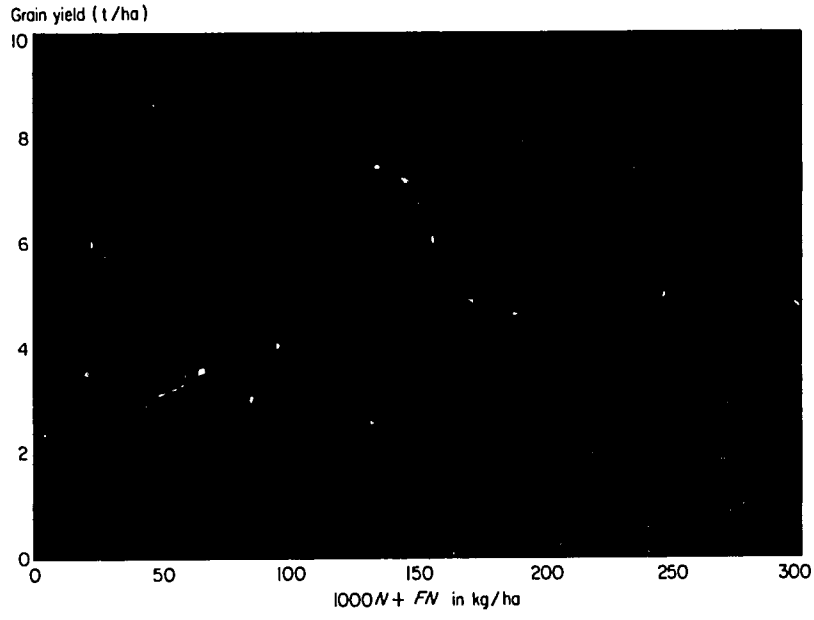
Iron toxicity on acid sulfate soil

Acid sulfate soils on large tracts of coastal plains in the tropics are not suitable for rice because of acidity and related toxicities. We found manganese dioxide at 100 kg/ha superior to lime at 5 t/ha as a remedy for iron toxicity for wetland rice on an acid sulfate soil.

Zinc response of rice on Histosols

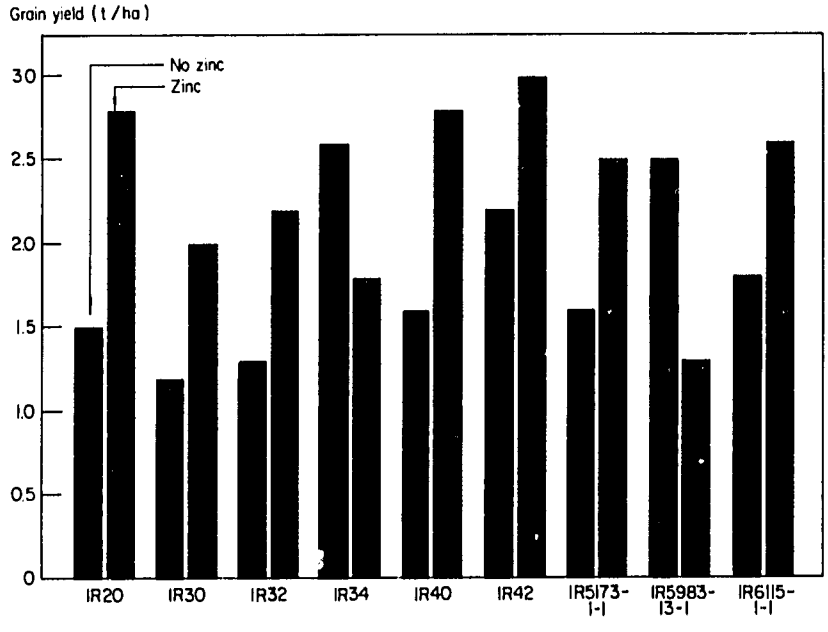
If our 1980 results with zinc on Histosols apply generally to peat soils, a growth-limiting factor on the 30 million hectares of peat soils in South and Southeast Asia can be removed by applying zinc.

8. Relationship between grain yield on 6 soils of varying nitrogen content and the value of the expression, 1000 $N + FN$, where Y = yield target in t/ha, N = total soil N percentage, and FN = fertilizer need in kg N/ha.



The first known instance of a rice crop response to zinc on peat soils was observed on a Histosol (pH: 5.4; organic matter: 46.1%; available zinc: 0.3 ppm) in Laguna, Philippines. In a test of 27 rices in a farmer's field, zinc increased grain yield by an average of 0.4 t/ha. Yields of nine rices with responses to zinc are shown in Figure 9. In a parallel experiment with 10 rices on another Histosol, 8 had yield increases of 0.4 to 0.8 t/ha when zinc was applied.

9. In 1980 on-farm trials on a Histosol, 9 rices had significant yield response to zinc application.



ENVIRONMENT AND ITS INFLUENCE

Rices developed in our GEU program face growth in a wide range of environments as they move into national programs. Research on the environment and its influence on the rice plant provides us an insight into how the rice plant can best adapt to its environment — both climate and soil. There are strong linkages between GEU activities and environmental management.

Climatic adaptability of indica-japonica rices

Indica rices are generally best adapted to the tropics; the japonica rices are considered a temperate climate crop. The japonicas are more cold tolerant than the indicas. Indica-japonica crosses help moderate the susceptibility of the two types to high and low temperatures.

Although indica-japonica rices are highly adapted to a wide climatic range their cold tolerance has to be increased if their performance at high latitudes and elevations is to improve.

Rice is most sensitive to low temperature at the reduction-division stage. Two kinds of low-temperature injury to the plant occur at that stage — degeneration of spikelets and spikelet sterility. The low-temperature tolerance of three indica-japonica rices at the reduction-division stage was not as high as that of cold-tolerant japonicas (Fig. 1).

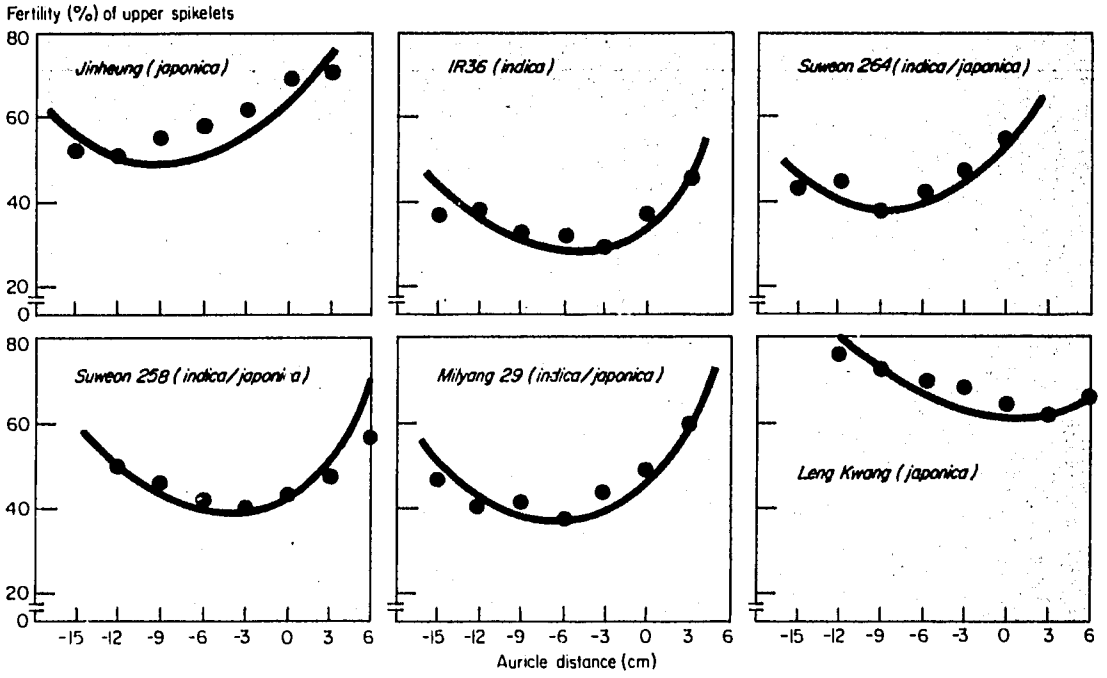
A similar trend was found during grain filling. The critical low temperature for grain filling was 17°/9°C for Jinheung and Leng Kwang, 20°/12°C for indica-japonica rices, and 23°/15°C for IR36.

This information adds support to the breeding program for developing cold-tolerant varieties.

Weather-nutrient interactions

A rice variety's tolerance for environmental stresses is usually examined in trials with adequately fertilized plots. The variety's tolerance may, however, be greatly affected by levels of plant nutrition, which are influenced in turn by soil fertility and fertilizer practices.

In 1980 experiments we found that increased nitrogen supply decreased a variety's tolerance for low- and high-temperature stresses. Increased potassium supply, on the other hand,

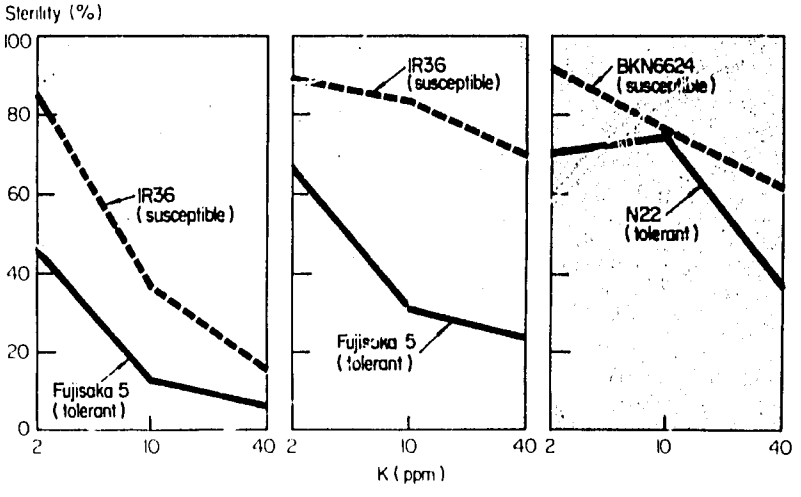


1. The temperature tolerance of indica/japonica crosses is seen in the relationship between fertility of the upper spikelets and auricle distance when the plants were subjected to low temperature (15°/15°C) for 4 days. Note the low tolerance of IR36.

increased a variety's tolerance for such stresses (Fig. 2). This work indicates that an adequate potassium supply can help all varieties overcome low- and high-temperature stresses.

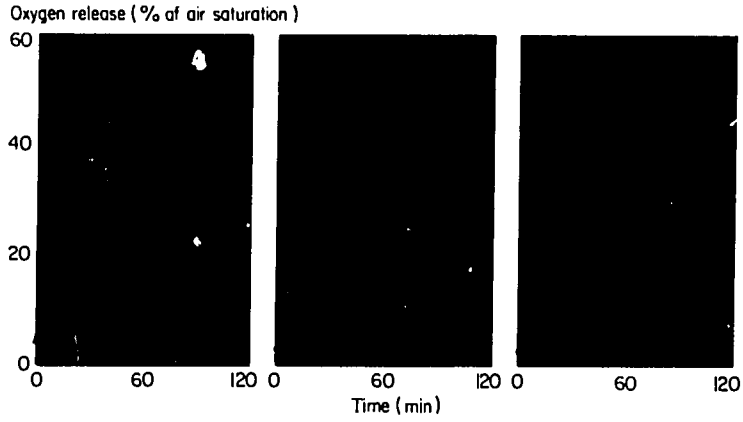
Tolerance for anaerobic soil conditions

Most of the world's rice is grown in highly reduced soils that result from flooding. Rice planted in those soils may suffer various physiological disorders due to toxicities of ferrous iron, organic acids, and hydrogen sulfide, or other factors associated



2. Effect of potassium on spikelet sterility induced by low temperature (15°/15°C) for 3 days (left) and 5 days (middle) at the reduction division stage and high temperature (35°/27°C) at heading (right). Note the marked change in sterility of cold susceptible IR36 in the period from 3 to 5 days.

