RESEARCH HIGHLIGHTS FOR 1978

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Our potential for future international cooperation was greatly enhanced in 1978 by development of productive cooperation with scientists from the People's Republic of China. This accomplishment was the culmination of 4 years of friendly exchanges among IRRI scientists and administrators, and officials of China. In 1974, the Director General of the International Rice Research Institute visited

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

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IV

An international focus on food production

History will surely record the 1970s as the *decade of international focus* on food production. The decade had barely started when the worldwide food shortages of 1973–75 occurred. That crisis produced the shocking realization that the world could face a period of chronic food shortages with their concomitant famines and social unrest.

The response to the 1973–75 debacle was dramatic. Most countries took positive steps to increase food producing (or purchasing) capacity. Existing international organizations focused – or refocused – their attention on food production. A world food conference was convened and a World Food Council organized. Food production was placed in highest priority by the World Bank and other major aid donors and lending agencies. Similarly national agencies put agriculture and food at high priority levels in their national plans.

The very favorable global food grain harvests since 1975 have not seriously altered the international concern for food. We are generally aware that the per capita food production in the developing countries was about the same in 1977 as it was in 1973 – despite favorable weather in 1977 (and continuing in 1978) that boosted food grain production markedly, especially in India. The post-1975 gains, plus an overall buildup of food stocks, have given the uninformed the impression that the world's food concerns may be over.

But a visit to Bangladesh would quickly dispel that impression. That country is faced with record droughts and a marked curtailment in rice production. Likewise, Indonesian farmers have endured bad weather and brown planthopper epidemics, as have rice farmers in Vietnam. Even Korea, which has one of the world's highest average rice yields per hectare, had a temporary setback in 1978 because of low temperatures and an unusual infestation of rice blast.

The overall increase in food grain stocks in recent years is also misleading. For example, most of the rice stocks are in three countries: India, Japan, and the United States. Stock levels in most other countries are small, and many countries continue to import rice. The increase in food grain stocks registered in 1978 was due mainly to increases in United States stocks. In fact a small decrease occurred in the total stocks of the developing countries.

Even though the world appears to have a temporary respite from the food crisis of the early 1970s, the need for international focus remains. We must deal with the immediate shifts in food to handle the current food shortage in Bangladesh, and with the longer-range problem of how to double the food production levels by the end of this century.

New high of IRRI international activity

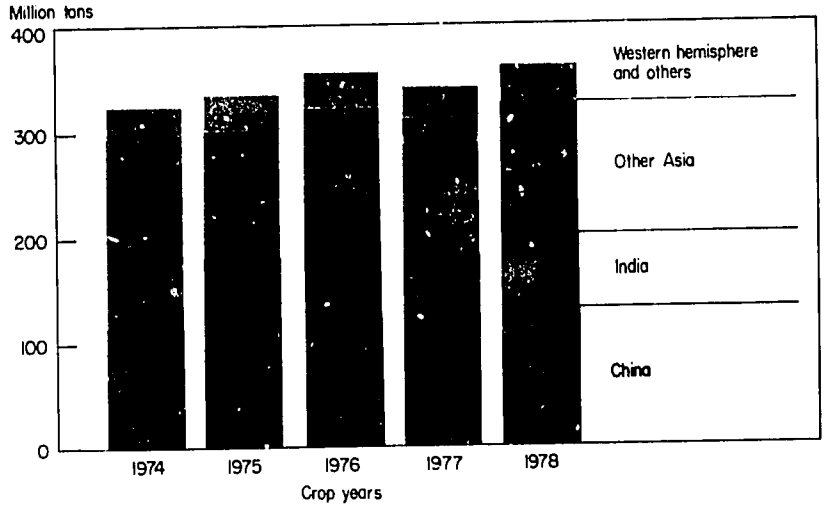
The year 1978 saw a new high in IRRI involvement in international cooperation. The international research networks, which IRRI helped initiate earlier, made continued achievements. The specific progress of the International Rice Testing Program and of the Cropping Systems Program were most impressive, and our agroeconomic constraints and farm machinery networks continued to provide linkages with scientists and engineers in other countries.

Our potential for future international cooperation was greatly enhanced in 1978 by development of active cooperation with scientists from the People's Republic of China. This accomplishment was the culmination of 4 years of friendly exchanges among IRRI scientists and administrators, and officials of China. In 1974, the Director General of IRRI visited China as a member of a U.S. Plant Sciences study team. Chinese agricultural officials on trips to the Philippines visited IRRI in 1975 and early in 1976. They invited three IRRI teams of scientists to tour important rice-growing areas of China. Many Chinese scientists and other officials visited IRRI.

In 1978, four Chinese rice scientists spent nearly 8 months at IRRI. While there they participated in a 4-month GEU training course and had joint research projects with IRRI scientists. Several Chinese scientists participated in 1978 international conferences at IRRI.

Early in 1979, we formalized our working relationships with the Chinese Academy of Agricultural Sciences and developed a formal resumé of cooperation that includes the exchange of genetic materials and scientists. Among the other areas of mutual interest are genetic resource collection and storage, international rice testing,

During the past 5 years sustained efforts have been made to increase the cooperation between the People's Republic of China and IRRI. Progress is illustrated in the photographs at right. 1. September 1974 Director General Brady visited China with a U.S. Plant Sciences study team. He presented IRRI rices to Chinese officials and extended them an invitation to visit IRRI. 2. March 1976 Agricultural Vice Minister Yang Li-Kung led a team of Chinese scientists and administrators on a visit to IRRI. Dr. Pathak shows them research on the brown planthopper. 3. October 1976 Eight IRRI scientists were invited to tour Chinese rice research and production areas. The IRRI team is shown with Chinese colleagues at the Shanghai Academy of Agricultural Sciences. 4. September October 1977 Mr. Wu Tung-Chiang, chairman of the Kwangtung Academy of Agricultural Sciences, led a team of scientists to IRRI. They visited on-farm research areas near IRRI. 5 & 6. August 1977 Two IRRI teams were invited to tour parts of China and observe research on genetic evaluation and utilization (GEU) and cropping systems. Shown are IRRI GEU scientists with Chinese colleagues in field plots in Kwangtung province and the IRRI cropping systems team visiting an irrigation project in Kwangtung province. 7. March 1978 Vice Premier Li Hsien-Nien and Foreign Minister Huang Hua, accompanied by Mrs. Imelda R. Marcos, headed a delegation to IRRI. 8. August 1978 The first four Chinese scientists arrived to participate in research and training at IRRI. They are shown with an IRRI scientist (center). 9. November 1978 Mr. Chin Li-Sheng, deputy secretary-general, Chinese Academy of Sciences, led a team of distinguished scientists to see IRRI research. 10. January 1979 Mr. Ho Kuang-Wen, vice president of the Chinese Academy of Agricultural Sciences, and IRRI Director General Brady formalized relationships by signing a resumé of future cooperation between scientists of the two institutions. 11. January 1979 Chinese and IRRI scientists witness the 7 January signing of the resumé by Vice President Ho Kuang-Wen and Director General Brady.



1. World rice production for 1974–78. China produced nearly 35% of the total in 1978.

innovative breeding techniques, biological fixation of nitrogen, small-farm machinery development, and fertilizer efficiency.

Cooperation with China on rice research is an important milestone, not only for IRRI, but for all rice-growing countries. China is the world's largest rice producer. It produces far more rice than all the countries of North and South America and of Africa, combined. Its production is about as much as that of all the other countries of Asia, excluding India, combined (Fig. 1).

But China's importance as a cooperator is not based strictly on the size of its rice crop. The rice genetic resources in that country are invaluable sources of genetic variability, which breeders can use to help improve rices around the world. Chinese scientists have made remarkable progress in developing and utilizing hybrid rice. They report about 5 million hectares of new hybrids.

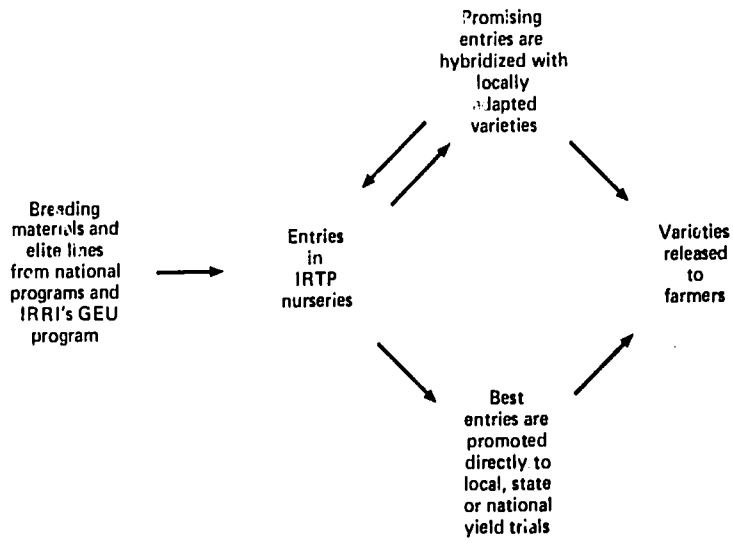
The expanding cooperation with China can also be significant to that country. It gives Chinese scientists access to the world's largest collection of rice genetic resources. It will encourage an interaction with scientists from other rice-growing countries, and especially those from Asia. Breeding lines with host resistance to major insects and diseases – a major concern in South China – can be exchanged as can scientists among cooperating countries. Already plans are under way for a jointly sponsored conference-cum-monitoring tour to be held in South China in October 1979. Scientists from other Asian countries and from IRRI will participate along with their Chinese counterparts.

Major achievements

The International Rice Testing Program (IRTP) continues to be a major focal point for cooperation among rice scientists around the world. In 1978 scientists from 52 countries requested seed sets of 862 nurseries from IRRI. Additional seeds were supplied by CIAT for nurseries in Latin America and WARDA, and by IITA for nurseries in Africa.

The flow chart in Figure 2 shows how IRTP assures the dissemination and testing of the world's best rice breeding materials. Entries in the IRTP nurseries that perform well in the country of testing are either included as parents in the national breeding programs or tested further directly in national yield trials. IRTP has been in operation long enough to show that the system works and that national scientists are making effective use of the genetic materials that IRTP is helping to disseminate. Table 1 lists the rices from IRTP nurseries that have been released or recommended for release in 12 countries around the world.

The computerization of data handling and the timely publication of performance data from the nurseries add greatly to the value of the IRTP. From these data, varieties or lines with unusual



2. The IRTP nurseries help farmers get new improved varieties either through direct introduction or through hybridization of promising entries.

Table 1. Entries originating from IRTP nurseries which have been recommended for release or have been released as varieties in national programs.

Region/Country	Designation	Origin	Name given
Southeast Asia			
Burma	BG90-2	Sri Lanka	Sinthiri
	BR51-91-6	Bangladesh	Sintheingi
	IR34	IRRI	Sinshwethwe
Vietnam	Juma	Dominican Rep.	
	Jaya	India	
	Pelita I-1	Indonesia	
	Biplab	Bangladesh	
South Asia			
Bangladesh	IR2061-214-3-8-2	IRRI	BR6
	IR2053-87-3-1	IRRI	BR7
India	BR51-46-CI	Bangladesh	–
	IR30	IRRI	IR30
	IR34	IRRI	IR34
	IR36	IRRI	IR36
Nepal	BG90-2	Sri Lanka	Janaki
	IET2938	India	Durga
	IR2061-628-1-6-4-3	IRRI	Laxami
	IR2071-124-6-4	IRRI	Sabitri
Sub-Sahara Africa			
Ivory Coast	Jaya	India	–
Mali	IET2885	India	–
	IR269-26-3-3-3	IRRI	–
	IR1529-680-3	IRRI	–
	Jaya	India	–
Niger	IR1529-680-3	IRRI	–
Senegal	Jaya	India	–
Sierra Leone	CICA 4//IR605/Tetep	CIAT	ROK 11
	CICA 4//IR605/Tetep	CIAT	ROK 12
Upper Volta	IR1529-680-3	IRRI	–
	Vijaya	India	–
Latin America			
Cuba	IR1529-430-3	IRRI	IR1529

performance stability are identified. The seven entries in the replicated yield trial for early-maturing rices shown in Table 2 illustrate this point. When grown in environments varying from the dry hot climate of Egypt to the relatively cooler and moist climate of Taiwan, these varieties generally performed well. They yielded as well as the locally adapted check in two-thirds of the trials.