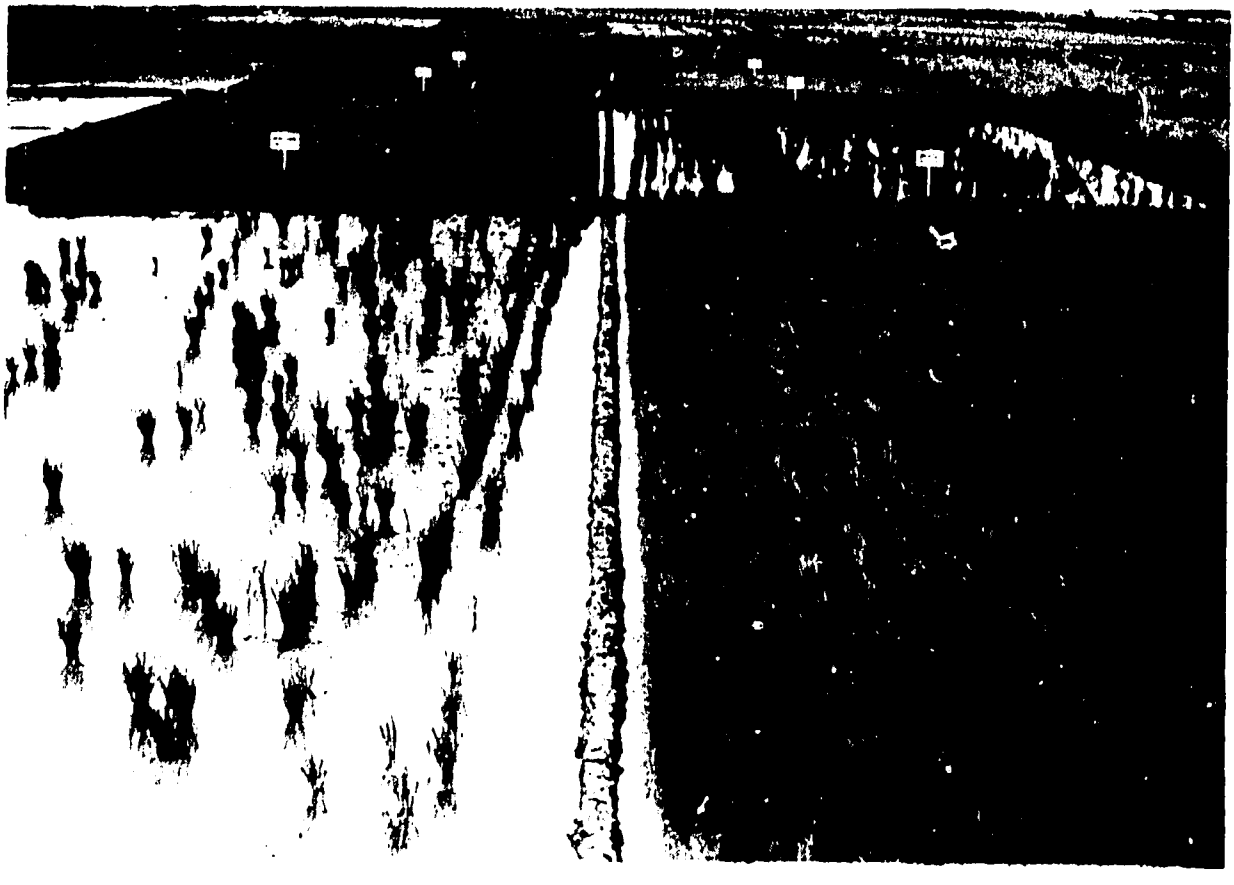
3. Oxygen, transported from the shoot and released by roots, plays an important role in protecting the roots against soil toxins such as ferrous iron and hydrogen sulfide at low temperatures. At high temperatures, oxygen release is drastically reduced. Its defense function is, however, replaced by enzymatic oxidation (see Fig. 4).

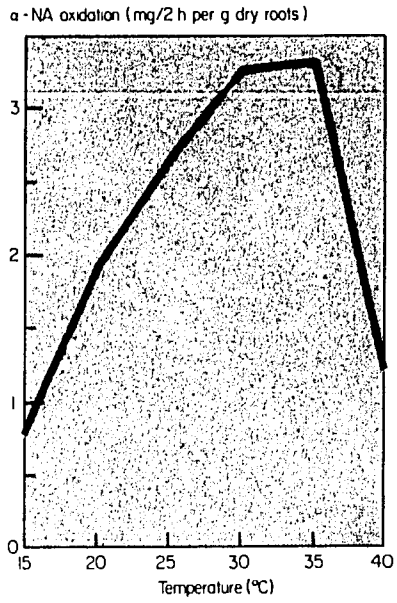


with lack of oxygen. The rice plant overcomes such adverse soil environments, directly or indirectly, by transporting oxygen to its roots. The importance of the rate of oxygen transport to the root in different soil conditions is not well understood.

At 25°C about 70% of the oxygen transported from shoot to root is used for the respiration of root tissues; most of the rest of the oxygen is released in the root zone. When temperature is increased, oxygen release by roots decreases sharply (Fig. 3)

The importance of oxygen to the rice seedling is seen in these 1980 trials at IRRI. Seeds for the plots in right foreground and left background were coated with calcium peroxide, which provided oxygen to the germinating seedlings. Plots with missing plants were planted with untreated seeds.





4. At high soil temperatures enzymatic oxidation by α-naphthylamine in rice roots increases and protects the roots against soil toxins.

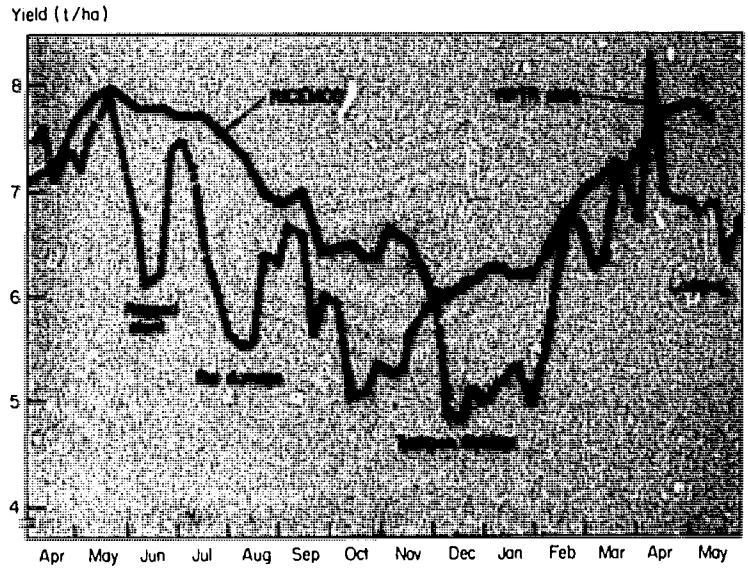
because more oxygen is consumed for respiration, but oxidizing power increases (Fig. 4). These results suggest that rice roots do not release molecular oxygen at high temperatures, but other mechanisms mediated by increased respiration may function in protecting the roots against toxic substances.

Rice, however, develops an oxygen transport system only after the first leaf is developed. Before that stage, rice requires an external supply of oxygen. Thus, when seeds are sown in water or into muddy soil, seedling emergence is poor. To overcome this, seeds can be coated with calcium peroxide before sowing. In the soil, calcium peroxide provides oxygen to germinating seeds, resulting in good seedling establishment.

Dynamic simulation of irrigated rice crop growth and yield

Crop modeling is often used to assess the effects of environment on plant performance. During 1979-80 a relatively simple rice plant model called RICEMOD was developed. It uses daily weather parameters — solar radiation, maximum and minimum temperatures, and day length — to predict rice yields in fully irrigated, well-fertilized fields.

Yields predicted by RICEMOD were compared with field yields obtained in an experiment in which IR36 was continuously planted and harvested. Figure 5 shows the maximum weekly yield harvested from the IRRI plots at Los Baños. Using IRRI's weather data, RICEMOD predicted IR36 field yields except when yields were depressed by disease, rat damage, or typhoons.



5. Comparison of maximum weekly 1977-78 yields of IR36 in Rice Production Training and Research (RPTR) plots and yields predicted by RICEMOD.

Limited experience with RICEMOD indicates that reasonably accurate results can be expected using daily weather data. RICEMOD can also be used to study the relative effects of radiation, leaf blade nitrogen content, respiration rate, and assimilate partitioning on rice plant growth.

CONSTRAINTS TO INCREASED YIELDS

Three major reasons make the study of on-farm constraints to rice yields important.

- There are constraints that existing technology can remove. Research results here can translate rapidly into extension activity.
- There are constraints that may be overcome through changes in agricultural policies now in effect.
- We must identify the constraints that we cannot remove with present knowledge. Research here provides feedback to scientists who are concerned with problem-oriented rice research.

Supply response of Laguna rice farmers

In the economic analysis of constraints to higher rice yields, we are concerned with issues of economic efficiency in rice production. Overall economic efficiency has two components — technical efficiency and allocative (or price) efficiency. Technical efficiency relates to a farmer producing as much rice as possible with a given level of inputs; allocative efficiency relates to the farmer using the level of inputs that maximizes profits.

In 1980 we studied the allocative efficiency of Laguna province rice farmers, with data collected for the 1978 wet season rice crop.

One way of studying allocative efficiency is by the profit function approach. If the underlying production function is represented in a logarithmic form, the restricted profit function will be:

$$\ln \pi^* = \ln A^* + \sum_{i=1}^{n} \beta_i^* \ln P_i + \sum_{j=1}^{m} \alpha_j^* \ln Z_j + u$$

where

π^* is normalized restricted profit;

A^* is a neutral shift parameter for the sampled farms;

P_i is the normalized prices of inputs variable in the production process; and

Z_j are factors fixed in the production process.

u is an error term.

The variable factors included in the analysis were:

P_1 = real price of fertilizer;
P_2 = real price of mechanical power per day;
P_3 = real price of pesticides;
P_4 = real price of animal power per day;
P_5 = real wage rate per labor day for crop establishment;
P_6 = real wage rate per labor day for crop maintenance.

The factors fixed per farm that were included were:

Z_1 = area of rice grown (ha);
Z_2 = value of capital assets used in producing the rice crop;
Z_3 = an irrigation quality variable;
Z_4 = a soil texture parameter (% clay).

The profit function and variable factor demand functions were simultaneously estimated using Aitken's asymptotically efficient method of estimation (Table 1). All the coefficients except the soil texture dummy were significant.

The farmers seemed less sensitive to changes in the price of crop production chemicals (insecticides and herbicides) and animal power than to the cost of mechanical inputs, fertilizer, and labor for crop establishment.

Our analysis showed that:

- Changes in rice supplies tend to be more sensitive to changes in rice prices than to changes in the price of inputs.
- The demand for inputs as mechanical power and fertilizer is more price sensitive than that for inputs as animal power and pesticides.

Table 1. Restricted normalized profit function and factor demand functions.

Coefficient (variable)	Parameter estimates[a]	
	Restricted profit function	Factor demand function
$\ln A^*$ (constant)	10.882***	
	(0.667)	
β_1^* (fertilizer price)	-0.281***	-0.281***
	(0.041)	(0.041)
β_2^* (price of mechanical power)	-0.354***	-0.354***
	(0.084)	(0.084)
β_3^* (price of chemicals)	-0.090***	-0.090***
	(0.019)	(0.019)
β_4^* (price of animal power)	-0.028***	-0.028***
	(0.003)	(0.003)
β_5^* (price of labor for crop establishment)	-0.270**	-0.270***
	(0.045)	(0.045)
β_6^* (wage for crop maintenance)	-0.149***	-0.149***
	(0.028)	(0.028)
α_1^* (area)	0.550***	
	(0.122)	
α_2^* (capital assets)	0.090**	
	(0.042)	
α_3^* (irrigation)	-0.104**	
	(0.046)	
α_4^* (soil texture)	-0.019	
	(0.035)	

[a]Figures in parentheses are standard errors of estimates. ** = significant at the 5% level. *** = significant at the 1% level.

- Rice yields are more sensitive to changes in the levels of fertilizer and mechanical power, than to changes in the use of animal power or pesticides.

CONSEQUENCES OF NEW TECHNOLOGY

An analysis of a 1978-79 study of two wetland rice villages in West Java, Indonesia, pointed out sharp differences between villages as a consequence of the use or nonuse of modern rice varieties. The village with a high rate of modern variety adoption (North Village) experienced a significant increase in cropping intensity and in yields per hectare between 1968-71 and 1978-79 despite lower fertilizer and labor use (Table 1).

The bench mark for the current study was the 1968-71 study. Per-capita land endowments were less than 0.1 ha in both villages, and each had a significant number of landless laborers. Significant improvements in irrigation contributed to the increased cropping intensity and higher yields in North Village; South Village started and ended the decade with a double-cropping system.

The last line of Table 1 shows changes in labor wage rates over the decade in the two villages. North Village, with a high level of adoption of modern varieties, experienced a 46% increase in labor wage rate, but in South Village, the wage rate declined.

Changes in average costs of production reflected similar changes. In South Village, rice output per hectare of crop area increased by 12%. Payments to labor increased little, with most of the increased output going to the operators in the case of owner farmers, or to landlords in the case of tenant farmers. In North Village, output increased by 40%, with a small portion of the increase going to current inputs and capital. The largest part

Table 1. Comparison of a village with limited adoption of modern varieties and a village with complete adoption of modern varieties in Subang, West Java, Indonesia, between 1968-71 and 1971-79.

	South Village		North Village	
	1968-71	1978	1968-71	1978-79
Modern varieties (%)	11	14	7	100
Multiple cropping index	1.9	1.9	1.5	2.0
Rice yield (t/ha)				
Per ha of crop area	2.6	2.9	2.4	3.4
Per ha of rice fields	4.9	5.5	3.6	6.7
Fertilizer (kg/ha)	191	329	75	209
Labor, preharvest (h/ha)	736	928	638	701
Labor wage rate (kg/day)	9.5	8.5	7.9	11.5

of the increase (an increase of 100 kg/ha per crop on tenant farms and 240 kg/ha per crop on owner farms) was split between hired labor and land. With the change in cropping intensity, laborers' incomes increased by only 4% in South Village and by 60% in North Village.

Work activities of rice farm families, Central Luzon

We did a 1-year study of 87 farm households in Central Luzon to determine the allocation of employment activities and the earnings of male and female farm family members of various ages.

Male family members worked an average of 1,228 hours/year and females 811 hours/year at farm work, nonfarm employment, and maintenance and provision activities. Female family members contributed 35% of the total work hours and 21% of the family labor hours in rice farming, concentrated mainly in pulling and transplanting of seedlings. They contributed more than half of the hired farm employment, exchange labor, and nonfarm employment of the study families.

Few children below 13 years were included in the labor force (< 5%). Males between 13 and 16 made up 20% of the male work force and worked an average of 577 hours/year; males 17-21

Three of eight harvesters in this Philippine rice field are women.

worked 925 hours/year, and males 22-65 worked 1,637 hours/year — about 82% of what might be called "full employment" — 40 hours/week for 50 weeks/year. For persons between 17 and 65 years of age, the family rice farm provided about 50% of work hours for males and 20-25% for females. Female family members across the 3 age classes worked about half as many hours as the males, but women over 65 worked 1,133 hours/year, about the same hours as males in that age class.

There was no relationship between effective crop area per farm and either total or each family member's hours of work on the farm. Female family members on farms that averaged 6.4 ha of rice/year worked more hours on their own farms than those on smaller farms, but worked fewer total hours than females from smaller farms. Total work hours by male family members were nearly identical for three farm-size classes (Table 2), but males from small farms worked fewer hours on their own farms.

The average male worker earned 3 times what the average female worker earned (Table 3) because he worked 50% more hours and because the average wage rate for males was 150% higher. The higher male wage reflects different sources of employment as well as higher rates for males.

Table 2. Hours of labor input by male and female household members on farms of 3 size groups in 87 farm households of 6 sample villages in Central Luzon, Philippines, 1978-79.

Activity	Work hours per year[a]					
	Males			Females		
	<4 ha (2.7)	4 to 5 ha (4.1)	>5 ha (6.2)	<4 ha (2.7)	4 to 5 ha (4.1)	>5 ha (6.4)
Family rice farm	525	705	720	174	161	262
Nonrice, farm	79	8	8	53	6	8
Hired farm employment	54	46	42	95	50	77
Exchange labor	45	15	42	44	40	87
Nonfarm employment	222	106	173	466	563	280
Maintenance and provision	288	297	237	43	5	19
Total	1219	1222	1236	875	825	733

[a]Values in parentheses are the effective crop area in hectares.

Table 3. Income contribution of labor force participants by age and sex, 87 farm households, 6 sample villages in Central Luzon, Philippines, 1978-79.

Sex	Income contribution ($/year)				
	Below 13 yr	13-16 yr	17-21 yr	22-65 yr	Over 65 yr
	Income ($/year)				
Male	21	80	165	575	202
Female	8	36	66	120	52
	Wage ($/8 hour day)				
Male	0.31	1.11	1.43	2.81	1.61
Female	1.03	1.06	0.63	1.07	0.37

CROPPING SYSTEMS

Thousands of small farmers of Asia, who depend on rainfall to grow their crops, continued their efforts to grow one more crop each year. These extra crops — and the added profits they brought farmers — were made possible by short-growth-duration modern rices in cropping patterns designed and tested by cropping systems researchers in the Asian Cropping Systems Network.

During 1980 a handbook, *A methodology for on-farm cropping systems research*, was completed and will be available to cropping systems workers worldwide in 1981. The handbook, written in close collaboration with the Asian Cropping Systems Working Group, drew on research and on-farm experience at more than 50 sites in Asia.

THE CROPPING SYSTEMS ENVIRONMENT

Land is the dominant physical resource farmers use in agricultural activities. Natural landscape facets and soil units develop by parallel genetic processes, and therefore landforms and soil bodies are often closely correlated locationally. The correlation is fortunate because land features are easily recognized and an approximate interpretation for agricultural use can be made if the association between land features and soil properties is known.

M. S. Venugopal, IRRI postdoctoral fellow, lifts rice plants from a hydroponic culture containing technical carbofuran insecticide. These greenhouse trials in a pest-free condition demonstrated that carbofuran and two of its metabolites can directly promote rice growth leading to significant yield increases over the untreated control.

In cropping systems projects, we classify land for two reasons:

- Research should focus on land types that are widely distributed and able to support improved production practices;
- To extrapolate research results, we must describe the characteristics of land on which research is conducted and then identify land areas with similar characteristics.

Landforms of rice-growing areas of the Cagayan Valley

In 1980, a study was initiated to devise a procedure for rapid land description and to assess its utility by classifying land in the Philippines' Cagayan Valley. A four-category system was adopted. The four hierarchal categories in the system and the bases on which they are interpreted are shown in Table 1.

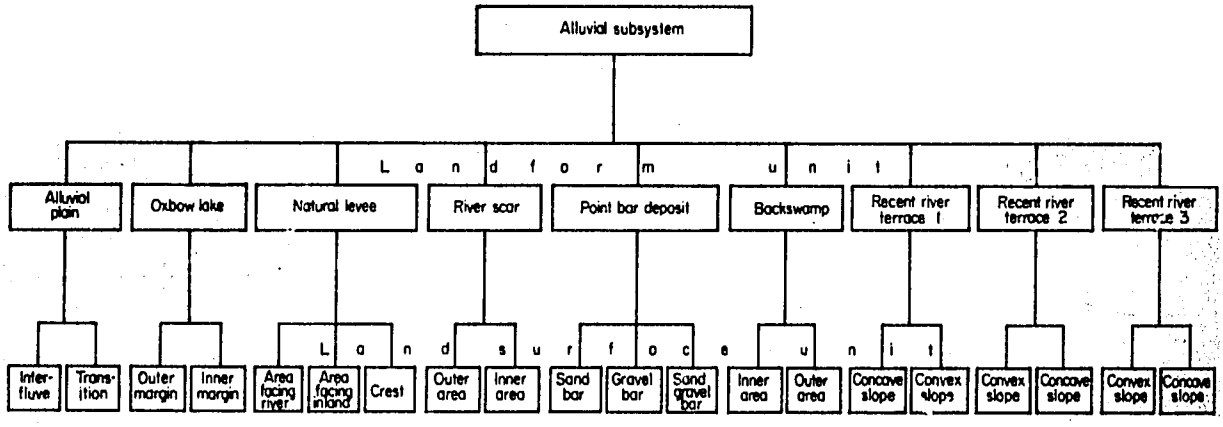
In the classification, 4 land systems, 10 land subsystems, 30 landform units, and 75 land surface units were recognized. Land surface units are regarded as the largest land units that can be managed uniformly with respect to the sequence of crops planted and the dates of planting. Landform unit and land surface unit classes within the two categories below the alluvial land system class are shown in Figure 1. Figure 2 diagrams several landform units.

To obtain a limited but objective evaluation of the procedure, soil profile data (17 variables) from 26 soils on land surface units from 7 short transects were subjected to cluster analysis. The clusters identified in the analysis generally agreed with profile groupings according to land surface unit classes.

Although this hierarchal system appears to work satisfactorily, the classification system requires evaluation in other areas. By enabling us to identify land with characteristics similar to that on which research is being conducted, the classification system promises to provide a basis for extrapolating research results from an area of about 1,000 ha to a much larger area in the Cagayan Valley.

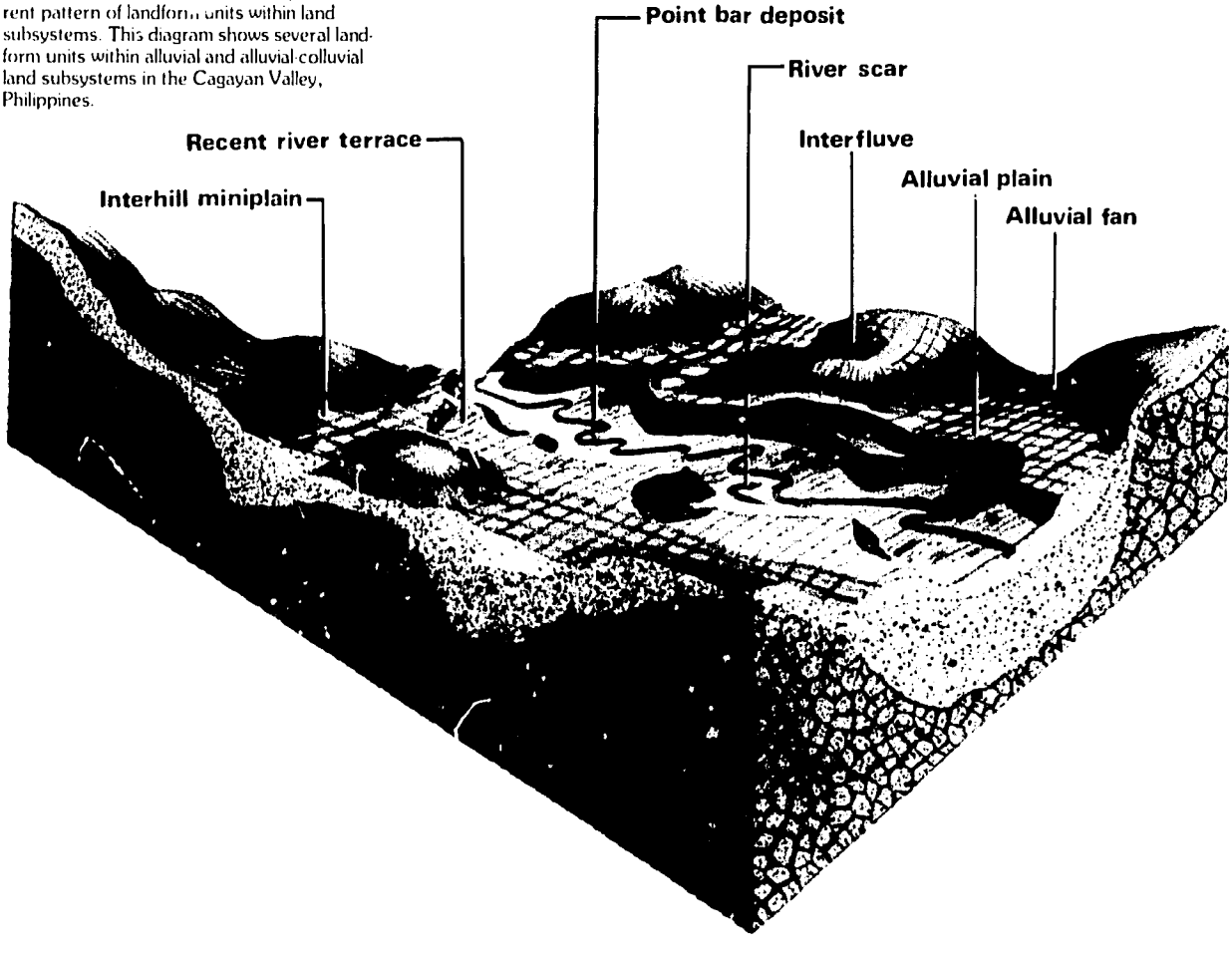
Table 1. Four hierarchal categories used in a land classification system tested in the Cagayan River Basin, Philippines, 1980.

Hierarchal category	Base
Land system	1:250,000 to 1:1,000 topographic map with contour interval of 100 to 400 m 1:250,000 composite color LANDSAT imagery
Land subsystem	1:50,000 to 1:250,000 topographic map with contour interval of 250 to 100 m 1:20,000 to 1:50,000 air photos
Landform unit	1:10,000 to 1:50,000 topographic map with contour interval of 5 to 20 m 1:10,000 to 1:20,000 air photos
Land surface unit	1:5,000 to 1:15,000 air photos 1:10,000 to 1:50,000 topographic map with contour interval of 5 to 20 m



1. Below the alluvial subsystem there are 9 possible landform units in the classification system developed for the Cagayan Valley, Philippines. Below each landform unit are 2 or 3 possible land surface units.

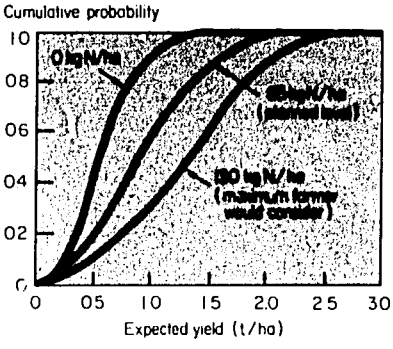
2. To aid agricultural technicians in recognizing landform units in a large target area, diagrams can be drawn to show the typical recurrent pattern of landform units within land subsystems. This diagram shows several landform units within alluvial and alluvial-colluvial land subsystems in the Cagayan Valley, Philippines.



Cropping systems simulation

Mathematical simulation in cropping systems allows us to relate a large number of diverse environmental and managerial factors to multiple cropping patterns and their performance. We simulated dryland rice-based systems in 1978 and wetland rice-based systems in 1977-79. In 1980 we used simulation to investigate and analyze the decision-making process and risk-taking of individual households.

To understand farmers' cropping pattern choice in relation to expected growing season duration, we asked them to evaluate the expected onset and termination of standing water in their paddies. Farmers were also asked to estimate crop yield at given fertilizer levels (Fig. 3).



3. Farmers' expression of their expectations of rice yield in relation to fertilizer application permitted estimation of subjective probabilities of yield response.

Farm operations were monitored on a day-to-day basis and plotted on a cropping system chart indicating crop areas, date, and type of operation for all parcels. Unexpected deviations from the farm plan were discussed with farmers, and biweekly yield expectations were used to determine the farmers' feeling with regard to the status of their crop.

The initial purpose of the simulation was *not* to find the best way of making decisions, but to see how farmers *think* they can best manage a complex agricultural system and how the idea varies across categories of farmers with different factor endowments and risk-taking capacities.

Table 2 shows the results of a sequential-crop simulation on the technical feasibility of a pattern. The simulated farmers' plan was to first plant dry-seeded rice (DSR), followed by wet-seeded rice (WSR), followed by mungbean. Certain decision rules permitted revision of the plan to delete any of the crops, depending on soil moisture, or to substitute WSR for DSR if the onset of rains was too abrupt. Planting of plots on the plain and plateau landscape positions was simulated for 16 years of rainfall data in Tigbauan, Iloilo. Speed of planting with the model was governed by family labor and one carabao. The planned pattern was feasible in 14% of the years — less than 3 of the 16 years — and only on the slightly drier plateau (Table 2).

A highly useful aspect of this research is the degree to which farmers' expectation of technology performance has been matched. We are encouraged that farmer information can be used in the technology design and testing process.

PEST CONTROL IN CROPPING SYSTEMS

A rice-based cropping pattern usually means a shift from dryland to wetland and then back to dryland culture within a growing season. The changes influence the incidence of crop pests —

Table 2. Simulation with 16 years of rainfall of the performance of a cropping strategy indicated 6 different outcomes in terms of patterns executed, and a high degree of rice crop failure. First priority for an early dry-seeded rice (DSR) crop followed by wet-seeded rice (WSR) followed by mungbean appears a doubtful strategy.