Monitoring and planning conferences

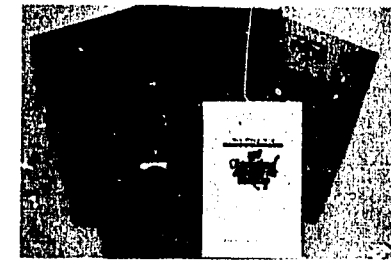
We utilize IRTP for further interaction among scientists from national programs. At the April 1977 International Rice Research

Table 2. Yield stability of early-maturing rices in tests run in 27 locations in Asia and Latin America.

Entry	Origin	Tests (no.) out of 27 where yields were		Av yield	
		At least as high as local check's	Higher than local check's	t/ha	kg/day
BR51-46-1-C1	Bangladesh	21	8	4.6	33.6
IR36	IRRI	21	8	4.5	36.0
B1014b-Pn-18-1-4	Indonesia	22	6	4.6	33.8
B1991-Pn-43-4-1	Indonesia	21	6	4.5	33.6
B541b-Pn-58-5-3-1	Indonesia	19	5	4.5	34.1
IR1561-228-3-3	IRRI	24	1	4.5	36.0
BPI Ri-2	Philippines	20	5	4.6	33.8

Conference attended by nearly 125 scientists, general plans for the 1978 and 1979 research years were made. The plans included a record number of monitoring tours in 1978. Four such tours focused on regional research activities, six were concerned with research problem areas.

After each monitoring tour, the participants make recommendations for improvement of the tests and for needed collaborative research. This year, following four of the tours, we expanded the *so what* sessions into formal planning workshops. The workshops support the concept on which the monitoring tours are based – that rice production problems are international and can be solved only with international cooperation among scientists.



Papers presented at the workshops, along with plans for the future, are published and made available not only to other rice scientists but also to research managers and other decision makers.

Incorporation of insect and disease resistance

We have succeeded in markedly increasing the degree of host plant resistance to major rice diseases and insect pests. Traditional varieties are susceptible to most of the major rice pests (Table 3). By screening varieties in the germplasm bank we were able to select the few traditional cultivars that are resistant to or tolerant of the major rice pests. They were used as parents in our GEU program to incorporate the desired trait into lines with other superior characteristics.

The extent to which we were successful is shown by comparison of the resistance of traditional varieties and the resistance of advanced lines in our replicated yield trials. Except in resistance to whorl maggot and sheath blight, the modern genetic materials are definitely superior to the traditional varieties. These modern pest-resistant lines are made available, through IRTP, to each cooperating country.

The monitoring tour group that covered South India and Sri Lanka in 1978 had a typical session to discuss the so what *question about IRTP tests and collaborative research.*

Table 3. Comparative resistance to major insects and diseases of traditional rice varieties in the germplasm bank and improved lines included in the 1978 replicated yield trials.

Insect or disease	Cultivars showing resistance or moderately resistant reactions (%)	
	Traditional varieties from germplasm bank	Modern lines in 1978 replicated yield trials
Brown planthopper (1)	7	88
(2)		50
(3)		60
Green leafhopper	15	55
Whorl maggot	15	9
Bacterial blight	31	100
Rice blast	76	98
Sheath blight	91	93
Rice tungro virus	52	81

Biochemical basis of insect resistance

We continued studies to determine the biochemical basis for resistance of rice varieties to insect pests. In one study we learned that naturally occurring chemicals in the resistant varieties are likely responsible for their resistance. Extracts from varieties resistant to gravid striped borer moths dramatically reduced the hatchability of the borer's eggs. Hatchability was 98% in the presence of extracts of susceptible varieties and only 2% with extracts of resistant varieties.

Even with low dosages of the extracts from resistant varieties, the larval development into pupae was abnormal. The moths that emerged from the few surviving pupae often had incompletely developed wings and a pupal abdomen (Fig. 3). Some moths did not completely emerge from the pupal case.

Lines with short growth duration

Widespread interest in methods of increasing cropping intensity has focused attention on rices with short growth duration. IR36, which matures in 110–115 days from seeding, has become popular in the

3. A 10 μl dose of an extract from a resistant rice variety caused abnormal development of striped borer moths (left). The moths on the right emerged from untreated pupae.

Table 4. Promising lines that mature in 90–100 days. Yields are from 1978 replicated trials.

Line	Parents	Growth duration (days)	Yield	
			t/ha	kg/day
IR10154-23-3-3	ADT4/IR747B$_2$-6//IR747B$_2$-6	90	5.3	59
IR10176-24-6-2	IR747B$_2$-6-3/29Lu 1/IR747B$_2$-6	90	5.4	60
IR10179-2-3-1	IR747B$_2$-6-3/Ai-nan tsao 1/ IR747B$_2$-6	92	6.1	66
IR10179-23-1-3	IR747B$_2$-6-3/Ai-nan tsao 1/ IR747B$_2$-6	90	5.2	58
IR13168-143-1	Cauvery/IR36/IR36	100	6.3	63
IR8608-167-2	IR2061-465-1-5/IR36	100	5.8	58
IR36		110	6.8	62

Philippines and has been released to farmers in Indonesia, India, and Vietnam.

Research to develop high yielding, pest-resistant rices with even shorter growth duration than IR36 began a few years ago. In our 1978 replicated yield trials breeding lines with a growth duration of 90–100 days were evaluated. These lines inherit this trait from the early-maturing Indian varieties ADT 4 and Cauvery and the Chinese varieties Ai-nan-Tsao 1 and 29 Lu 1. Yields from the new lines were from 5.2 to 6.3 t/ha. IR36, which requires 10 to 20 days longer to mature, yielded 6.8 t/ha in the same tests (Table 4).

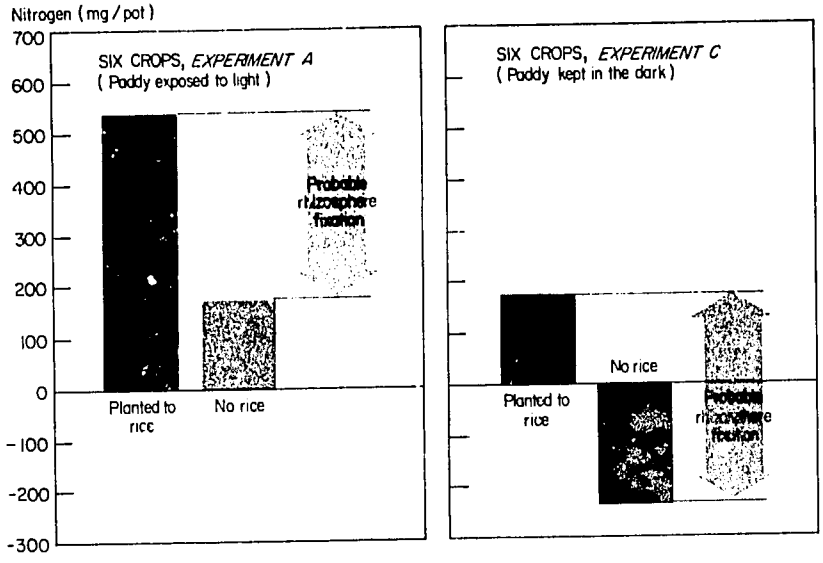
Nitrogen fixation

We continued our efforts to determine the magnitude of nitrogen fixation from different sources in wetland rice culture. Previous research, with indirect analytical techniques, had suggested that considerable quantities of nitrogen were being fixed by heterotrophic organisms in the root zone of the rice plant. But no direct measurements of such fixation had been made.

We used Kjeldahl nitrogen techniques to demonstrate that nitrogen fixation other than that associated with blue-green algae does occur in paddy rice culture (Fig. 4). To do that we grew rice in the greenhouse where we could control the light striking the paddy water, thereby limiting the growth of light-dependent blue-green algae. These experiments provide additional evidence that nitrogen fixation by heterotrophic organisms and by light-dependent blue-green algae occur simultaneously in the rice paddy.

Constraints on rice production

Farmers do not automatically obtain economic benefits when they produce more food. Four years' data from experiments in six Asian



4. Direct measurement of nitrogen balance suggests significant nitrogen fixation in the root zone of paddy rice as a complement to that by blue-green algae (pots exposed to light) or in the absence of the blue-green algae (pots kept in the dark).

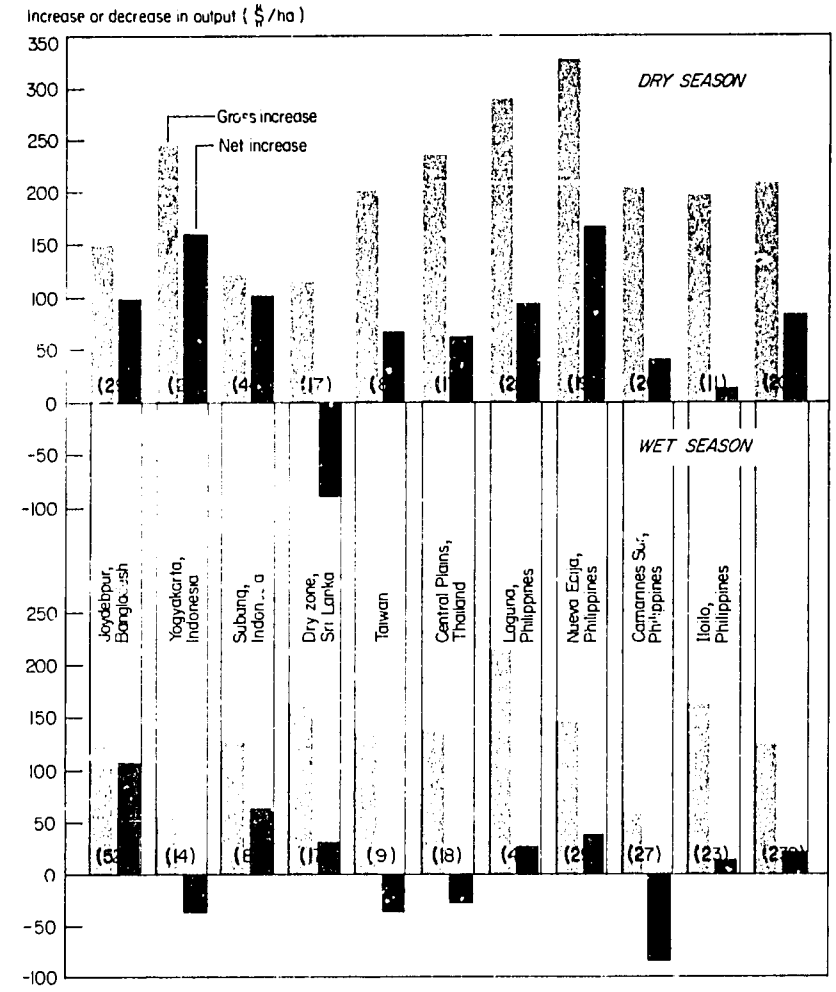
countries on factors constraining rice yields on farmers' fields were summarized in 1978. We found that technology inputs higher than those used by the farmers generally gave good returns in the dry season. But in the wet season the costs of added inputs negated most of the production gains and in some cases resulted in losses from the higher inputs (Fig. 5).