	Realization (%) of pattern	
	Plain (0.20 ha)	Plateau (0.20 ha)
DSR	6	6
WSR · mung	25	31
Total single rice	31	37
DSR · WSR · mung	—	14
WSR · WSR · mung	25	6
DSR · WSR	31	25
WSR · WSR	12	12
Total double rice	68	62
DSR early failures[a]	40	20
2d crop failed[b]	36	50
Mean turnaround	6.5 days (6-11)	10 days (6-18)

[a]Failures due to early drought stress or flooding. [b]Crops with simulated yields below 300 kg/ha.

weeds, insects, diseases — and often present risks that keep farmers from adopting new patterns.

Insecticides to measure yield losses

Cropping systems entomologists evaluate potential insect control practices during cropping pattern development. To select practices they convert crop losses caused by insects into monetary terms.

Carbofuran, which has broad-spectrum activity, has been used to measure yield losses, but there are indications it stimulates plant growth. We made tests with rice grown in a hydroponic culture treated with carbofuran and two of its metabolites.

A field of dryland rice is checked for rice bug damage by Rodolfo Apostol, IRRI research aide. A 1980 study found that the rice bug can be controlled by synchronous planting.

Carbofuran significantly increased growth and yield and reduced the maturation period. Therefore, we replaced it with plant-neutral insecticides to measure yield losses caused by insects.

Weed control in dry-seeded rice by stale-seedbed technique

For weed control using the stale-seedbed technique, a conventionally prepared dryland seedbed is left unplanted until weed growth starts. This stale seedbed is then harrowed lightly or sprayed with herbicides to kill weed seedlings without bringing other weed seed to the soil surface.

Weed control on a stale seedbed, on conventionally prepared land, and after zero tillage for dry-seeded wetland rice were compared at IRRI. At 40 days after emergence, the total weed weight in the unweeded plots was significantly lower in the stale seedbed than in plots tilled conventionally.

Herbicides failed to control the weeds in the conventionally prepared and the zero-tillage plots, but good weed control was achieved in the stale-seedbed plots (Table 3). The highest yields in the hand-weeded plots were obtained in the zero-tillage plots, but more than 1,700 weeding hours/ha was required compared to 700 hours in the stale-seedbed plots treated with paraquat.

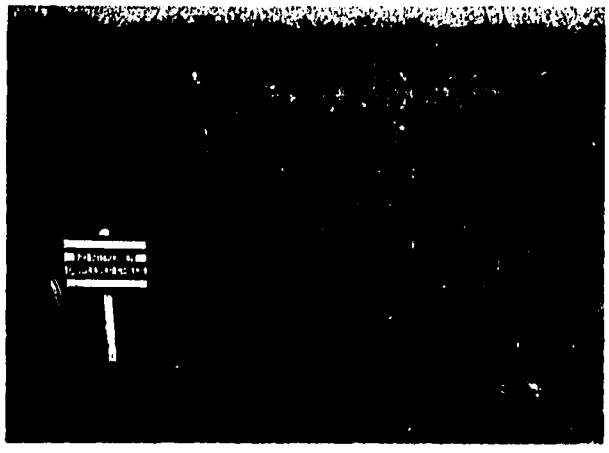
Reduced tillage for second crop transplanted rice

In an irrigated field that had been prepared conventionally and weeded twice, we tested four levels of tillage before planting a second transplanted rice crop. The weight of weeds harvested from the unweeded plots 35 days after transplanting ranged from 15.4 g/m^2 in a plot that received 1 plowing and 3 harrowings to 79.2 g/m^2 in a plot harrowed once.

Table 3. In 1980 wet-season trials of herbicides and different land preparation methods, use of the stale seedbed showed definite advantage on the yield of dry-seeded IR50 rice.[a]

Land preparation method	Yield[b] (t/ha)				
	No weeding	Butachlor (2.0) fb 2,4-D (0.5)	Thiobencarb (3.0) fb 2,4-D (0.5)	Pendimethalin (2.0) fb 2,4-D (0.5)	Hand weeding 14 DE fb 35 DE
Zero tillage	0 a	0 b	0 b	0.8 b	3.5 a
One plowing + one harrowing	0 a	0 b	0 b	1.1 b	2.0 b
Two plowings + two harrowings	0 a	0.5 b	0.8 b	0.9 b	3.2 ab
Stale seedbed (harrow)	0 a	1.9 a	2.7 a	2.9 a	2.9 ab
Stale seedbed (paraquat)	0.5 a	2.5 a	3.5 a	2.6 a	2.9 ab

[a]Av of 3 replications. [b]Herbicide rates in kg a.i./ha are indicated in parentheses; fb = followed by, DE = days after emergence. In a column, means followed by the same letter are not significantly different at the 5% level.



Azolla's suppression of weed growth is seen in these IRRI plots. Growth of Cyperus difformis *was significant in plots with no azolla (left) but was largely controlled in the plots with azolla (right).*

There was no significant difference in rice yield among the tillage and weed control treatments. The data suggest the potential of using reduced tillage for establishment of a second transplanted rice crop, provided that weeds in the first crop are adequately controlled.

Weed suppression with azolla

Azolla inoculated into a transplanted rice field at the rate of 500 g fresh weight/m^2 rapidly covered the water surface and caused a 79.1% reduction in total weed weight 50 days after transplanting. Rice yields from the azolla-inoculated plots were not significantly different from yields of plots that were hand weeded, but were significantly higher than those of the unweeded check. *Cyperus difformis*, which comprised 65.5% of the total weed weight, was 91.8% suppressed by azolla.

SOIL AND CROP MANAGEMENT

Early establishment of a rice crop by dry seeding has proven to be a key to cropping pattern intensification in many rainfed areas. A dry-seeded early rice crop allows a second rice crop and often a third dryland crop, rather than just one or sometimes two crops a year. But frequently stand establishment problems occur with dry seeding.

Comparison of planting methods for dry-seeded rice

We compared five planting methods — two new small planters and three farmer methods — for dry-seeding rice at IRRI in the 1980 wet season. Three seeding rates and two depths of planting were included.

The dry-seeded area had grown wetland rice in puddled soils during 1979. A well-prepared seedbed was fertilized and weeds

Table 4. Grain yield from dry-seeded rice was highest with traditional planting methods in 1980 trials at IRRI.

Planting method	Seeding rate (kg/ha)	Depth of planting (cm)	Grain yield[a] (t/ha)
Mechanical planters			
IRRI inclined plate seeder (drill planting)	100	3	4.02 bc
		6	3.60 c
	150	3	3.88 c
		6	4.07 abc
	200	3	3.78 c
		6	3.95 bc
IITA punch planter (hill planting)	150	3-5	4.13 abc
Traditional farmer methods			
Broadcast on furrow made by a wooden furrower	100	8-10	4.44 abc
	150	8-10	4.26 abc
	200	8-10	4.80 ab
Dibble	150	8-10	4.05 bc
Broadcast on well-prepared seedbed, and harrowed	150	0-2	4.92 a
CV (%)			10.9

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

were controlled by a preemergence herbicide followed by hand weeding. Insects were controlled with insecticides. Rainfall was generally good for dry-seeded rice.

Surprisingly the Filipino farmer's method of simply broadcasting seeds and harrowing to cover them gave a higher yield than that obtained by using either of the two planters (Table 4).

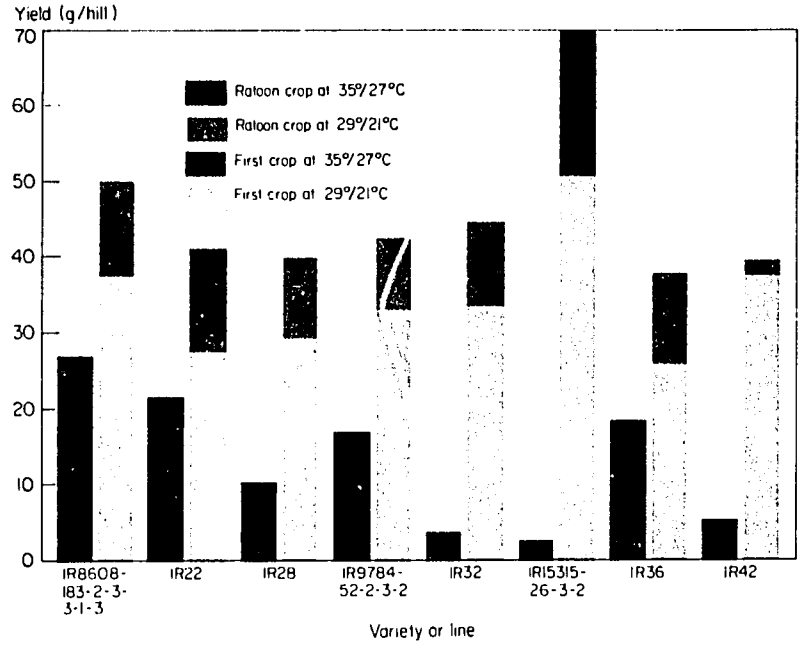
Previous trials had shown the farmers' broadcast planting method produced low yield because of high weed populations. Our 1980 study indicated that with weeds controlled by a herbicide and hand weeding, the yield potential with the traditional methods of dry seeding may equal, or be better than, that obtained from specialized planters — good news for the small farmer with limited resources.

Varying the planting rate or depth of planting with the experimental inclined-plate planter gave no differences in yield in this trial.

Rice ratooning remains a challenge

Cropping systems researchers maintain continuing interest in the potential of rice ratooning for crop intensification. Ratooning offers economic gain in time, labor, and seed and tillage costs in establishing a second rice crop. Agronomic gains can come from higher production accruing from the elimination of turnaround time, the earlier ripening of a ratoon crop, and for rainfed areas the presence of favorable growing conditions for such a crop.

Six IRRI lines have exhibited good ratooning in collaborative screening with the Genetic Evaluation and Utilization program. Because ratoon crop yields were relatively low — 1.5 t/ha — we tried to identify management practices to increase yield.



4. Effect of 2 temperature regimes (red = 35°/27° C, green = 29°/21° C) on the yield of 8 IR rices tested for the first and ratoon crop in the IRRI phytotron.

In tests of cutting heights of the main crop, the 15-cm height produced higher yields, more tillers, and earlier maturity for the ratoon crop than did the 3-cm height.

The earlier maturity could be extremely important to intensifying cropping systems in areas where farmers wish to plant a dryland crop after the second rice crop.

We grew 5 IR varieties and 3 experimental lines in the phytotron at day/night temperature regimes of 35°/27°C and 29°/21°C to determine the effect of temperature on rice ratoon yields. Number of tillers was higher in the high temperature regime, but so was panicle sterility. Consequently grain yields from plants grown in the cooler temperatures were higher (Fig. 4). Plants grown in the hot room were taller and matured earlier than the plants grown in the cooler room.

Diseases in ratoon rice

We continued to seek improved yields from a ratoon rice crop in a cropping system. When the main crop of IR32 was treated with benomyl-thiram, the severity of stem rot caused by *Helminthosporium sigmoidea* var. *irregulare* was reduced (Table 5), and the ratoonability of the crop was improved. Lodging of ratoon tillers decreased as did stem rot incidence.

Yellow dwarf was observed on the ratoon crop, but not on the main crop. Sheath blight incidence was lower than that of stem rot, but the trend of the two diseases on the main crop and ratoon crop was the same.

Table 5. Use of benomyl-thiram on IR32 main rice crop reduced stem rot infection as the ratoon crop developed.

Fungicide application	Main crop		Ratoon crop			
	Stem rot (%)	Yield (t/ha)	Tillers (no./hill)		Lodging tillers with stem rot (%)	Yield[a] (t/ha)
			Basal	Nodal		
Seed	84 a	7.65	10.1	8.1	57	1.27 ab
Max tillering	86 a	7.89	12.0	6.4	51	1.34 ab
Filling	83 a	7.44	10.5	6.2	67	1.33 ab
Seed + max tillering	80 a	6.72	11.5	5.6	45	1.51 ab
Seed + filling	59 b	7.43	12.2	8.8	39	1.57 ab
Max tillering + filling	61 b	7.50	12.0	8.5	36	1.57 ab
All three stages	60 b	7.84	11.4	10.0	14	1.75 a
Check	85 a	7.28	10.2	7.0	86	1.15 b

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

Stable yielding mungbean for rice-based patterns

From 1978 to 1980 cropping systems researchers tested 10 cultivars in 8 IRRI environments representing growing conditions encountered in an intensive rice-based cropping system.

We found:

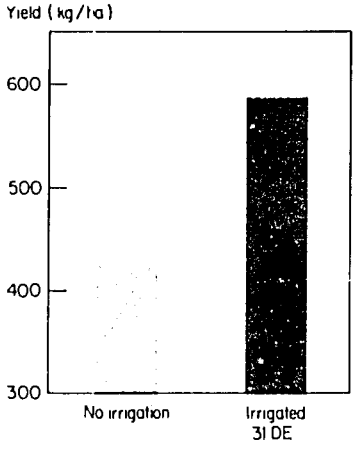
- Yields of early-maturing cultivars were generally higher under relatively low rainfall and yields of medium-maturity cultivars were greater where high rainfall prevailed.
- Cultivars EG-MG174-3 and CES-55 yielded well over a wide range of environments and should be useful in breeding programs to improve yield stability.
- Yields of mungbean intercropped with maize were reduced by 73% during the wet season and 45% during the dry season. Yet a comparison of gross returns favored the intercropping system in both seasons by about 13%.
- Several plant characteristics were highly correlated with bean yield (Table 6).

Cropping systems trainees from 5 countries talk with a Pangasinan, Philippines, farmer about 1980 mungbean trials in his fields.

Table 6. Ten mungbean cultivars were grown in 8 different environments at IRRI in 1978-80. The correlation coefficients between yield and characters contributing to it are given here.[a]

Plant character	Seed weight (plant)	Pods (no./plant)	Branches (no./plant)	Days to flowering	Leaf area index (30 DS)[b]	Total dry matter (t/ha)	1,000-seed wt (g)	Yield (kg/ha)	Pod length (cm)	Seeds (no./pod)
Plant height (cm)	0.495**	0.433**	0.416**	-0.011[ns]	0.551**	0.333**	-0.108[ns]	0.392**	0.385**	0.554**
Seed wt (plant)		0.807**	0.502**	-0.211**	0.717**	0.543**	0.078[ns]	0.855**	0.521**	0.573**
Pods (no./plant)			0.522**	-0.259**	0.582**	0.417**	-0.295**	0.702**	0.174**	0.432**
Branches (no./plant)				-0.211**	0.639**	0.569**	-0.157	0.392**	0.302**	0.491**
Days to flowering					-0.246**	-0.258**	0.149*	-0.271**	0.038**	-0.142*
Leaf area index 30 DS						0.798**	0.004[ns]	0.693**	0.463**	0.611**
Total dry matter (t/ha)							0.061[ns]	0.456**	0.346**	0.424**
1,000-seed wt (g)								0.432**	0.431**	0.633**
Yield (kg/ha)									0.482**	-0.142*
Pod length (cm)										0.468**
Seeds (no./pod)										

[a]ns = not significant, * = significant at the 5% level, ** = significant at the 1% level. [b]DS = days after seeding.



5. The equivalent of 11 mm of row-applied irrigation water at 31 days after emergence increased by about 30% yields of mungbean grown after rice. IRRI, 1980 dry season.

Small irrigation applications on mungbean

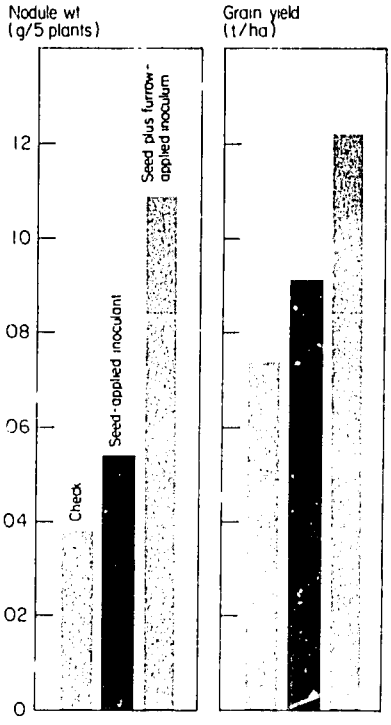
Mungbean and other crops grown after rice during the wet season-dry season transition are often hit by drought. During critical drought periods, small properly timed applications of water at selected growth stages may reduce crop stress. In the 1980 dry season, we applied water by plastic piping to a narrow band of soil along rows of mungbean plants. We found that timely application of small quantities of water can have a positive impact on yields of mungbean grown after rice.

The equivalent of 11 mm of water was applied 16 days after emergence (DE), 31 DE, and 16 and 31 DE. The plants were flowering at the time of the last application. Irrigation did not give an expected stimulation of root growth but seed and dry matter yields were affected. The irrigation 16 DE did not significantly affect yield, but that 31 DE increased yield by 150 kg/ha (Fig. 5). There was no interaction between applications 16 and 31 DE.

Inoculation and nitrogen fertilizer on soybean

Soybean could be an important crop following rice, but farmers' yields are generally low. Nitrogen deficiency is suspected as a cause of the low yields. The soybean plant normally draws nitrogen from rhizobia-containing nodules on its roots. Sometimes, however, the soil rhizobial population after a wetland rice crop may be too low to infect the soybean root or the natural rhizobia may be ineffective. Standard seed inoculation has been used but seldom gave yield increases.

To test the effect of high rhizobial inoculation rates on soybean performance, we conducted a series of experiments at two sites. At one site, there was no known history of soybean production; at the other, soybean had been grown irregularly with applications of inoculants. We applied inoculant to the seed alone, and to both the seed and the seed furrow at a rate equal to 6 times that applied to the seed alone.



6. For soybean after wetland rice, seed- and furrow-applied inoculum increased nodule weight at 7 weeks after planting and grain yield in a field without a history of soybean crops. Pangasinan, Philippines, 1980 dry season.

At the site where soybean had not been previously grown, significant nodule weight and yield increases were obtained with inoculant application on the seed alone and both on the seed and in the furrow (Fig. 6). Basal fertilizer applications also increased grain yield, but did not significantly reduce nodule weight. A yield response to fertilizer topdressing was not obtained. Apparently, nitrogen fertilizer increased yields by providing nitrogen to promote critical early vegetative growth, but nodules provided nitrogen during the flowering and grain formation stages.

Where soybean had grown previously, many small nodules were found even where seeds had not been inoculated. Nodulation did not differ whether the seeds or the seeds and the furrow had been inoculated. No significant yield response to inoculation was obtained, but a basal application of 25 kg N/ha significantly increased yield.

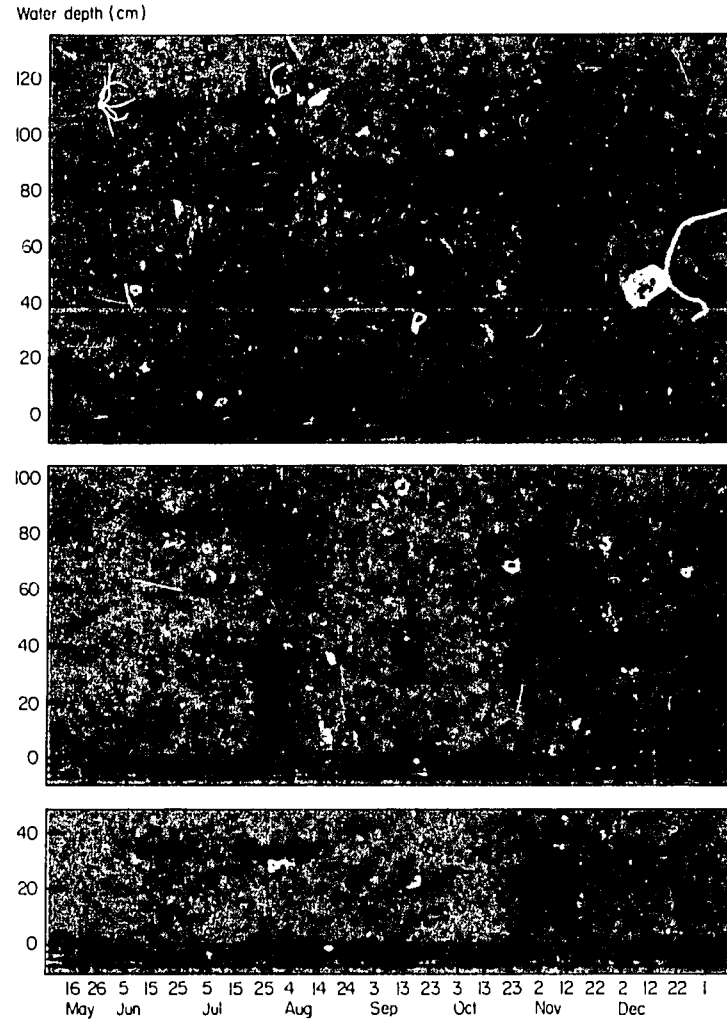
Our study suggests that small basal applications of nitrogen where soybean is a common crop after rice will increase yields. Where soybean has not been extensively grown, applications of basal nitrogen and inoculant to both the seed and the seed furrow can increase yield significantly.

Rice-based patterns on flood-prone, shallow, rainfed rice land

Rice crops grown on many thousands of hectares of rainfed land suffer from drought at unpredictable times. The same crops may also suffer from deep flooding caused by occasional intensive monsoon rains.

In 1980, cropping systems researchers initiated studies in an area where both drought and flooding are prevalent. Three land strata were identified and the water regimes on these fields were

Both drought and deep flooding are unpredictable on these rainfed lands in the Cagayan Valley, Philippines. In the foreground is an alluvial plain; behind it is a recent floodplain backed by bar deposits and river scars. A hill system is seen in the distant background.

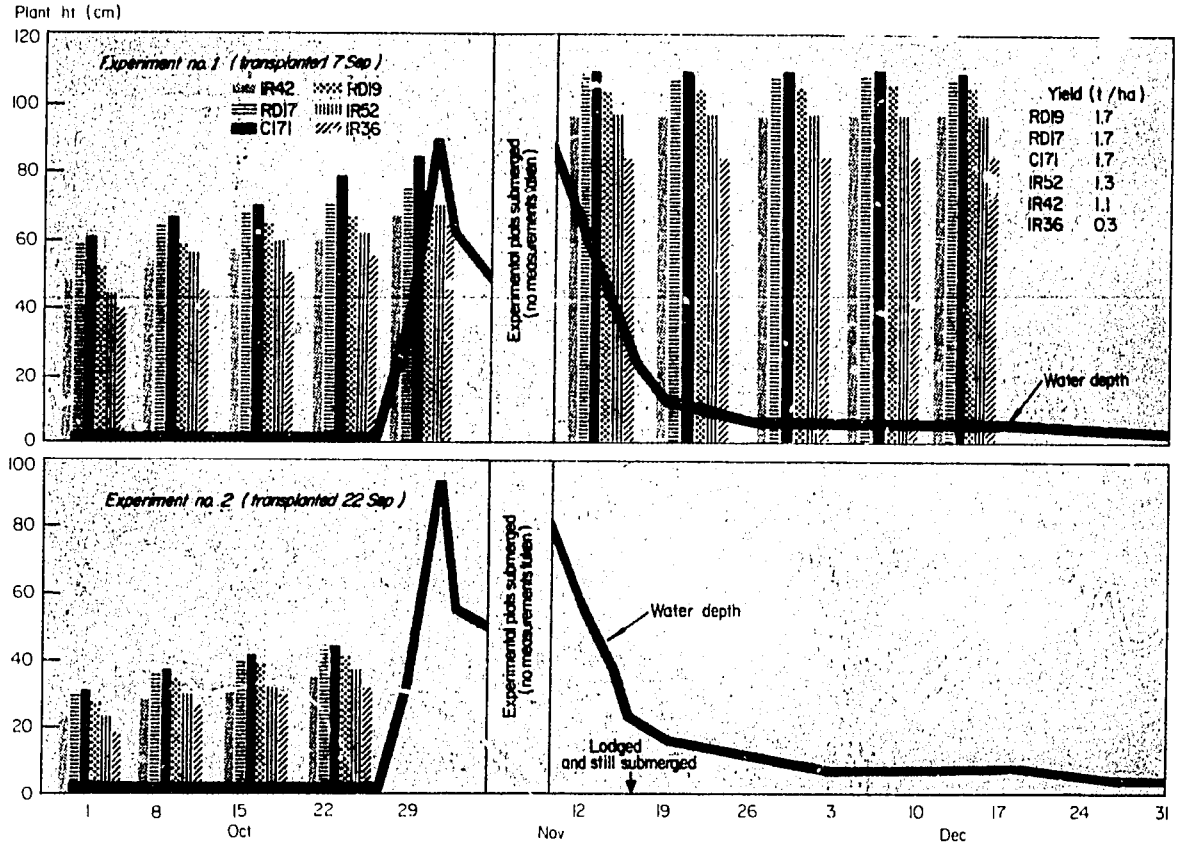


7. Three field water regimes were observed in land strata of the Cropping Systems Research site in Solana, Cagayan, Philippines, 1980. S = saturated state, W = wet state, M = moist state, D = dry state. In the lowest stratum (C) 3 serious flood periods occurred.

monitored from May to December. Mean water depths are shown in Figure 7. Variety trials with six entries were transplanted 6-27 September at five sites on strata B and C.

A major flood 29 October-12 November resulted in the loss of all crops planted after 20 September. In a 7 September transplanting, RD17, RD19 — modern deepwater rices from Thailand — and C171 were less affected by flooding than were IR36, IR42, and IR52 (Fig. 8). Plant height, water depth, and yields from two experiments illustrate typical conditions and their effects on crops. RD17, RD19, and C171 matured 1 month earlier than traditional varieties used by local farmers. Although their 3 yields were not high, RD17, RD19, and C171 were better adapted to the severe conditions than the widely grown IR36 and IR42.

The results have encouraged further research to identify management practices that promote survival and increase yields in flood-prone shallow rainfed areas.



8. Floods in the Solana Cropping Systems Research site between 29 October and 16 November ruined late transplanted rice varieties and damaged early transplanted varieties. RD17, RD19, and C171 were clearly superior to varieties widely grown elsewhere.

Tillage and fertilizer for sorghum after rice

Sorghum has potential as a crop after rainfed rice because it tolerates both drought and flood conditions.

In 1980 we compared the response to different nitrogen levels of sorghum after dry-seeded rice (DSR) and transplanted rice (TPR). Our results indicated that improved cropping systems with sorghum can be developed with a minimum of outside energy inputs — with only fertilizers and limited pest control.

Yields of sorghum after DSR were about 20% higher than those for sorghum after TPR on puddled soils (Table 7) primarily because of larger seed size and more vigorous plants. The optimum rate of nitrogen for sorghum after DSR was 80 kg/ha, whereas the optimum rate after TPR was 120 kg/ha.