Levels of fertilizer application higher than those used by farmers gave profitable increases especially during the dry season. In contrast, high input levels for insect control gave discouragingly low net increases in the dry season, and resulted in losses in wet-season trials (Fig. 6). These findings provide a challenge to scientists concerned with pest management. They also explain the reluctance of many farmers to use insecticides unless the pest threat to their crop is obvious.

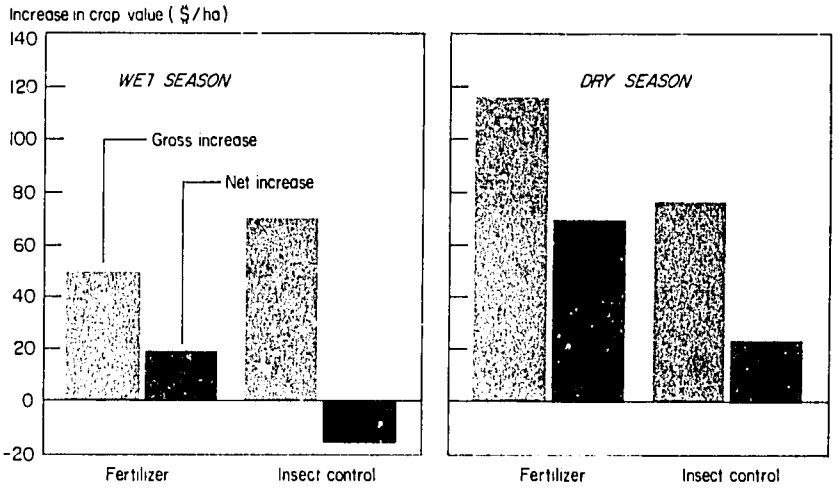
Among the more interesting findings from *constraints* experiments was the discovery of a performance gap in fields managed by farmers. The farmers obtained lower yields than the researchers with the same given levels of fertilizers.

Computer-based data management

We have developed computer programs to assist us and our cooperators in national institutions in handling the tremendous volume of data collected annually. In 1978, our computerization efforts centered on three major program areas – Genetic Evaluation and Utilization (GEU), Cropping Systems, and other networks (INFER, IRAEN, etc.). The scope and nature of work are summarized in Table 5.



5. Average increases in gross and net returns from test inputs were higher than those from inputs used by farmers. The number of trials for each location is shown by numbers in parentheses. Note that the higher inputs were generally profitable during the dry season but gave low net returns or even losses during the wet season.



6. Gross and net increases in crop value from inputs for fertilizer and insect control were higher than those from inputs used by farmers in six Asian countries, 1974–77.

Table 5. Computer-based data management in 1978 handled about 14 million records for IRRI scientists.

Program	No. of computer records	Major features
GEU:		
Germplasm Bank (GB)	1,314,870	Data storage Retrieval of desirable accessions
Breeding	924,815	Tracing of family tree of IR crosses Inventory of selections
Testing and Evaluation	672,201	Generating standardized fieldbooks Data analysis
IRTP	5,223,500	Data analysis and reporting Information storage and retrieval
Cropping Systems:		
Cropping Pattern Monitoring (CPM)	1,468,755	Model development Analysis of agroclimatic zones
Farm Record Keeping (FRK)	3,217,800	Economic analysis
Network:		
IRAEN	1,016,996	Agronomic and economic analyses
INFER	97,546	Data analysis and reporting

- *GEU.* The germplasm computer data bank (GB) now contains 1,314,870 records (representing information on variety name and origin; and data on 38 morphoagronomic characters and 37 GEU traits) for 38,535 registered accessions of *O. sativa.* The breeding records of 25,066 crosses are stored, and can be used in tracing the family tree of any desired crosses. We also keep the inventory of all selected lines from IRRI crosses. The GB information retrieval system (developed and completed in late 1976) is used frequently by our GEU scientists and other rice researchers. It provides instant access to – and retrieval of – desired information from the germplasm data bank.
- *Cropping systems.* The Cropping Pattern Monitoring (CPM) project is an undertaking of the Asian Cropping Systems Network. So far, only data for 3 years (1975–78) from the Philippine sites (Pangasinan and Iloilo) are in our computer files.

  The Farm Record Keeping (FRK) data files are farmers' daily records of production operations on their farms.
- *Networks.* The data for the IRAEN and INFER are computerized and are easily accessible to scientists throughout the two networks.

Major research results

Genetic evaluation and utilization

Activity within the Genetic Evaluation and Utilization (GEU) program during 1978 reflects the tremendous momentum of IRRI's on-going research. Our massive breeding program continues to generate improved germplasm for the wide range of farm, soil, and weather conditions where rice is grown. During 1978 our GEU teams:

- noted an all-time high of 13 IRRI rices named as varieties in national rice programs,
- developed monogenic male-sterile mutants as a first step in the production of hybrid rices,
- put rapid generation advance breeding in full operation, thus making improved photoperiod-sensitive rices widely available for testing in local environments,
- made a massive computer-stored information system fully operational, allowing accurate and fast handling of data for rice researchers worldwide,
- isolated antifeedant and antagonistic chemicals from rices resistant to brown planthopper, thus ascertaining the biochemical basis of resistance, and
- institutionalized the planning of intra- and international GEU research by making it an integral part of International Rice Testing Program monitoring tours.

SERVICE TO A BROAD RANGE OF ENVIRONMENTS

IRRI rices named as varieties in national programs during 1978 hit an all-time high, reflecting the momentum and potential of our GEU research. The rices chosen as acceptable in national programs also reflect our success in serving rice farmers across diverse agroclimatic conditions (Table 1). The 13 IR lines named as varieties in 1978 make a grand total of 75 named since 1963.

High-volume crossing in 1978 continued to generate improved germplasm for a wide range of farm, soil, and weather conditions. Such crossing also broadened the genetic base of our breeding lines. The overall increase in breeding operations gave a solid increase in

Table 1. IRRI lines named as varieties in different countries in 1978 brought to 64 the total of IR lines named in national programs. IRRI had named 11 rices before 1976.

Variety name given	IRRI line	Country	Special traits
Asahan	IR2071-621-2	Indonesia	For irrigated farms; resistant to major diseases and insects
IR36	IR2071-625-1	Indonesia	For irrigated, dry-seeded wetland and dryland conditions
IR38	IR2070-423-2	Indonesia	Popular in east Java; resistant to brown planthopper biotype 2
IR43	IR1529-430-3	Philippines	For dryland areas; drought tolerant
IR44	IR2863-38-1	Philippines	For irrigated farms; resistant to major diseases and insects
IR45	IR2035-242	Philippines	For dryland areas; drought tolerant
IR46	IR2058-78-1	Philippines	For rainfed wetland
IR1529	IR1529-430-3	Cuba	For dryland
NN3A	IR2071-625-1	Vietnam	For irrigated farms
NN4A	IR2070-734-3	Vietnam	For irrigated farms; resistant to major diseases and insects
NN5A	IR2071-179-3	Vietnam	For irrigated farms
PR103	IR661-1-140-3	India (Punjab)	For irrigated farms; late planting
Prasad	IR1561-216-6	India (U.P.)	For irrigated farms; early maturing
Tamale 1	IR1820-210-2	Ghana	Long slender grain; resistant to blast

the number of crosses made and the F_2 combinations and pedigree lines grown (Fig. 1). Because it is desirable to expose the early segregating breeding material to diverse agroclimatic conditions, we developed several collaborative projects with national scientists.

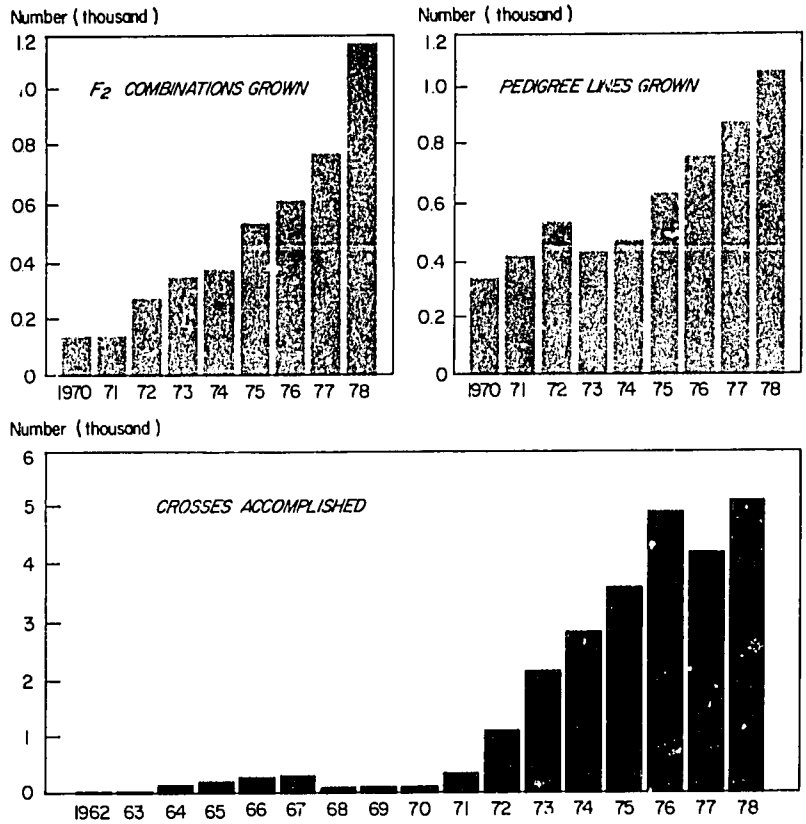
Plant Breeder G. S. Khush takes notes on IRRI breeding lines in the field. His fieldbook notes were later added to IRRI's computer-based information system.

Breeding methods

Our rice breeders continue to use two main methods – the pedigree method to develop breeding lines with multiple resistance to insects and diseases and the backcross method to transfer resistance to the brown planthopper from donors of resistance genes, and resistance to the green leafhopper from *Oryza glaberrima.*

For fast development of photoperiod-sensitive improved breeding lines, we put a system using rapid generation advance techniques – developed and tested in 1976–77 – into full operation. About 50 improved photoperiod-sensitive breeding lines with intermediate stature and resistance to major insects and diseases were identified. Rapid generation advance will put them rapidly into tests in local environments.

We used a chemical mutagen, ethyleneimine, to develop four monogenic male-sterile mutants from IR36 in 1978. The mutants are a first solid step toward hybrid rice production. They showed complete fertility after hand pollination, but gave no seed from self-pollination. In the field, they gave about 15–34% seed set by outcrossing with neighboring pollen donors.



1. Growth of the IRRI GEU program reflects in the rapid upswing of activity after 1974. We filled special requests for nearly 15,000 packets for scientists in 39 countries. F_2 seeds from 1,025 crosses went to scientists in 12 countries.

New lines with multiple attributes

For the irrigated areas the resistance to diseases and to insects of improved rices are of primary importance. Because of our heavy emphasis on that aspect, most of our improved breeding lines have a broad range of resistance to diseases and insects. Characteristics of 9 such lines are shown in Table 2. Note that we have improved breeding lines that are resistant to the three biotypes of the brown planthopper prevalent in the Philippines.

Varieties of short growth duration are highly desirable for irrigated areas. They permit a high cropping intensity and allow for more economical use of water. Early maturity is also important for rainfed wetland rices when the first of two crops is direct seeded, or when the rainy season is short. Several breeding lines are at least a week to 10 days earlier than IR36, one of Asia's most popular varieties, and give comparable grain yield. We have em-

Table 2. Important characteristics of 9 selected lines at IRRI, 1978. Ratings are R = resistant, MR = moderately resistant, and S = susceptible. Internediate amylose content (20–25%) indicates acceptable eating quality.

Type of culture and lines	Ht (cm)	Growth duration (days)	Amylose content (%)	Reaction to					Brown planthopper biotype			Special traits
				Blast	Bacterial blight	Tungro	Grassy stunt	Green leaf-hopper	1	2	3	
Irrigated wetland												
IR3351-38-3-1	110	130	15	R	R	R	R	R	R	R	S	Aromatic, excellent grain
IR4432-52-6-4	110	125	25	R	R	R	R	R	R	R	S	Very vigorous
IR4570-83-3-3-2	115	130	22	R	R	R	R	R	R	R	S	Suitable for rainfed lowland
IR9129-209-2-2-2-1	102	105	21	R	R	R	R	R	R	R	S	Early-maturing
IR13240-10-1	106	108	25	R	R	MR	R	R	R	R	R	Resistant to biotypes of BPH
Rainfed wetland												
IR4219-35-3-3	130	135	27	MR	R	R	R	R	R	S	R	Intermediate height
IR9264-321-3	125	140	27	R	R	R	R	R	R	R	S	Intermediate height
IR4422-480-2-3-3	110	121	25	MR	R	R	R	R	R	S	R	Salinity tolerant
Dryland												
IR3839-1	96	115	25	R	R	S	S	R	S	S	S	Drought resistant

phasized relatively longer growth duration and intermediate plant stature for some rainfed wetland conditions where only one crop is feasible.

Computerized data management

During 1978 a massive computer-based information system became operational. The system provides an inventory of all selected lines in each generation and prints a fieldbook that identifies the pedigree of selections for use in the nursery of the next generation. The inventory maintains the performance records of all selected lines for all generations from as early as the F_3 generation through advanced lines included in the International Rice Testing Program. Thus, we can give any interested rice scientist a complete historical performance of a line.

A computer data file characterizes the parentage of the 25,066 crosses made at IRRI. The file gives easy access to the immediate parentage of any cross and will trace its family tree. It also allows search for all the crosses in which a parent is involved.

Statistician K. A. Gomez and Plant Breeder G. S. Khush examine the family tree of promising IR crosses. The family tree (sequence of the crosses) was printed by a terminal at IRRI, which links scientists with an IBM 370/135 computer at the Agricultural Resource Center (ARC) at Los Baños. Any scientist can use the IRRI terminal to retrieve information from the IRRI computer data base at ARC.

International rice genetic survey

An international rice genetic survey, which was initiated in 1978, identified a need for a broader genetic base for modern rices. The survey's major objective is to establish permanent records on the genetic ancestry of rice varieties. The genetic background of 700 varieties – widely grown by farmers or often used as parents in crossbreeding programs – was traced to their original progenitors. Similar information was compiled for 350 varieties released by national programs since 1963. The survey data are available to rice breeders and other scientists on request.

GERMPLASM CONSERVATION AND DISSEMINATION

Any local rice varieties that are still planted by farmers in remote areas may carry genes that could eventually mean the difference between famine and food for a great number of people in the rice-growing world. Joint efforts with national rice scientists to survey and collect local unimproved rice varieties in remote areas

Table 3. The volume of activity by the IRRI Genetic Resources Program for field collection, preservation, and seed distribution of *Oryza sativa* germplasm is the world's largest for any crop at any place. Data for 5 years are shown; collection started in 1963.

Year	Samples collected in Asia	Distinct accessions in germplasm bank	Samples distributed	
			Inside IRRI	National programs
1974	2,982	26,818	19,236	2,603
1975	566	30,332	22,155	4,043
1976	1,466	34,229	40,200	4,819
1977	696	36,956	50,354	4,126
1978	1,134	40,768[a]	31,941	7,316

[a]About 13,000 recently received seed samples are not registered; since 1963, 4,051 duplicate accessions and 2,790 nonviable seed samples have been removed.

of Bangladesh, Indonesia, Philippines, and Sri Lanka continued. The work netted 1,561 seed samples from many areas where the local varieties could soon be *lost* through replacement by improved varieties. We also joined Indian scientists in planning a massive 16-state project to collect India's indigenous varieties.

Since our intensive field program began in 1972, we have directly participated in the collection of about 9,500 seed samples from farmers' fields in 14 collaborating Asian countries. With our indirect assistance local extension workers, rice breeders and others collected another 28,507 samples. The IRRI germplasm bank now holds nearly 41,000 registered accessions. Table 3 shows the growth of the seed bank and its activities since 1974.

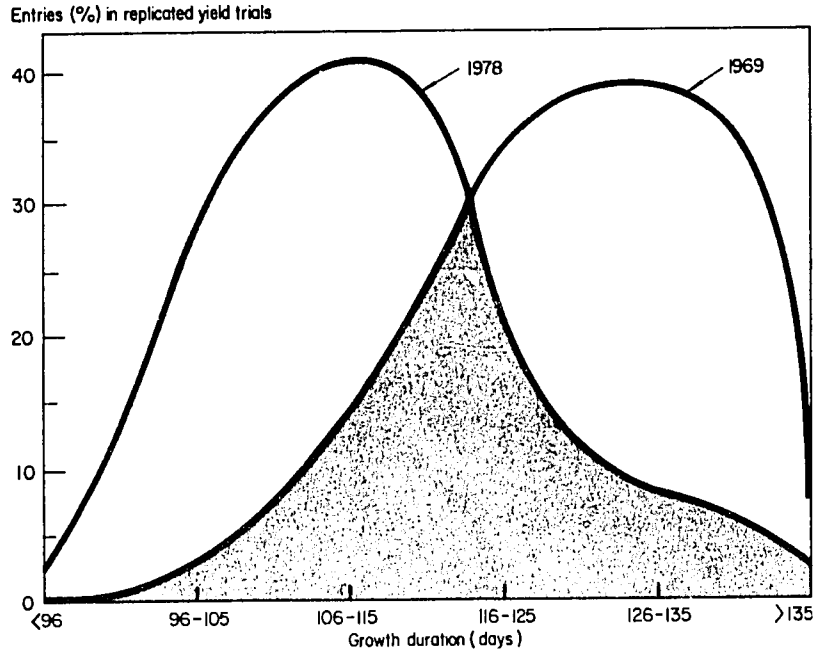
Geneticist T. T. Chang supervises the addition of seed samples to IRRI's medium-term (0°C) seed storage facility. The massive storage shelves move on rails to permit maximum use of space.

AGRONOMIC CHARACTERISTICS

Asian farmers continue to demand rices with short growth duration. They made that clear by widespread acceptance of IR36 with its early maturity plus high yield potential and resistance to major rice diseases and insects. Rices that matured in 90–95 days were, for the first time, in our 1978 advanced yield trials. About 70% of the rices in our replicated yield trials matured in less than 110 days (96–110 days), a marked change from the 1970 trials where about 18% of the entries required less than 116 days to mature (Fig. 2).

Yield of irrigated and rainfed rice

We evaluated several varieties and promising breeding lines in nitrogen-response trials at IRRI and three other Philippine sites. IR42, which was outstanding in yield performance in 1977, was



2. Farmers' interest in increasing rice production by growing 2 crops where only 1 grew before has created a demand for varieties that mature earlier. There has been a significant shift to earlier-maturing rices in IRRI replicated yield trials.

again the top yielder in many trials, particularly during the wet season.

Several breeding lines (IR2058-78-1-3-2, IR4432-52-6-4, IR4570-117-2-1-2, and IR5853-83-3-3-2) yielded as well as IR42. Two lines (IR4568-86-1-3-2 and IR4570-83-3-3-2) outyielded IR42 during the dry season, but their wet-season yield was slightly lower. A short-growth-duration entry (IR9224-117-2) outyielded IR36 in several trials.

We have also combined large grain size with improved plant traits to increase the yield potential of semidwarf varieties. The larger grain size is associated with more vigorous early growth, which helps the short-duration varieties overcome competition from weeds.

Sources of dwarfism

Because most of the short-statured modern rice varieties get their dwarfism from Dee-geo-woo-gen, we continue to seek and test new genetic sources for the dwarf rice plant. During 1978, 24 crosses involved the recessive semidwarfing gene from Dee-geo-woo-gen and a new dwarfing source. We grew 28 F_1 and 10 F_2 populations, which indicated we have at least four sources of the dwarfing gene, or genes, different from Dee-geo-woo-gen.

DISEASE RESISTANCE

Outbreaks of rice diseases in Asia in 1978 provided clear evidence that the crop can be devastated in farmers' fields – or it can be left inexplicably disease-free. An outbreak of blast disease seriously damaged the rice crop in parts of Korea and China. Sheath rot, a rice disease of minor economic importance in the past, did major damage in some areas in 1978. But ragged stunt, which rated serious attention as a new disease in 1977, was rare.

Against that background we continued screening to identify rice germplasm with resistance to major diseases.

Resistance to rice blast

Breeding of rice varieties with stable resistance to the blast fungus continued to claim the bulk of our resources allocated to fungus disease research. Among 63,000 entries field-screened for resistance, about 25,000 were resistant to the fungus races prevalent in the 1978 nurseries.

The rice blast fungus caused serious yield loss in many farmers' fields in Asia during 1978. Where blast struck, only the resistant varieties, such as the one in the field in the background, remained healthy. IRRI researchers have proposed an improved system for identifying host plant resistance in routine blast nurseries.

The variability of the blast fungus was again obvious in the 1978 blast nurseries. Artificial inoculation of selected field-resistant varieties from Japan with Philippine blast isolates resulted in differential interactions, indicating that field resistance in the Japanese varieties was not stable. Formerly susceptible IRRI varieties were resistant to the races present in 1978, and some formerly resistant lines became susceptible.

A major problem in the search for rice blast resistance is lack of a system to distinguish various types of host resistance. We examined the data of the International Rice Blast Nursery (IRBN) to detect prevailing types of host resistance. From 397 entries tested in the IRBN in 1976–77, 261 entries were tentatively classified into 19 major groups of resistance type. As a result we proposed a more functional set of differentials for the IRBN and routine blast nurseries.

Screening to identify other disease resistance genes

Sheath rot, caused by *Acrocylindrium oryzae*, has increased in significance as a rice disease in the Philippines. In 1978, we demonstrated that the organism was capable of functioning as a primary pathogen. An effective screening technique was developed and 244 entries were evaluated.

We screened nearly 11,000 entries for sheath blight resistance. No resistant entries were found and only 2% of those screened were moderately resistant. Of more than 430 elite breeding lines evaluated for resistance to *Cercospora* leaf spot, about 8% were resistant. We artificially inoculated varieties from the germplasm collection with leaf scald to confirm an earlier field-resistance observation. None were found free from leaf scald, 4% were classified as resistant, and more than 50% were susceptible.

Resistance to bacterial blight

Four distinct resistance groups for bacterial blight of rice were identified after 2 years of field tests. The *overall resistance group* includes rices with a resistance reaction at all growth stages. The *adult plant resistance group* includes rices resistant as adult plants (based on infection of flag leaves) but not at the tillering stage. Rices of the *moderate resistance* and *partial resistance* groups are common in the germplasm collection but are unstable with change of place and season.