We also compared tillage and method of basal fertilizer applications for sorghum after DSR and TPR. Sorghum yielded almost 90% higher after DSR than after TPR. Every tillage and fertilizer treatment provided higher yields on DSR plots (Table 8). The highest yield was from plots that had no tillage —seed and fertilizer dibbled. High tillage and complete incorpo-

Table 7. Sorghum after dry-seeded rice (DSR) in a cropping pattern has greater potential for the small farmers than sorghum after transplanted rice (TPR).

Rice preceding sorghum	Nitrogen (kg/ha)	Sorghum	
		Total dry matter[a] (t/ha)	Grain (t/ha)
DSR	0	6.50 ef	1.9
TPR	0	4.05 g	1.7
DSR	40	9.15 bc	3.1
TPR	40	6.54 de	2.6
DSR	80	10.39 a	3.8
TPR	80	7.82 c	2.8
DSR	120	9.99 ab	3.8
TPR	120	8.80 b	3.3

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

Table 8. Grain yield of sorghum as affected by the preceding rice crop, tillage, and method of basal fertilizer application. IRRI, 1980.

Tillage	Method of basal fertilizer application	Grain yield[a] (t/ha)	
		After DSR	After TPR
High	Incorporated	2.07 de	1.21 f
Strip	Incorporated	3.31 c	1.90 de
Strip	Surface banded	3.34 bc	1.87 de
Strip	Dibbled	3.84 ab	2.08 de
Zero	Surface banded	4.09 a	1.71 ef
Zero	Dibbled	4.29 a	2.40 d
Av		3.49	1.86

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

ration of fertilizer before planting gave lower yield than either the banded or dibbled application methods in two different experiments.

SOCIOECONOMIC CONSTRAINTS

Although crop and livestock sales provide substantial cash flows through farm households, farmers often say they don't have money for crop inputs.

Consumption patterns of farm households

We analyzed daily records of the 1975-79 cash income and expenses of about 40 farmers at 3 Philippine cropping systems sites to determine proportions of income that farmers allocate to each of various expenditure items.

Table 9 shows the average and marginal shares of four major expenditure categories in the budgets of farm owner-operators and tenant farmers. The patterns of average expenditures are similar, with food taking more than a third of the budget and farm inputs 20%. The marginal shares show that farm operators tend to spend increases in income for personal and household needs.

Tenant farmers tend to reduce the share of personal needs —clothing, education, medical care — as well as food and

Table 9. Although farm owner-operators and tenants spend equivalent average proportions of their cash income on farm inputs, tenants tend to increase the input share as their incomes increase. That reflects a more aggressive strategy for increasing tenant welfare.

Expenditure item	Budget shares (%) by tenurial class			
	Owner-operators		Tenants	
	Average	Marginal	Average	Marginal
Food and beverage	34	29	37	32
Personal needs	25	26	20	17
Household items	21	25	23	19
Farm inputs	20	20	20	32

Table 10. As incomes increase in both small and large households, slight increases in the budget share of farm inputs can be expected. They are made possible by decline in food and personal expenditure shares combined.

Expenditure item	Budget shares (%) by size of household			
	Large household		Small households	
	Average	Marginal	Average	Marginal
Food and beverage	34	34	39	28
Personal needs	26	22	16	24
Household items	21	22	23	23
Farm inputs	19	22	22	25

household items as their incomes increase. More striking, however, is the high marginal budget share of farm inputs of 32%, compared to a present 20% average budget share. Compared with owner-operators, tenant farmers spend a higher proportion of their income increases on cash inputs.

The number of family members in a household obviously affects the manner in which income is spent, particularly for items such as food and clothing (Table 10). The linear expenditure system was estimated for small and large households by dividing the original sample at the medium household size — five members. The average budget share of food plus personal items was larger for large households, but expenditures were more highly weighted toward personal items than in small households.

Slight increases in the expenditure share of farm inputs may be expected as the incomes of both small and large households increase, but the household expenditure share appears stable.

The analysis indicates farmers are willing to invest their cash resources in farm inputs, and expand farm investments as their incomes increase. By investing in cash inputs, farmers who don't own the land they operate appear to be following a catch-up strategy in relation to owner-operators.

Work roles of family members

Studies in Iloilo province, Philippines, have shown that availability of labor is critical to the intensification of rice cropping. First crop plantings are often spread over 6 weeks after the onset of rains and there are long turnaround periods between crops.

Table 11. A study of 24 Iloilo village households observed that husbands are mainly responsible for field crops and wives for home activities. The womens' role in marketing of produce and petty merchandizing enhances their financial power in farm households.

Activity	Work time (%)	
	Husbands	Wives
Rice production	86	14
Maize production	67	33
Vegetables and minor field crops	59	41
Labor on other farms	68	32
Animal raising	61	39
Nonfarm enterprises	46	54
Home production activities	14	86

Both result from a shortage of labor — or from power shortage The end result is less crops grown in a year.

To assess the capacity of farmers to intensify cropping, we studied household activities to establish the division of tasks between women and men. Households for the study were from three categories:

- those that usually run short of rice for consumption,
- those that produce just enough rice each year, and
- those that usually have a surplus of rice.

Three stages in the family life cycle of households were distinguished:

- the childbearing stage (all children younger than 10),
- the child-rearing stage (children older than 10 and also children younger than 5), and
- the child-leaving stage (all children older than 5).

Labor data were collected from 24 of 100 farm households in an Iloilo village. The labor time spent by sample households on seven activity groups was estimated for the crop year 1978-79. Table 11 shows the division of labor between wife and husband.

The effect of the family life cycle on the labor pattern is seen in Tables 12-13. In later stages of the family life cycle, children take over many of the home production activities, and the mother spends more time on the farm and other activities. Children also

Table 12. Farm wives in poorer households supplement income by working on other farms; but without investment capital, they engage less in livestock raising.

Household group	Work hours/year						Hours/day (av)[a]
	Farm production			Farm wage labor	Other enterprises	Home production	
	Rice	Other crops	Live-stock				
Wealth category							
Rice deficient	68	67	122	149	258	1179	5.0
Rice sufficient	46	96	580	20	119	1452	6.3
Rice surplus	32	99	1213	—	322	1497	8.7
Stage in life cycle							
Childbearing	34	75	428	24	189	1885	7.2
Child-rearing	95	82	436	112	146	1070	5.3
Child-leaving	40	96	607	62	236	1201	6.1
Av	52	86	516	63	202	1361	6.2

[a]Excludes walking time to fields; computed as total per year divided by 365.

Table 13. Husbands in wealthier households assist more at home and generally work less at farm activities. As children get older, fathers hand over much of the job of grazing carabaos.

Household group	Work hours/year						Hours/day (av)[a]
	Farm production			Farm wage labor	Other enterprises	Home production	
	Rice	Other crops	Live stock				
Wealth category							
Rice deficient	251	140	979	147	193	178	5.2
Rice sufficient	261	145	1230	50	125	275	5.7
Rice surplus	219	125	794	-	120	262	4.2
Stage in life cycle							
Childbearing	252	165	1613	90	148	312	7.1
Child rearing	301	172	992	140	244	119	5.4
Child leaving	225	110	792	37	102	255	4.2
Av	251	140	1070	77	149	238	5.3

[a]Excludes walking time to fields; computed as total per year divided by 365.

take over part of the grazing of carabaos and the farmer can spend more time in farm activities during the critical child-rearing stage when household composition requires relatively high food production.

To increase family income directly, wives in the lowest income group spend less time in home production and more time working for wages on other farms, in other enterprises, and on their own farm's rice production. The husbands also work more on other farms than their wealthier counterparts, and spend less time in home production.

Children contribute to farm labor and earnings. They work on other farms for wages more than their parents do and actively assist in farm and home production (Table 14). Significantly, they are excluded from enterprises such as marketing and petty merchandising.

Generally, work time approaches 6 hours a day, 365 days a year. If walking time to fields were included, a 7-hour workday would be a good estimate of allocatable labor per adult. A small

Table 14. Children in farm household supply labor equivalent to that of one parent. Particularly in poorer households, the children work more than their parents for wages on other farms.

Household group	Work hours/year						Hours/day (av)[a]
	Farm production			Farm wage labor	Other enterprises	Home production	
	Rice	Other crops	Live stock				
Wealth category							
Rice deficient	164	82	365	226	11	605	4.0
Rice sufficient	209	104	674	114	7	713	5.0
Rice surplus	165	34	534	16	13	552	4.5
Stage in life cycle							
Childbearing	0	0	0	0	0	5	0
Child rearing	374	173	664	302	28	1216	7.6
Child leaving	200	194	795	138	5	739	5.7
Av	186	134	541	139	9	648	4.5

[a]Excludes walking time to fields, computed as total per year divided by 365.

Grain drying is work that is often left to women and children on the farm.

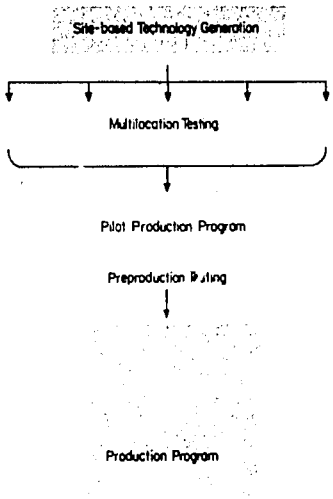
proportion of that is available to rice farming, however — 13% of farmers' time and 2% of wives' time — although the proportion is higher if carabao tending time is included as part of rice farming. About 50% of the husband's and 20% of the wife's time is spent tending livestock.

PREPRODUCTION TESTING OF CROPPING SYSTEMS

The preproduction phase of cropping systems research consists of multilocation testing and pilot production programs (Fig. 9). During 1980, the Philippines' highly successful KABSAKA pilot production program, which we helped start in 1977-78, became a production program in Iloilo province. The achievements of KABSAKA in Iloilo helped the Philippine Government obtain a loan from the World Bank for a provincewide development project. During 1980, the KABSAKA technology was adopted rapidly by farmers in other provinces of Panay and Negros.

We continued to assist with preproduction testing of a two-rice-crop system in rainfed areas of Mindanao, with pilot production programs called KASATINLU, MATISAYON, and ZAMDUGANI in the provinces of South Cotabato, North Cotabato, and Zamboanga del Sur.

During 1980, more than 800 farmers cooperated in KASATINLU. First crop (direct-seeded) rice yields averaged 4.8 t/ha. The yield of the second crop, which was also direct seeded because of high labor costs associated with pulling and transplanting of seedlings, was 4.5 t/ha. Because Mindanao is free



9. Preproduction testing is a link between site-based technology generation and production by farmers.

from typhoons and has a long wet season, the two-rice-crop system may have greater potential there than in Iloilo. KASATINLU farmers increased their cropping intensity from 190% to 255%. In Iloilo, KABSAKA farmers had a cropping intensity of 213%.

We started work with MANBILAYKA, a pilot production program with a rice-dryland crop pattern in Pangasinan province. Improving the management practices for mungbean or peanut grown after rice gave substantial income increases to Pangasinan rice farmers.

Intensive cropping systems

Two intensive cropping systems — a continuous rice production system and sorjan — were further refined in 1980.

Continuous rice production system. We harvested 20.1 t/ha from 4 crops in the 1980 *rice garden* at IRRI — close to the 1979 yield of 21.7 t/ha. The rice garden was tested on farms at 7 sites in the Philippines with an annual yield ranging from 18 t/ha in Bicol to 33 t/ha in Batangas.

Variability of rice production in the rice garden was influenced more by solar radiation than by any other factor. Typhoon damage occurred but yield loss was reduced because each plot was at a different stage of growth — a selling point for the system. Again in 1980 we noted no obvious insect buildup or conspicuous rat damage in the IRRI rice garden. Severe rat damage in October-December was reported from a Mindoro rice garden, but the farmer had no rice or other crops in surrounding fields.

Sorjan. Tests of the sorjan system were repeated in rainfed fields at IRRI (Table 15). During the rainy season, raised beds successfully produced a first crop of rice with yield of 2.1 t/ha. Dryland crops were planted following rice in the sinks, but typhoons kept the sinks flooded and only peanut withstood the standing water.

We compared dryland crop production in sorjan beds with flat beds in an open field. The raised beds showed a slight favorable

Table 15. In rainfed plots at IRRI, yields of dryland crops on raised beds and rice in sinks of the sorjan system were slightly lower in 1980 than in 1979. The yields reported here are for one crop. With sorjan two to three such harvests per calendar year are possible.

Site and crop	Crop yields			
	Jun-Sep		Oct-Dec	
	1979	1980	1979	1980
Raised beds				
Soybean (t/ha)	3.2	2.0	2.5	1.4
Mungbean (t/ha)	1.2	1.2	1.7	0.8
Maize	15.8[a]	3.0[b]	86.5[a]	4.5[b]
Sinks				
Rice (t/ha)	2.1	2.1	1.7	—[c]

[a]Yield in thousand marketable ears per hectare. [b]Grain yield in tons per hectare. [c]Rice replaced by dryland crops, which failed.

Mungbean on a raised bed in 1980 sorjan trials at IRRI is checked by Rodolfo Salcedo, IRRI training assistant. The bed-sink system has (front-rear) soybean – rice – mungbean – rice – sorghum.

effect on crop performance in some patterns (Table 16). Tests of the sorjan system continued in farmers' rainfed and irrigated fields throughout 1980. Irregular rains and typhoons gave combinations of scanty and excessive water. Yields of dryland crops suffered at several sites, but rice yields were moderately high, ranging from 2.7 to 5.7 t/ha.

Table 16. Comparative yields of the first 2 crops in 8 rainfed cropping patterns in a sorjan system and a rainfed flatbed system at IRRI in 1980. The third or fourth crops in the patterns were still in the field at the end of 1980.