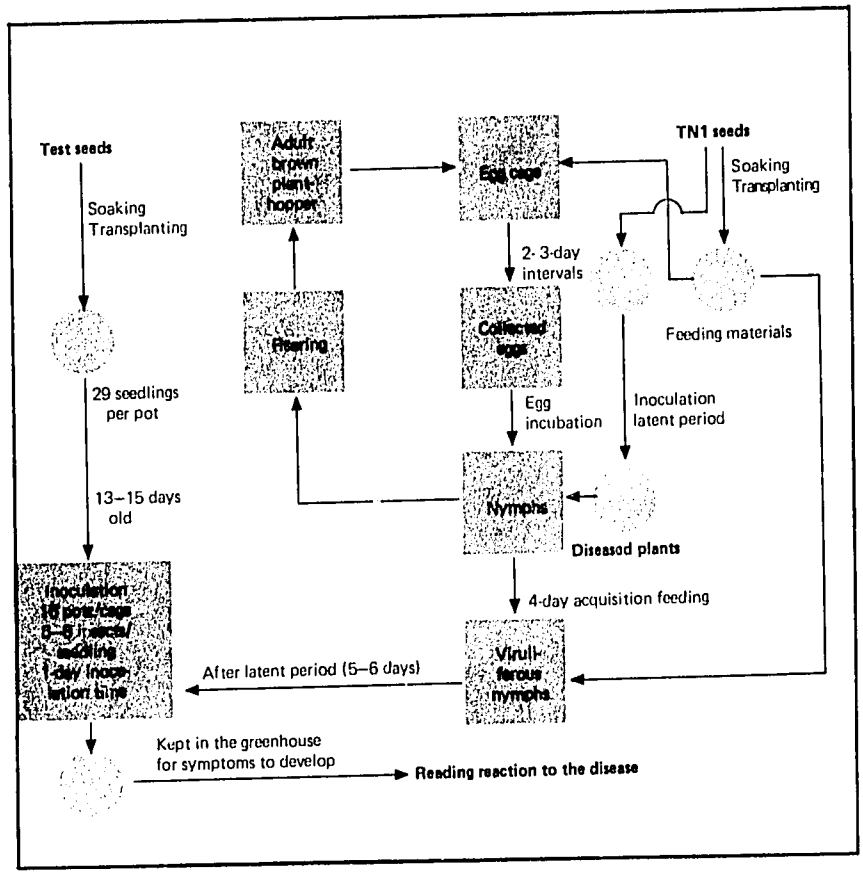
Varieties with *overall resistance* to specific pathotypes showed no increase of the disease after an increase in nitrogen fertilizer. After

nitrogen fertilizer was applied at tillering to varieties with *adult plant resistance* the reaction was the same as that of susceptible varieties.

Resistance to ragged stunt

A rice plant's resistance to ragged stunt disease may not always be associated with its resistance to the disease vector, the brown planthopper. For instance, the variety Ptb is resistant to ragged stunt and to the brown planthopper; compared with Gangala, the variety WC1240 is more resistant to ragged stunt but more susceptible to the brown planthopper; and TN1 is susceptible to both.

A mass-screening method for testing varietal resistance to rice ragged stunt in the greenhouse (Fig. 3) was developed. A total of 1,746 rice varieties and lines was screened in 1978 (Fig. 4). Preliminary results indicated that 10 varieties have a low percentage of infection after inoculation.



3. Diagram of a mass-screening method developed at IRRI for testing varietal resistance to rice ragged stunt disease.

4. This cage is used in inoculating rice seedlings with ragged stunt disease by the brown planthoppers. With 2 cages 928 seedlings of 32 entries can be inoculated daily.

INSECT RESISTANCE

Devastation of the rice crop by insects remains a constant threat in Asia. Many of the popular rice varieties lack resistance to the brown planthopper. Other insects, of minor economic importance to rice farmers so far, have the potential to become a serious menace. And the development of a new brown planthopper biotype - a group within the species capable of overcoming a rice plant's resistance to attack – remains a somber threat to rice growers throughout South and Southeast Asia.

Brown planthopper resistance

The seedbox screening of seedlings to evaluate resistance to the brown planthopper has been an effective and rapid method. But the test gives us either *green* or *brown* seedlings – resistant varieties remain healthy and *green* and the susceptible varieties are hopper-burned and *brown*. Any intermediate level of resistance is difficult to assess. We recognized the need for a precise, rapid method to detect:

- moderately resistant varieties, which are less apt to encourage the emergence of a new biotype,
- field-resistant varieties – those that often have lower levels

The difference in brown planthopper resistance between IR42 and IR40 is seen in these plots. Both varieties have the bph 2 *gene for resistance but IR40 is hopperburned. See Figure 5 also.*

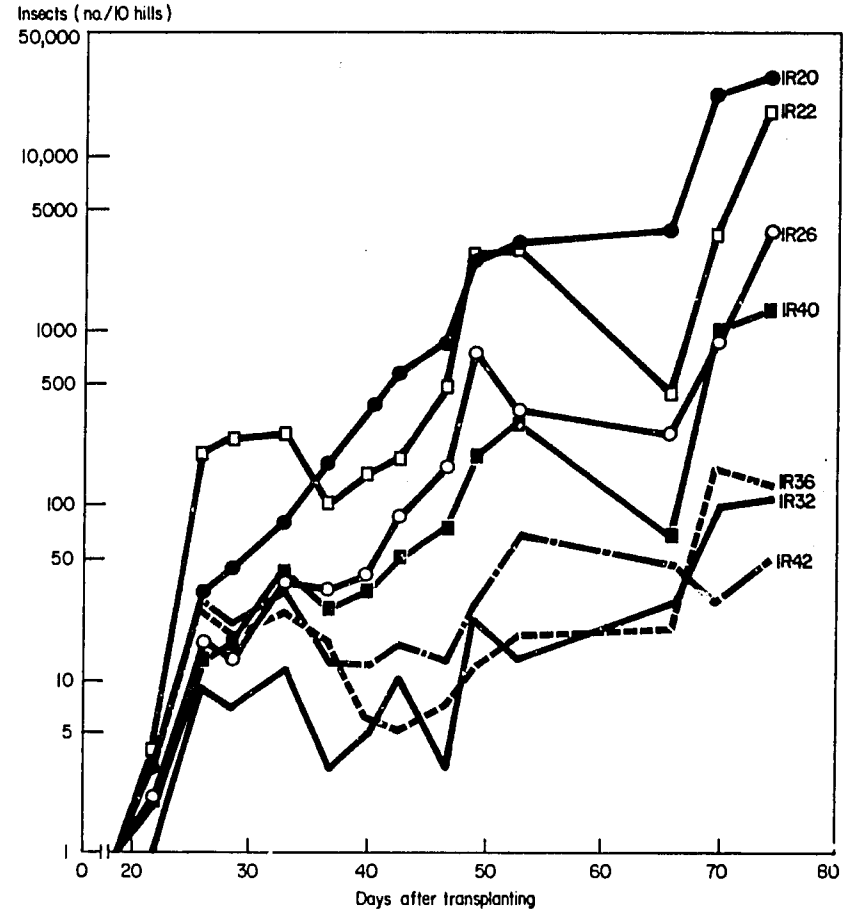
of resistance than varieties with major genes for resistance but have horizontal resistance to all BPH biotypes – and

- the biotype composition of field populations.

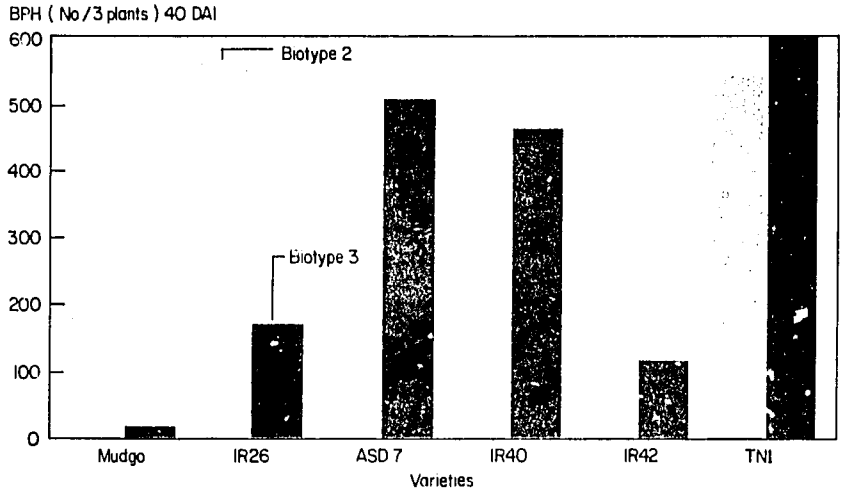
We developed practical techniques to indicate resistance through population increase and feeding activity of the planthopper.

We noted during field tests for brown planthopper resistance that varieties with the same major genes for resistance respond differently to planthopper attack. For example, fields of IR32, IR36, and IR42, which have the *bph 2* gene for resistance had low planthopper populations, but fields of IR40, also carrying the *bph 2* gene, had high populations (Fig. 5) and were hopperburned. Our new techniques can detect the greater susceptibility of IR40, something that seedbox screening did not show.

POPULATION INCREASE. One technique was based on population increase. By our population-increase technique, the level of resistance of selected varieties to biotypes 2 and 3 is indicated in Figure 6. As in our field studies, the population increase of both biotypes 2 and 3 was significantly more on IR40 than on IR42.



5. Field population of the brown planthopper on IR varieties. The population was induced by spraying 20 g a.i. cypermethrin/ha 6 times at 10-day intervals. IRRI, 1978 dry season.



6. The brown planthopper population from 10 nymphs of biotype 2 or 3 feeding on selected varieties. Each bar represents the population on 3 plants in 1 cage, 40 days after the nymphs were added (DAI).

Yet in seedbox tests both rices appear equally susceptible to biotype 2.

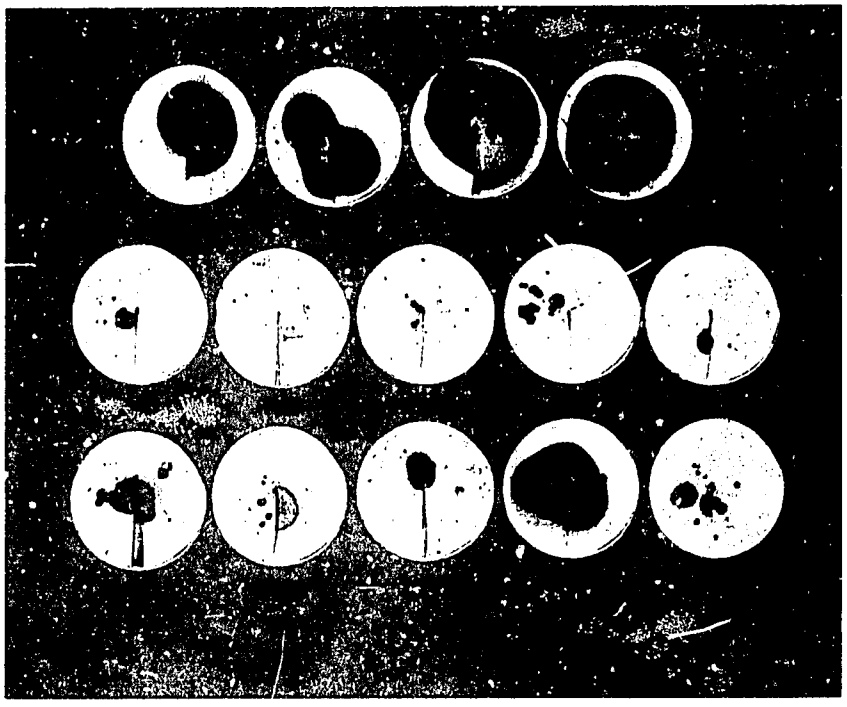
Note also that the population of biotype 2 on IR26 was equal to that on Mudgo – both varieties have the susceptible gene for biotype 2 – but the population of biotype 3 on IR42 was significantly less than that on ASD7 even though both have the susceptible gene for biotype 3.

Our population-increase technique detected IR42's higher levels of resistance. Such resistance may be due to some minor genes or to some other factors that make the variety more resistant to biotype 3 than ASD7. With this knowledge we can expect IR42, which is now widely grown in the Philippines, to last longer than IR26, which succumbed rather quickly to a shift in biotype population.

FEEDING STUDIES. Three methods of measuring brown planthopper resistance are based on feeding studies. One offers an effective, simple measure for use in national programs.

- *Area of honeydew on filter paper.* Honeydew excreted on filter paper by five planthoppers in a feeding chamber (Fig. 7) was stained with ninhydrin (Fig. 8) and the stained area measured. Varieties with no resistance gene (IR8, IR20, IR22, IR24) and those with the *bph 2* gene (IR32, IR36, IR38, IR40, IR42) all had larger stained areas than the varieties with the *Bph 1* gene for resistance to biotype 3 (IR26, IR28, IR29,

7. This feeding chamber was developed to measure feeding activity of the brown planthopper. Filter paper at the bottom of the chamber catches honeydew excreted by the feeding hopper. Area of honeydew on the filter paper allows assessment of hopper feeding on different varieties.



8. These filter papers from the chamber shown in Figure 7 show the area of honeydew excreted overnight by five biotype 3 brown planthopper females feeding on IR varieties.

IR30, IR34). However, feeding on IR32, IR36, IR38, and IR42 was less than that on varieties with no gene for resistance. IR40 again was the most susceptible of the *bph 2* varieties as indicated by the large stained area. The results agree with those of our field study (see Fig. 5).

- *Volume of honeydew.* We assumed that honeydew excretion was closely related to feeding activity and that we can indirectly assess planthopper feeding activity by volume measurement. We slightly modified the feeding chamber used in the honeydew area method and used a parafilm sachet (Fig. 9) to collect honeydew for volume measurements. Biotypes 2 and 3 feeding on susceptible and resistant varieties showed distinct differences in honeydew excretion (Fig. 10). Biotype 3 hoppers feeding on IR40 excreted significantly more honeydew than those on IR42.

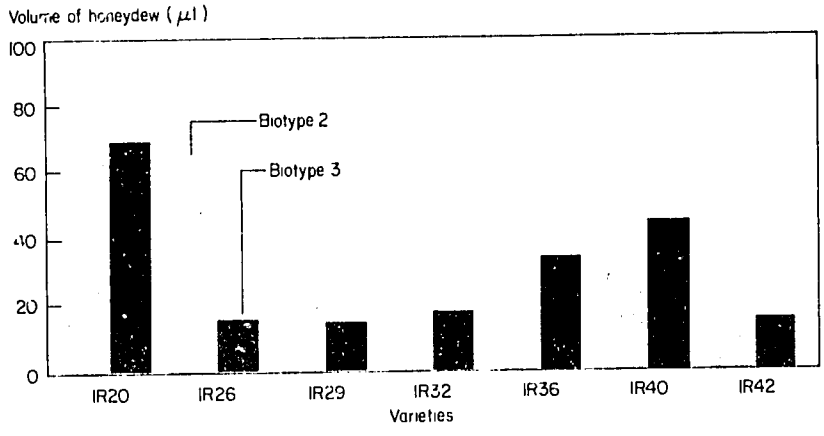
The techniques of measuring honeydew area and volume use readily available materials to provide a practical way of determining planthopper feeding activity.

- *Measurement of honeydew color intensity.* When honeydew is streaked on filter paper and treated with ninhydrin (for amino acid) or aniline hydrochloride (for sugars), the intensity of

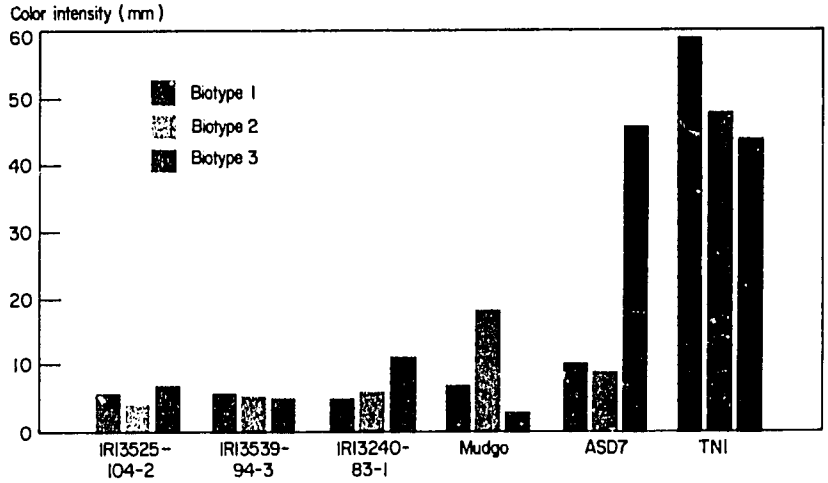
9. This simple parafilm sachet was developed to collect honeydew from brown planthoppers. It provides a low-cost practical way for researchers anywhere to test rice plant resistance to the brown planthopper biotypes.

the resulting color indirectly indicates the level of feeding activity. Densitometer readings of the color intensity of ninhydrin-treated paper showed a much higher peak (more feeding) for IR40 than for IR42.

We used the densitometer technique to evaluate lines with recently identified genes for brown planthopper resistance. Densitometer readings showed that the feeding activity of the three biotypes was low (Fig. 11), and the lines would be expected to be



10. Volume of honeydew excreted by five brown planthopper females feeding on seven IRRI varieties, 1978.



11. Color intensity expressed in peak height (mm) of densitometer readings of ninhydrin and aniline-treated honeydew excreted by brown planthopper biotypes 1, 2 and 3 feeding on 25-day-old breeding lines and check entries. IRRI laboratory, 1978.

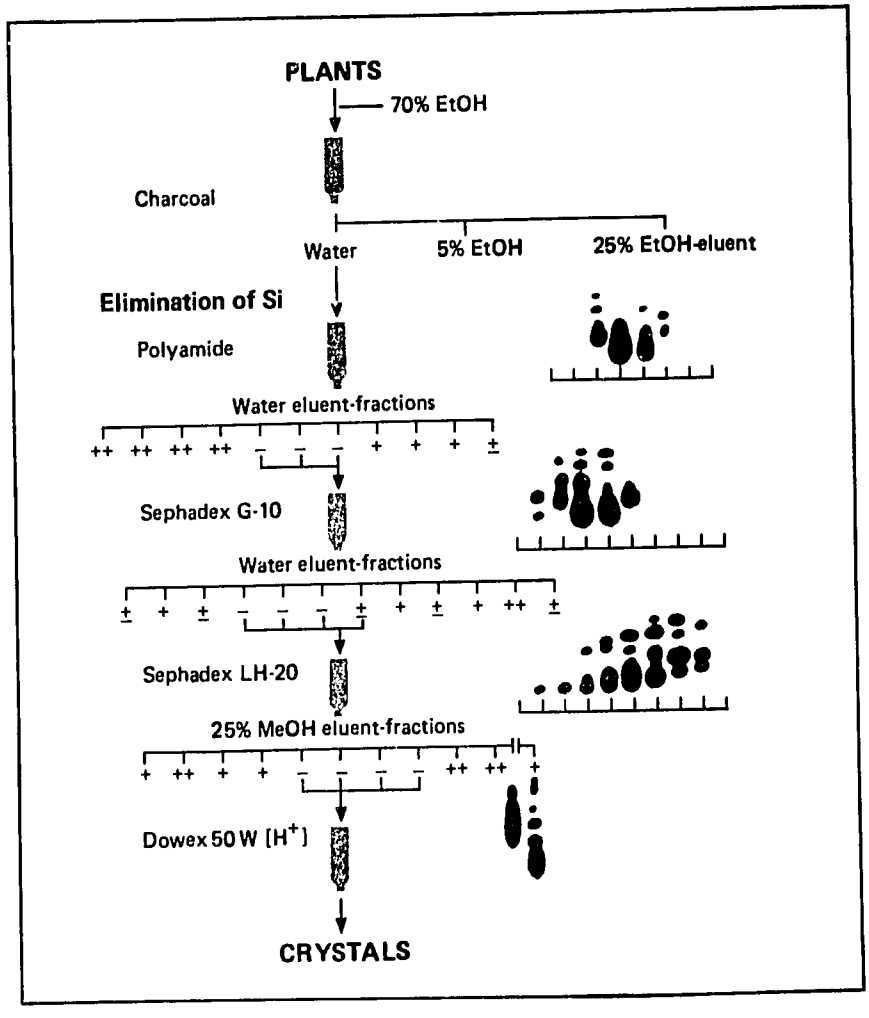
resistant to biotype 3 if it becomes abundant in the Philippines where IR36 and IR42 are grown extensively.

BIOTYPE IDENTIFICATION. We also used the densitometer to determine the color intensity of amino acid bands separated through paper chromatography. Densitometer readings indicated eight distinct bands with high levels of aspartic acid, glycine-glutamic acid-serine, and alanine in honeydew from hoppers that had fed on susceptible varieties. Only three bands were separated from the honeydew of hoppers feeding on resistant varieties, and they produced low-color-intensity readings. We can use standard differential varieties with this method to make biotype identification.

ISOLATION OF BROWN PLANTHOPPER ANTIFEEDANT FROM MUDGO. In cooperation with scientists from the Tropical Agriculture Research Center, Japan, we worked on determination of the biochemical basis for the rice plants' resistance to the brown planthopper. One antifeedant chemical, oxalic acid, was isolated from the resistant variety Mudgo (Fig. 12). A concentration of 0.01% of the chemical (as potassium and sodium salts) inhibited brown planthopper feeding.

INHIBITOR OF BPH EGG HATCHING. Because brown planthopper eggs incubate in the rice plant's tissue, the plant's internal chemistry can influence hatching. We know that a high percentage of hopper eggs do not hatch on barnyard grass and on certain hopper-resistant rice varieties. We therefore tested trans-aconitic acid (t-AA), a

12. The crystals of oxalic acid, an antifeedant isolated from Mudgo, are shown above. The isolation process is shown in the diagram on the right.



chemical prominent in barnyard grass, for its effects on brown planthopper hatching. Hatching was low for all three brown planthopper biotypes when the t-AA concentration was high and the solution was acidic (Table 4). Even when t-AA was neutralized with calcium hydroxide, its adverse effects on hatching persisted.

Increasing levels of resistance to the yellow stem borer

The breeding line IR1820-52-2-4-1 is our line most resistant to the yellow stem borer, but it is susceptible to bacterial leaf blight and the brown planthopper biotype 2, which now predominates in most of Southeast Asia. We initiated a breeding scheme in 1977 to attain a level of stem borer resistance higher than that of

Table 4. Trans-aconitic acid (t-AA), a chemical present in barnyard grass, significantly reduced hatching of brown planthopper eggs in IRRI tests, 1978.[a]

t-AA conc (%)	Eggs hatched (%)		
	Biotype 1	Biotype 2	Biotype 3
1	4 e	13 e	5 e
0.5	21 d	21 e	27 d
0.1	40 c	42 d	43 c
0.01	59 b	68 c	70 b
0.001	70 b	83 b	77 b
0.000 (water)	88 a	90 a	92 a

Table 5. Breeding specifically to increase yellow stem borer resistance has produced lines with more resistance than the best breeding line IR1820-52-2-4-1. Resistance to other insects was also incorporated by breeders.