System	Crop yield (t/ha)			
	Rice	rice	cassava	
Sorjan bed	2.0	1.0		
Flat bed	2.3	1.2		
	Maize	soybean	maize	soybean
Sorjan bed	3.4	1.6		
Flat bed	1.8	1.2		
	Mungbean	sorghum	mungbean	sorghum
Sorjan bed	1.0	1.8		
Flat bed	0.9	1.6		
	Maize	soybean	cassava	
Sorjan bed	2.5	1.7		
Flat bed	1.9	1.2		
	Sorghum	mungbean	sorghum	mungbean
Sorjan bed	1.6	0.6		
Flat bed	2.5	0.2		
	Soybean	maize	soybean	maize
Sorjan bed	2.3	4.0		
Flat bed	2.6	1.9		
	Soybean	soybean	soybean	soybean
Sorjan bed	2.0	1.3		
Flat bed	2.6	1.2		
	Mungbean	mungbean	mungbean	mungbean
Sorjan bed	1.3	0.2		
Flat bed	0.9	0.2		

Table 17. One-crop yields of dryland crops on sorjan beds and rice in sinks on heavy clay soils at IRRI. Three to four such crops per year can be harvested in the sorjan system.

Crop	Variety	Maturity (days)	Yield (t/ha)
Soybean	Clark 63	90	2.2
Mungbean	CES ID-21	68	0.9
Sorghum	Cosor-3	110	3.2
Cowpea	EG No. 3	72	0.9
Rice	IR36	110	6.1

A 1980 test showed that rice-based cropping patterns can be grown on heavy clay soils. Raising of sorjan beds eliminated flooding of the bed soil in an irrigated area on heavy clays even during the rainy season. A granular soil developed on the raised beds and moderately high yields of dryland crops resulted. Rice yield in the sinks was high (Table 17).

MACHINERY DEVELOPMENT

Speed is an essential element to farmers for taking advantage of modern rice production technology. To intensify — and increase — rice production a farmer must harvest his crop, prepare the land, and plant the next crop in as short a time as possible. But those operations — especially when they are done manually — usually come when there is a shortage of labor.

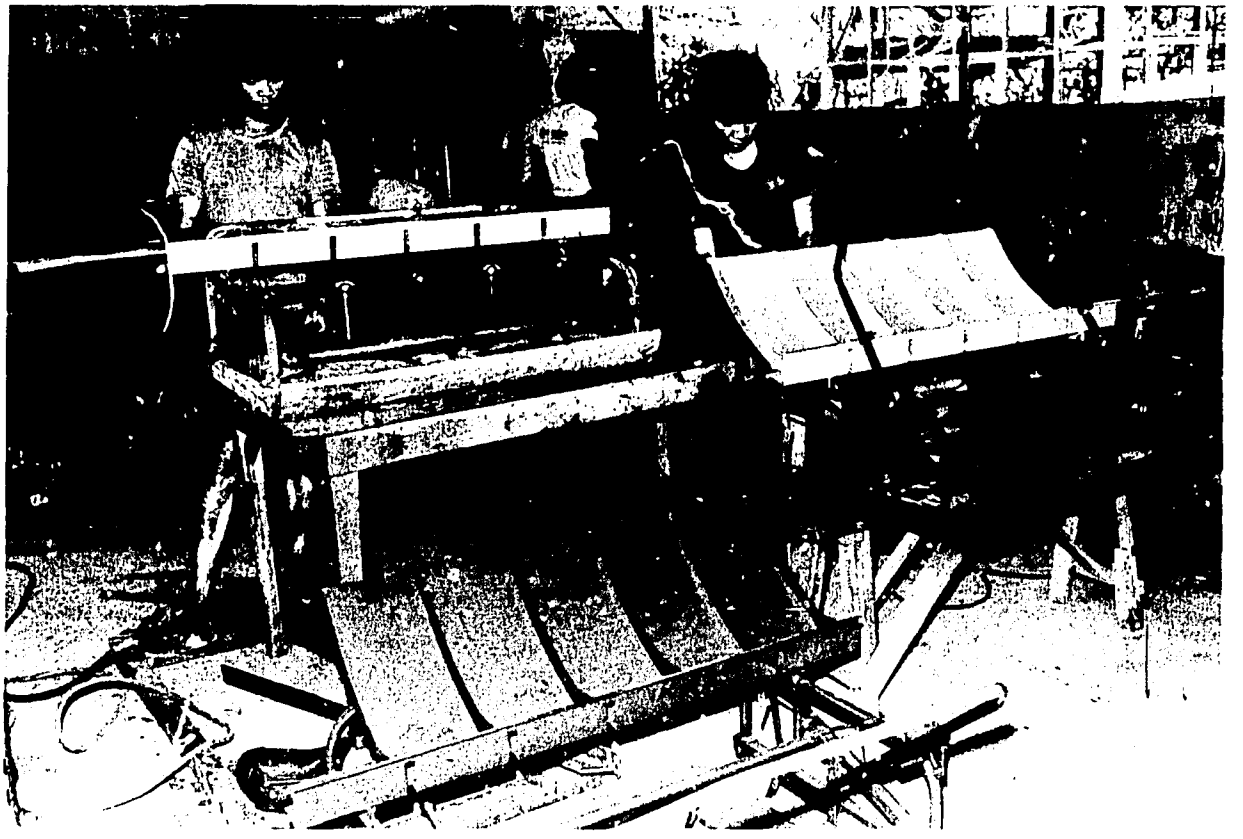
In 1980 we introduced two machines that can help farmers save time — a manual rice transplanter and a rice hull furnace. We also began working on a reaper attachment for the IRRI power tiller, which will enable the farmer to harvest his crop faster.

Manual 5-row transplanter

IRRI engineers worked for several years on a manual rice transplanter that will enable a farmer to plant his crop without outside labor. A transplanter was officially released in 1980 for production by local manufacturers. The machine will plant 5 rows at 20-cm row spacing and can reduce planting time 30-50%. One man can transplant 1/4 ha/day. The low-cost, simple machine can be manufactured by any local machine shop and is in demonstrations and tests in several countries of Asia.

Rice hull furnace

Rapid grain drying after harvest is essential for farmers to maintain high grain quality. Drying in the sun can be slow and tedious, and is often impossible in the rainy season. A fuel-fired



The manual 5 row transplanter went into production in local manufacturing shops in 1980. Two men in this small shop in the Philippines produce an average of 1 transplanter per week.

dryer can mean speed, savings, and higher rice price. But with increasing costs of fossil fuels, there is considerable interest in finding cheaper ways of drying grain. A rice hull furnace introduced early in 1980 provides sufficient heat for the 1- or 2-ton batch dryers we introduced in 1977.

The initial cost of the rice hull furnace is about US$320 — about 4 times the cost of a kerosene burner with the same drying capacity.

Vertical reaper

Under a machinery exchange arrangement with China, IRRI engineers began working on a reaper for small paddies. A Chinese design was adapted to fit the IRRI two-wheeled tractor and two machines are being tested: a 1.6-m-wide model, and a 1-m-wide model. The 1-m reaper is powered by a 3-hp tractor developed at IRRI but not yet released for production.

A farmer can harvest about 3 ha/day with the 1.6-m reaper, and 2 ha/day with 1-m reaper.

Machinery extension in Asia

Our Industrial Extension Program assists local manufacturers in the fabrication and sale of IRRI-designed machines. International

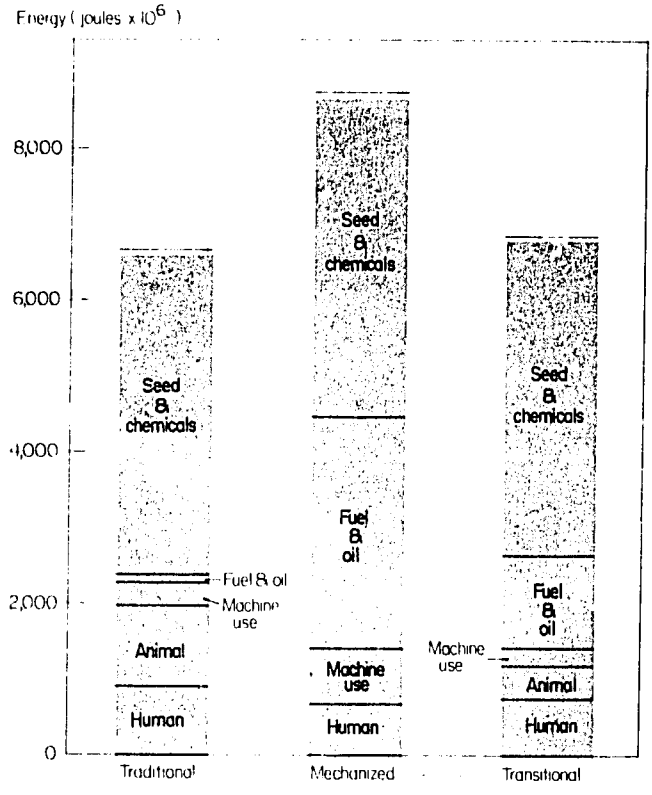
standards are translated into the local language, and training programs for engineers are conducted in the local language. The program covers Pakistan, Burma, Indonesia, Thailand, Egypt, and the Philippines. Plans were formulated in 1980 to include India and to expand the work in the Philippines.

ECONOMICS OF MECHANIZATION

Energy in rice production

In a study of three levels of mechanization in rice production systems using modern varieties, we found that increased use of machinery increases the dependence of farmers on commercial forms of energy. In all three systems, however, the largest quantity of energy was supplied as chemical fertilizers and pesticides. A similar picture emerged when the source of energy in each system was examined (Fig. 1). Even in the mechanized system, which used mechanical land preparation, threshing, and drying, the energy content of the fuels used was less than that contained in inorganic fertilizers.

Despite the higher overall use of energy in both the transitional and mechanized systems, the mechanized system cost less than the traditional system (Table 1). This indicates that mechanized



1. Total energy inputs by source, in joules per hectare, in 3 levels of mechanization in rice production systems

Table 1. In a 1980 study of rice farm mechanization in Central Luzon, inputs costs for a mechanized system were appreciably lower than costs in the traditional human- and animal-powered system.

Item	Input costs[a] (US$/ha)		
	Traditional	Transitional	Mechanized
Seed	8.00	8.00	8.00
Fertilizer	23.20	23.00	23.30
Insecticide	27.00	27.00	27.00
Herbicide	26.60	26.60	26.60
Fuel	0.38	6.04	15.41
Machinery	10.00	24.00	29.34
Animal power	68.25	25.35	0
Human labor	125.00	114.46	92.68
Total	288.43	254.65	222.24

[a]Input prices are averages prevailing in rural areas of the Philippines. US$1 = P7.35

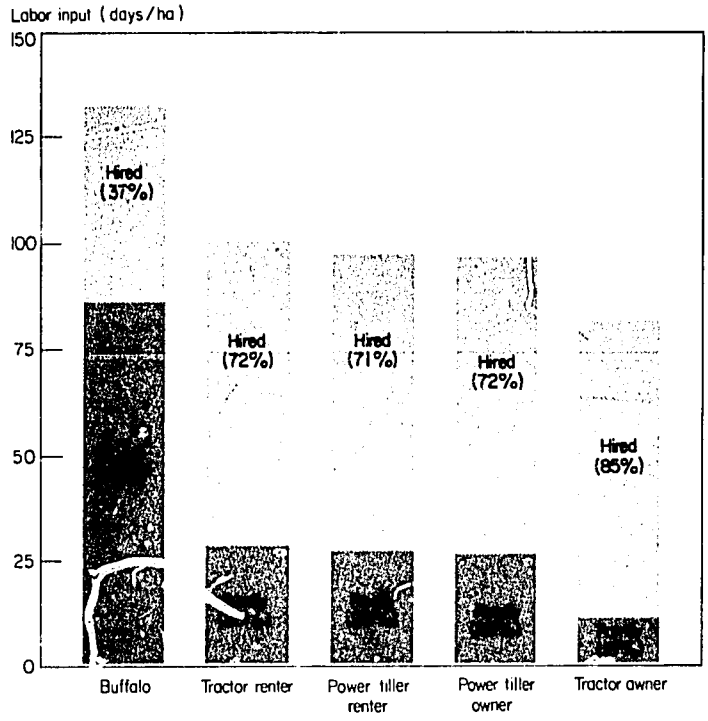
systems are competitive. It also points to improved efficiency in the use of chemicals as potentially the greatest source of energy savings in all systems.

Mechanization and employment

As farmers mechanize, they frequently increase the use of hired labor. A sample survey of 184 farms in Central Luzon, Philippines, where various combinations of machinery were used for land preparation, indicated little difference in total labor use for land preparation on farms using 2-wheel tractors or renting 4-wheel tractors (Table 2). More labor was used on farms where water buffalo were used. Animal-powered farms tended to be smaller, however, than mechanized units. They also retained a higher proportion of their crop for home consumption. Larger farms often sold a major portion of the crop immediately after threshing, which reduced labor requirements for drying and storage compared with those on buffalo-powered farms. Nevertheless, the percentage of hired labor requirements was higher on mechanized farms than on buffalo farms (Fig. 2). Although mechanized farms have lower total labor requirements, the proportion and total days of hired labor were greater for such farms than for the animal-powered units in the study area.

Table 2. Data gathered for the 1978 wet season in Central Luzon indicate that tiller and tractor owners or renters used less labor but increased their use of hired labor (see Fig. 2).

Farm operation	Total (family plus hired) labor used (days/ha)				
	Power tiller (2-wheel)		Tractor (4-wheel)		Water buffalo
	Owner	Renter	Owner	Renter	
Irrigation	1.6	1.9	1.5	1.5	1.2
Land preparation	8.3	13.3	7.0	11.2	21.9
Seedbed & transplanting	21.9	22.8	20.6	24.9	24.7
Chemical application	4.2	3.0	3.5	4.2	4.8
Weeding	8.6	5.7	5.5	9.9	15.8
Harvesting	26.2	25.7	28.8	27.2	30.6
Threshing	18.3	17.3	10.3	16.4	20.3
Drying	7.4	6.2	5.0	6.2	18.1
Total	96.5	95.9	82.2	101.5	137.4



2. The 1978 labor requirements, by source, among 184 farms with different sources of power for land preparation in Central Luzon, Philippines.