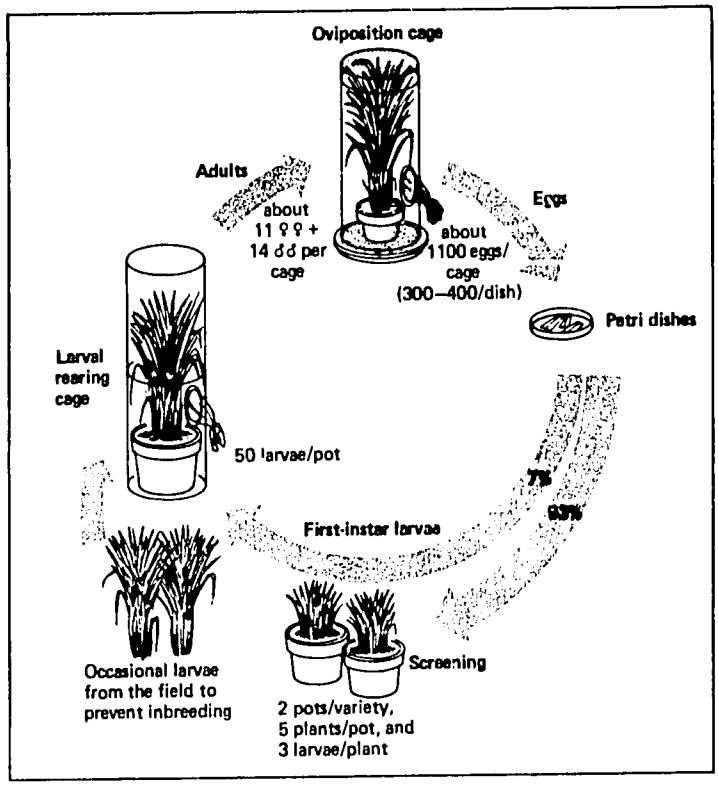
Line	Yellow stem borer deadheart (%)	Damage rating[a]				
		Blast	Bacterial leaf blight	Brown planthopper biotype		Green leafhopper
				1	2	
IR13639-37	26	1	1	1	1	3
IR13639-42	24	1	1	1	3	3
IR13641-4	14	1	1	1	5	3
Checks						
IR1820-52-2-4-1	39	2	7	1	9	3
Rexoro	74					

[a]1 = resistant, 9 = susceptible.

IR1820-52-2-4-1 and also to incorporate resistance to other insects and diseases. Several moderately resistant varieties were used in multiple crosses and several crosses produced progeny with levels of stem borer resistance higher than that of the moderately resistant parents. The most resistant were tested for resistance to blast, bacterial leaf blight, brown planthopper, and green leafhopper. Table 5 indicates the high level of resistance of three F_3 lines.

Mass rearing of the rice leaf folder

A limitation on screening rices for resistance to the rice leaf folder is ease of producing the insect. We developed in 1978 a mass-rearing method that will allow screening for varietal resistance to the leaf folder. Figure 13 outlines the method's four basic steps. We obtained an average of about 120 eggs/female initially put into the oviposition cages. If the cages average 11 females each, egg pro-



13. Four basic steps complete the leaf folder rearing cycle developed in 1978. 1) Larvae are reared in the greenhouse on plants covered by a mesh sleeve. 2) Newly emerged adults are transferred to plastic oviposition (egg laying) cages, which contain rice plants and a feeder with 25% (volume) solution of honey in water. 3) Eggs are collected from the plants in the cages daily for 7 days and placed on wet filter paper in petri dishes. 4) Newly hatched larvae are transferred to plants for screening (93%) or taken back to step 1 (7%).

duction should be more than 16,000/week. At a hatching rate of about 92%, production should be about 15,000 first-instar leaf folder larvae/week.

Inheritance of resistance to whitebacked planthopper

Our genetic analysis of N22 for resistance to whitebacked planthopper revealed the presence of one dominant gene *Wbph* for resistance. We analyzed 12 more resistant varieties during 1978. Eight – P580, Sathra 267, Sonpattar 45, Sufaida 172, ARC 10239, Jhinuwa, N32, and Latighawar – each have one dominant gene for resistance. IR2035-117-3 has two dominant genes, and Colombo, 368, and WC1240 each have one dominant and one recessive gene for resistance. We summarize the mode of inheritance and allelic relationships of resistance genes of 12 varieties in Table 6.

GRAIN QUALITY

Final acceptance of a new rice variety is in the marketplace – or more precisely, in family rice bowls. Our team of chemists and breeders continues to develop rices with high acceptability to con-

Table 6. Summary of information on the mode of inheritance of resistance and allelic relationships of the genes for resistance in twelve rice varieties.

Variety	Nature of resistance	Genes for resistance
IR2035-117-3	Digenic (2 dominant)	Wbph 1 and Wbph 2
P580	Monogenic (1 dominant)	Wbph 1
Sathra 267	Monogenic (1 dominant)	Wbph 1
Sonpattar 45	Monogenic (1 dominant)	Wbph 1
Sufaida 172	Monogenic (1 dominant)	Wbph 1
ARC 10239	Monogenic (1 dominant)	Wbph 2
Colombo	Digenic (1 dominant and 1 recessive)	Wbph 2 + 1 recessive
368	Digenic (1 dominant and 1 recessive)	Wbph 1 + 1 recessive
WC 1240	Digenic (1 dominant and 1 recessive)	Wbph 1 + 1 recessive
Jhinuwa	Monogenic (1 dominant)	Wbph 1
N32	Monogenic (1 dominant)	Wbph 1
Latighawar	Monogenic (1 dominant)	Wbph 1

sumers. In 1978 our 3-day workshop on the chemical aspect of rice grain quality was attended by 28 breeders and chemists. They identified two priority research areas – character of cooked rice, and inheritance of characteristics influencing grain quality.

We summarize our 1978 grain quality work:

- In laboratory tests C4-63G and intermediate-amylose lines derived from it were found to have softer cooked rice than BPI-121-407 and the intermediate-amylose lines derived from it (Table 7).
- We cooperated in a study by the Institute of Human Ecology, University of the Philippines at Los Baños, to see if the difference in hardness can be detected by consumers.

Table 7. IR lines with intermediate amylose from BPI-121-407 have harder cooked rice than those from C4-63G as intermediate amylose parents.

Parent and lines	IRRI crop	Alkali spreading value	Gel consistency (mm)	Instron cooked rice	
				Hardness (kg)	Stickiness (g·cm)
BPI-121-407	1977 wet	6.9	68	7.2	68
"	1978 dry	7.0	70	6.6	99
3 BPI-121-407 lines	1977 dry	6.9-7.0	73-94	7.2-7.9	75-90
"	1977 wet	7.0	38-73	6.8-8.0	51-58
Mean		7.0	72	7.3	80
C4-63G	1977 wet	3.0	79	6.6	80
"	1978 dry	4.0	94	5.7	89
3 C4-63G lines	1977 dry	2.5	80-100	5.5-6.4	84-122
4 C4-63G lines	1977 wet	3.1-5.3	78-100	5.8-6.5	75-107
Mean		3.4	90	6.0	93

Consumers score rice for hardness during a cooperative field study by the Institute of Human Ecology, University of the Philippines at Los Baños, and IRRI.

- Two intermediate-amylose lines – IR4570-83-3-3-2 and IR9129-209-2-2-2-1 – were in advanced trials.
- Instron measurement of hardness and stickiness of cooked rice was included in the periodic screening of rice varieties from 15 countries.
- Data on the gelatinization temperature of starch were obtained for more than 10,500 germplasm bank entries.
- In infants the digestibility of the starch of cooked waxy rice was verified to be as high as that of cooked nonwaxy rice.

The amount of water used for cooking rice is generally based on amylose content. We initiated a study on cooking rice in excess water with or without presoaking of grain. With elongating rices, lengthwise expansion seemed to be preferred to girthwise expansion. Hard gel in high-amylose rice was associated with poorer solubility in hot water.

PROTEIN CONTENT

Protein research for 1978 centered on cooperative studies with nutritionists in India, Peru, Philippines, and Taiwan.

- Filipino and Peruvian children on rice diets in cooperative nitrogen balance studies confirmed that the protein of high-protein rice is not inferior to that of normal-protein rice (Table 8). Because of the similarity of results obtained with these children we feel that nitrogen balance data from differ-

Table 8. A 1977–78 cooperative nitrogen balance study at the Food and Nutrition Research Institute, Manila, Philippines, and Instituto de Investigacion Nutricional, Lima, Peru, showed no significant difference between rice with 11% protein (IR480-5-9) and rice with 7.2% protein (IR32).

Subjects and properties	Dietary and major protein source[a]		
	First casein diet	Low-protein rice diet	High-protein rice diet
Filipino children			
Daily N intake (mg/kg body wt)	248.0a	256.0 b	257.0 b
Apparent N digestibility (% of intake)	76.8 c	66.2 b	60.0a
Apparent N retention (% of intake)	30.8 b	26.9a	23.4a
Peruvian children			
Daily N intake (mg/kg body wt)	240.0a	240.0a	240.0a
Apparent N digestibility (% of intake)	86.1 b	66.6a	64.9a
Apparent N retention (% of intake)	35.2 b	28.6a	23.0a

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

Filipino farmers often grow rice seedlings on a plastic sheet or banana leaves. This system, called dapog, keeps seedling roots from touching the soil. IRRI studies indicate that rice from dapog seedlings has lower protein content than rice from wetbed seedlings (grown in soil).

ent places may be compared despite a difference in basic diets.

- A study with Taiwanese adults also showed that the protein quality of high-protein IR580-5-9 was comparable with that of a local lower-protein variety.
- Paired Indian preschool children were fed an 80% rice diet, the rice protein of which was either low or high. After 5 months of the 1-year study, apparent digestibility and retention of protein were similar in both groups of children.

In studies of factors affecting protein content, we found seedling management affected the protein content of early-maturing varieties. The protein content of rice from seedlings grown in a dapog seedbed was generally lower than that of seedlings from a wetbed system. We also found that younger seedlings gave lower protein content.

We also looked at the effect of split application of nitrogen on protein content. Split application increased the protein content of the rice grain only when the rate of fertilizer application was high.

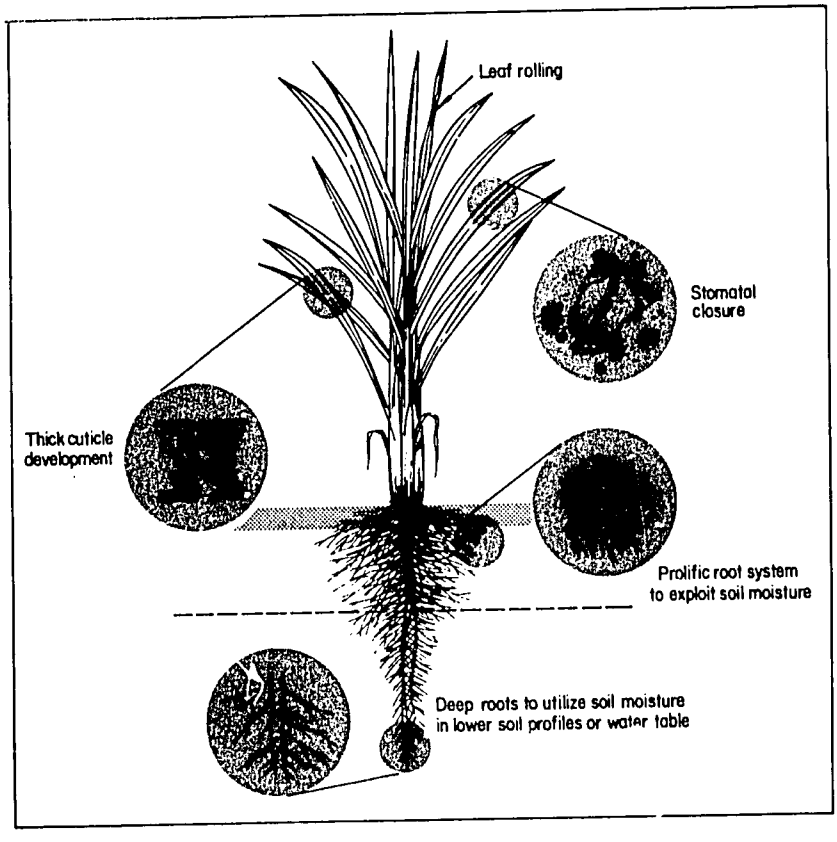
In our continuing study of content and distribution of nutrients in the milling fractions of rice we found that only starch content was affected by change in protein content. As protein increased, starch decreased. Ash, lipid, and fiber levels did not change.