The reduction of use of family labor on farms has been shown, in other IRRI studies, to allow the wife to spend more time in the home and children to spend more time in school.

ASSOCIATED FORMAL TRAINING

Our training program continued to serve national rice improvement programs through a wide range of training activities at IRRI. We had 455 participants from 28 countries worldwide in training programs at IRRI during 1980. Among them were 38 postdoctoral fellows, 89 MS and 44 Ph D candidates, 46 nondegree scholars and fellows, and 238 participants in formal training courses. The distribution of the participants in the various training programs is shown in Tables 1 and 2.

Most of our research fellows and scholars do course work at the University of the Philippines at Los Baños (UPLB) and conduct their thesis research at IRRI. In 1980, however, a few students did course work in developed countries and some of those will return to IRRI to do their thesis research.

Table 1. Distribution, by department, of IRRI research fellows and scholars, 1980.

Department	Post-doctoral	Research fellows			Research scholars		Total
		Ph D	MS	N.D.[a]	MS	N.D.[a]	
Agronomy	8	5	4	2	6	3	28
Plant Breeding	4	7	–	2	7	6	26
Agricultural Economics	3	6	5	1	7	1	23
Entomology	5	4	2	–	4	6	21
Multiple Cropping	2	4	6	–	6	2	20
Plant Physiology	3	2	3	4	1	3	16
Agricultural Engineering	1	3	1	2	6	1	14
Soil Chemistry	5	2	3	1	1	2	14
Water Management	1	3	–	–	8	1	13
Plant Pathology	2	1	–	2	7	–	12
Soil Microbiology	4	–	1	1	2	2	10
Chemistry	–	1	–	–	–	1	2
International Rice Testing Program	–	1	3	–	1	–	2
Office of Information Services	–	–	–	1	–	1	2
Rice Production Training and Research	–	–	2	–	–	–	2
Statistics	–	–	1	–	–	–	1
Training Office	–	–	–	1	–	–	1
Total	38	39+5[b]	28	17	56+5[b]	29	217

[a]Nondegree. [b]Abroad.

Table 2. Distribution by country of participants in various training courses.[a] 1980.

Country	CSTP[b]	GEU[c]	RPTP[d]	INSFFER[e]	IWMT[f]	AEC[g]	Total
Bangladesh	8	9	4	2	–	1	24
Indonesia	6	5	4	2	5	2	24
Philippines	8	3	–	2	10	–	23
China	–	12	–	8	–	2	22
Thailand	7	3	3	2	4	–	19
Malaysia	5	1	3	1	1	–	11
Sri Lanka	2	3	2	1	2	–	10
India	–	–	6	–	–	3	9
Burma	3	3	2	–	–	–	8
Pakistan	–	4	1	2	–	–	7
Nepal	2	–	1	–	–	–	3
Egypt	–	–	–	–	–	2	2
Vietnam	2	–	–	–	–	–	2
Kenya	–	–	1	–	–	–	1
Senegal	–	1	–	–	–	–	1
Uganda	–	–	1	–	–	–	1
Total	43	44	28	20	22	10	167

[a]Excludes participants in 2-week Rice Production Training Course which was offered twice, one in June and another in December, and had a total of 71 trainees. [b]Cropping Systems Training Program. [c]Genetic Evaluation and Utilization. [d]Rice Production Training Program. [e]International Network for Soil Fertility and Fertilizer Evaluation for Rice. [f]Irrigation Water Management Training. [g]Agricultural Engineering Course.

The participants in our formal training course spent about 50% of their time working on field and greenhouse experiments. This practical side of training was supported by lectures on basic principles and methodologies by IRRI and UPLB scientists.

Special short courses were offered to train workers — 24 persons from 6 countries — in component technology for rice-based cropping systems — economics, plant pathology, entomology, and cultivar testing.

INTERNATIONAL ACTIVITIES

Our international projects and activities include

- training,
- cooperative country projects,
- international research networks,
- collaborative research, and
- general services to national programs, such as workshops, conferences, symposia, and distribution of rice literature.

Cooperative country projects operate in Bangladesh, Burma, Indonesia, Pakistan, Philippines, Sri Lanka, and Egypt.

In 1980, collaborative work plans with Indonesia, Russia, and Vietnam were developed. We continued discussion via this approach for implementing research collaboration with Bangladesh, Sri Lanka, and Thailand.

IRRI scientists continued to coordinate a number of international research networks. The continuing success of those networks involves mutual interest on the part of national programs and IRRI; joint planning and consultation on the kinds of entries or treatments to be included; joint evaluation of results; and joint planning of future work and activities of the network.

There were five such research networks in 1980:

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

We continued to post liaison scientists in Africa, India, Indonesia, Malaysia, Latin America, and Thailand. The liaison scientist assisted in developing and administering collaborative projects and helped coordinate the activities of the different research networks. The liaison scientists provided essential close contacts with national programs for identification and recommendation of scientists to participate in our training programs and various conferences and workshops.

FINANCES

The Institute received $19,263,203.71 during 1980.

The Ford Foundation gave $315,565 — $100,000 for core operations and capital expenditure, and $215,565 in support of rice research and development in Thailand ($20,565), Bangladesh ($170,000), and the Philippines ($25,000).

The Rockefeller Foundation gave $253,429.46, which included $200,000 for core operations and capital needs, $26,400 toward the stipend and miscellaneous expenses of a postdoctoral appointee; $25,000 toward preparation and planning of a conference on chemical research and its application to the world's expanding food needs; and $2,029.46 as a grant for 1979-80 in appreciation for the cordial reception accorded to Rockefeller Foundation fellows.

The United States Agency for International Development (USAID) gave $5,574,080.18 — $3,830,000 for core operations, $50,702.18 for expanding, strengthening, and further institutionalizing the National Applied Research and Extension Program for Transplanted Rice; and $337,468.42 for industrial extension of small-scale agricultural equipment developed at IRRI.

USAID also released $1,355,909.48 for continuing contracts:

- $214,253.64 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 a USAID loan.
- $408,084.47 for supporting a 2.5-year project for accelerated development and use of improved rice technology in Indonesia.
- $99,035.25 for collaborative rice research in Pakistan.
- $273,557.22 for a project on the consequences of mechanization on small farms.
- $227,275.90 for the services of an industrial extension engineer for the small-scale agricultural equipment extension project of the Government of Indonesia.
- $133,703 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 for children.

The Japanese Government gave $2,800,000 for purchase of research and training equipment, for partial support of cropping systems research, for expenses of the Plant Physiology and Soil

Microbiology Departments, and for partial support of the GEU program.

The Ministry of Overseas Development, United Kingdom, gave $1,148,250 for the core program.

The Canadian International Development Agency gave $1,088,750 for core operations; $341,855 for cooperation between the Bangladesh Rice Research Institute and IRRI; and $634,785.45 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 Centre (IDRC), Canada, gave $412,907.42. Of that $29,748 was part of a 3-year grant for cropping systems outreach in South and Southeast Asia. The IDRC grant included $43,306.42 as part of a 2-year support of research in cooperation with the Central Research Institute for Agriculture, Indonesia, to develop cropping systems for rainfed and partially irrigated rice areas and to adapt them in farmers' fields; $209,543 as part of a 4-year grant to support a multiple cropping research project at the Bangladesh Rice Research Institute; $120,430 for the International Rice Agro-Economic Network (IRAEN) Phase II; and $9,880 to support scholarships at IRRI and the University of the Philippines at Los Baños leading to MS in Weed Science.

The European Economic Community gave $1,352,885.51 for water management, scholarships for candidates from developing countries, and partial support of the GEU program.

The Australian Government gave $811,433.86, of which $583,569 was for core operations, including travel of Australian scientists, and $227,864.86 for expansion of technical assistance and collaborative relationships with the Bangladesh Rice Research Institute.

The Federal Republic of Germany gave $850,464.70 for core operations; $15,000 for support of a research associate; $9,129.47 for support of a visiting scientist in soil microbiology; and $79,125 as first installment for the construction of an Isotope Laboratory.

The International Development Association gave $255,000 for core operations and capital expenditures.

The United Nations Development programme released $1,439,028, of which $1,152,900 was for the International Rice Testing Program; $274,128 to investigate nitrogen fixation associated with wetland rice; and $12,000 toward a meeting of the Nitrogen Fixation Advisory Committee.

The International Fund for Agricultural Development gave $500,000 for research on rice-based cropping systems.

The OPEC Special Fund gave $200,000 to support the GEU program.

The Government of Indonesia, using a World Bank loan, released $168,362 to IRRI for development of research facilities at the Sukamandi Branch of the Central Research Institute of Agriculture and for scientific and technical assistance to rice research at Sukamandi.

The Government of Denmark gave $165,158.16 for the core program.

The Government of the Philippines gave $100,000 for the core program.

The Government of Sweden gave $119,760.48 for the core program.

The Swiss Federal Council, represented by the Swiss Development Corporation, gave $255,700 to support the studies on the effectiveness of nitrogen fertilizers used for rice.

The Government of New Zealand gave $24,300 for the core program.

Since July 1976, a contract between IRRI and the International Centre of Insect Physiology and Ecology has supported a joint program for ecological research on rice planthoppers using funds from the Australian Government. In 1980, $25,562.01 was released for use.

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 $36,557.46.

In 1976, IRRI entered into a cost-reimbursement contract with the U.S. National Institutes of Health to study ways of increasing protein and essential amino acids in the rice grain through plant breeding. In 1980, $13,729.42 was reimbursed.

Other donors were:

- Philippine Council for Agriculture and Resources Research:
  - (a) cooperative applied research on rainfed rice $24,961.42
  - (b) cooperative project toward improved organization of small farmers for intensified rice production 5,421.62
- National Food and Agriculture Council, training government extension technicians 94,024.38
- International Board for Plant Genetic Resources, field collection of indigenous rice germplasm in South and Southeast Asia 20,000.00

- 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 2,500.00
- FMC, International, entomological research 3,000.00
- Montedison, pest control 3,000.00
- Cyanamid Overseas Corporation, weed control and insect control 2,000.00
- Uniroyal Chemical, pesticide research 496.06
- Shell Chemicals Co., research on agricultural chemicals 6,756.75
- University Hohenheim Stuttgart, travel for Dr. Ottow's research project 4,370.40
- United Nations University, research on protein requirements of young Filipino adults 7,764.50
- Office of Rural Development, Korea, seed multiplication program and cooperative research program 86,590.00
- Kemanobel, pesticide research 500.00

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OSAMU HORINO, D Agr, visiting plant pathologist*
ROBERT E. HUKE, Ph D, visiting scientist*
SISIRA JAYASURIYA, Ph D, associate agricultural economist
DEBRAH JEFFERSON, MS, visiting associate editor
JOHN PAUL JONES, Ph D, visiting scientist
ULYSSES S. JONES, Ph D, visiting scientist*
BIENVENIDO O. JULIANO, Ph D, chemist
HAROLD E. KAUFFMAN, Ph D, plant pathologist
GURDEV S. KHUSH, Ph D, plant breeder
MASAO KIKUCHI, D Agr, associate agricultural economist
HAJIMU KOMADA, Ph D, visiting scientist*
DONALD W. KUETHER, MS, associate agricultural engineer*
KEH-CHI LING, Ph D, plant pathologist
JAMES A. LITSINGER, Ph D, entomologist
JOHN A. MCMENNAMY, MS, agricultural engineer*
TWNG-WAH MEW, Ph D, plant pathologist
KEITH MOODY, Ph D, agronomist
RICHARD A. MORRIS, Ph D, agronomist
CHARLES J. MOSS, BS, agricultural engineer*
MARVIN L. NAFZIGER, BS, associate agricultural engineer
JATA S. NANDA, Ph D, plant breeder*
FLOYD H. NORDLAND, Ph D, training specialist*
JOHN C. O'TOOLE, Ph D, agronomist
J. C. G. OTTOW, Ph D, visiting soil scientist
CHON SUH PARK, Ph D, visiting scientist
MANO D. PATHAK, Ph D, entomologist†
JOHNNY W. PENDLETON, Ph D, agronomist
JOHN PERFECT, MS, visiting scientist
FELIX N. PONNAMPERUMA, Ph D, principal soil chemist
EDWIN C. PRICE, Ph D, agricultural economist
FEDERICO V. RAMOS, MS, farm superintendent
W. HARVEY REISSIG, Ph D, visiting scientist*
WALTER G. ROCKWOOD, MS, editor
PIERRE A. ROGER, D Pedologie, visiting scientist*
MILTON C. RUSH, Ph D, visiting plant pathologist*
ORLANDO G. SANTOS, MPS, associate farm superintendent
RAMESH C. SAXENA, Ph D, associate entomologist
LESLIE E. SMALL, Ph D, visiting agricultural economist*
WILLIAM H. SMITH, BS, editor
JOHN VARLEY, Ph D, visiting scientist*
BENITO S. VERGARA, Ph D, plant physiologist
LINA M. VERGARA, MS, librarian
S. S. VIRMANI, Ph D, visiting scientist
IWAO WATANABE, D Agr, soil microbiologist
J. PAUL WEBSTER, Ph D, visiting scientist
JOHN A. WICKS, Ph D, associate agricultural engineer
SHOUICHI YOSHIDA, D Agr, plant physiologist
HUBERT G. ZANDSTRA, Ph D, agronomist and cropping systems program leader*

*Left during the year
**On study leave
†Part time