DROUGHT RESISTANCE

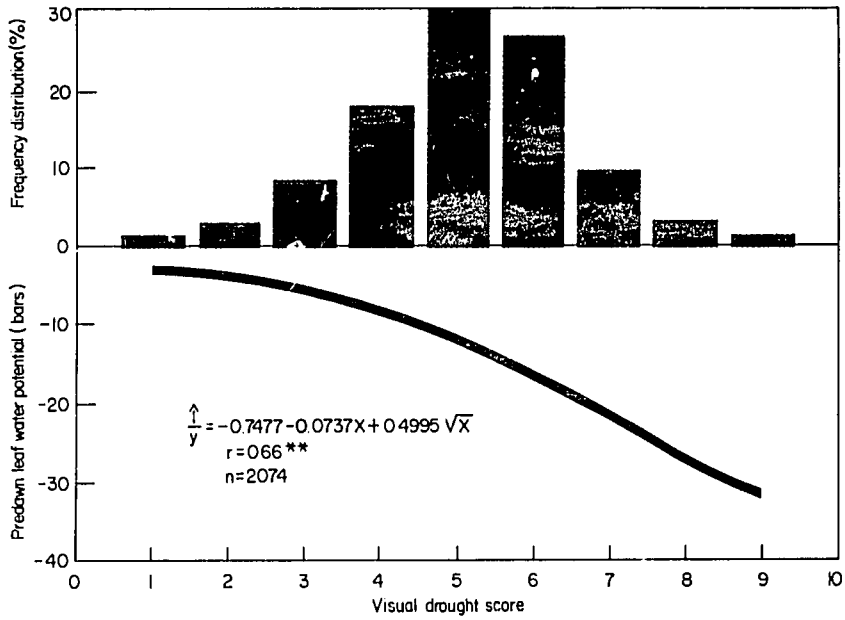
A specially designed greenhouse at IRRI simulates dryland conditions for our scientists and allows screening of rices for drought resistance during the wet season. Original use of the special greenhouse was to confirm dry-season field screening results and to select drought-resistant rices for hybridization. During 1978 we used it more for screening the International Rice Testing Program nurseries that required some drought resistance. We also routinely monitor GEU efforts to combine drought resistance and higher yield potential in new varieties.

Field evaluation of dryland breeding lines

We tested 80 breeding lines for dryland culture on fertile, wet fields at IRRI; on a well-drained low-fertility field at IRRI; and on a farmer's field. Among the early-maturing lines (maturing in 110–115 days), IR7790-18-1-2 and IR3839-1 did well at all sites.



Our study of drought resistance concentrates on the plant characteristics that prevent water deficits in a rice plant. For example, African, South American, and Asian dryland rices have deep and prolific root systems; we see greater development of epicuticular wax in African and Brazilian rices, and there is dynamic leaf rolling of dryland rices, which may be as useful as stomatal closure for regulating plant water loss during drought.



Frequency distribution of the visual drought resistance scores of 2,074 entries screened in IRRI's specially designed drought screening greenhouse. A score of 1 means none to slight effects of drought, a score of 9 indicates all plants apparently dead. The relationship between visual drought score (top) and predawn internal plant water status (bottom) illustrates that drought resistance screening is selecting rices with an ability to rehydrate overnight.

In the 135-day maturity group IR6115-1-1-1 and IR1529-430-3-1 yielded high at all sites. IR6115-1-1-1 and IR3839-1 were also the best performers on the same sites in 1977.

Screening for drought resistance

We field screened 5,701 traditional varieties and 2,216 breeding lines for drought resistance in the dry season. Among them, 1,014 entries showed moderate to high levels of drought resistance. Most of the resistant entries were from India, Indonesia, Brazil, and Burma. A high percentage of experimental lines selected from the dryland breeding nurseries were also observed to have high levels of drought resistance.

In a simulated rainfed wetland drought screening trial in the dry season, we tested about 500 varieties and lines. Breeding lines and varieties that produced well-filled grains after prolonged drought were IR2058-78-1-3-2-3, IR9995-65, IR3880-13-5, IR4427-315-2-3, IR4186-70-1, IR4819-77-3-2, IR6115-1-1-1, IET5118, Bala, MGL 2, Mahsuri, Kalubalawee, Wanni Dahanala, Vellai Illankali, Paedi Kalibungga, Maralle, and several IR3646 lines.

In tests of 14 rices in farmers' fields in Central Luzon – the Philippines' rice bowl – the most promising line was IR2058-78-1-3, whether fully irrigated, partially irrigated, or rainfed.

Table 9. Grain yield and growth duration of selected rices in wet-season dryland yield trials at several Philippine sites. The trials were at three sites in 1976, four in 1977, and five in 1978.

Designation	Mean growth duration (days)	Grain yield (t/ha)		
		1976	1977	1978
Early-maturing				
IR36	110	3.8	3.6	3.5
IR3839-1	110	3.6	3.7	3.6
IET 1444	107	3.4	3.6	3.7
IR2061-522-6-9	111	3.4	3.4	3.2
Kn 361-1-8-6	107	3.2	3.4	3.1
Ml-48 (early check)	118	2.5	2.2	2.8
Late-maturing				
IR9669 selection	130	3.1	3.5	3.6
IR1529-430-3	126	3.3	3.6	3.3
IR9575	124	2.7	3.6	3.4
C46-15/IR24[2]	124	3.0	3.2	3.1
C22 (late check)	126	2.8	3.4	2.8

Dryland yield trials

During the past 3 years yield trials of promising rices from dryland and wetland breeding programs around the world were planted at several rainfed dryland sites in the Philippines. We found five early-maturing and four late-maturing rices exhibiting markedly superior adaptation to dryland culture (Table 9).

Advantages of leaf rolling during drought

Leaf rolling is a common indication of water stress in cereals. Along with other symptoms it has been used by IRRI scientists to visually score rices for drought resistance. During rainless periods dryland rices exhibit more leaf rolling and unrolling than wetland-adapted rices. We also commonly observe leaf rolling in irrigated dry-season rice crops when there is a short drought period.

We investigated the advantage associated with leaf rolling and found the trait indeed effective in decreasing water loss from rice leaves. Leaf rolling may be related to the maintenance of relatively high water status in well-adapted rice varieties. We know from earlier research that more extensive root systems can be responsible for maintaining leaf water potential by giving the plant more absorptive capacity. Leaf rolling may also contribute to maintaining high leaf water potential by decreasing water loss during drought periods.

TOLERANCE FOR ADVERSE SOILS

Since the creation in 1974 of our GEU team to work with adverse soils problems more than 60,000 rices have been tested in the search for needed germplasm. The list of rices that hold promise for rice growers who farm on the world's 100 million ha of adverse soils has grown considerably.

In 1978, we screened 21,403 rices, which included varieties from the germplasm bank, elite breeding lines, and the progeny from the salt-tolerance and alkali-tolerance breeding programs. Among them, 2,670 showed some tolerance. Outstanding among those were IR4630-22-2-10 and IR9824-54-3 for salt tolerance; IR4417-179-1, IR4630-22-2-10, and six IR4763 lines for alkali tolerance; and IR20 and four IR2071 lines for iron-toxicity tolerance (Fig. 14).

The seasonally saline areas in the lower river basins need flood-tolerant varieties in the wet season and short-duration salt-tolerant varieties in the dry season. In areas where salinity is due to upwelling or seepage of saline groundwater, our present salt-tolerant rices should do well.

14. IR4630-22-2-10 was found outstanding in tests on alkaline and saline soils in IRRI plots during 1978. Rhoda Lantin, senior research assistant, checks a plot of IR34, which has low tolerance for alkali or salt soil conditions.

Table 10. Performance of IR42 in farmers' fields compared with that of other IR varieties on six problem soils during 1978. Note that IR42, while rated as less tolerant, generally produces higher yields.

Problem	Variety	Rating	Grain yield (t/ha)
Salinity	IR42	Moderately tolerant	5.6
	IR4630-22	Tolerant	5.1
Iron toxicity	IR42	Moderately tolerant	4.6
	IR36	Tolerant	2.2
Peat soil	IR42	Moderately tolerant	4.2
	IR34	Tolerant	2.4
Nitrogen deficiency	IR42	No rating	4.6
	IR34	No rating	1.2
Phosphorus deficiency	IR42	Moderately tolerant	3.9
	IR20	Tolerant	4.2
Zinc deficiency[a]	IR42	Moderately tolerant	5.4
	IR34	Tolerant	5.0

[a]Partly corrected by zinc oxide dip.

Field testing

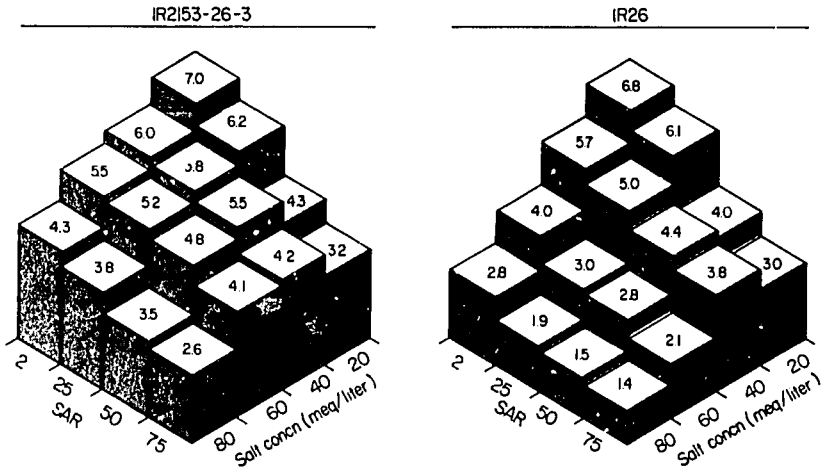
In our tests of salt-tolerant hybrids in Filipino farmers' fields, the salt-tolerant IR9824-54-3 yielded 3.6 t/ha, and IR4619-48-3 yielded 3.2 t/ha compared with IR26's 2.1 t/ha. Twelve salt-tolerant IRRI lines had 4.0–5.6 t/ha yields in a field reclaimed from a coastal swamp only a year ago.

In a test in an iron-toxic field, tolerant IR42, IR4432-56-6, and IR2058-7-1 gave yields of nearly 4.5 t/ha; IR26 had 1.4 t/ha. In a phosphorus-deficient farmer's field, IR4568-86-1 yielded 5.4 t/ha without phosphate fertilizer where 24 rices had yields ranging from 1.3 to 2.8 t/ha.

Of the IR varieties IR42 is the best adapted to adverse soils (Table 10). It also has resistance to drought, insects, and diseases. IR42's remarkable yield stability in several adverse environments accounts for its ready acceptability to farmers.

Breeding emphasis shifted

We supplemented our salt-tolerance hybridization work with the use of improved rices to enhance recovery of salt-tolerant lines with high yield potential. IR9824-54-3 is such a line. Salt- and alkali-tolerant lines identified among the progeny of our general breeding programs are being tested at national breeding centers through the International Rice Testing Program. Hybrid populations for acid-sulfate-soil tolerance were developed in 1978 from varieties



15. Salinity-tolerant IR2153-26-3 produces more dry matter yield of tops (g/plant) than nontolerant IR26 at higher salt concentration and sodium adsorption ratios (SAR). The LSD (5%) for varieties is 0.56; for salt concentration and SAR, 0.51.

native to acid sulfate soil areas or varieties with iron-toxicity tolerance.

Ion uptake and tolerance for mineral stresses

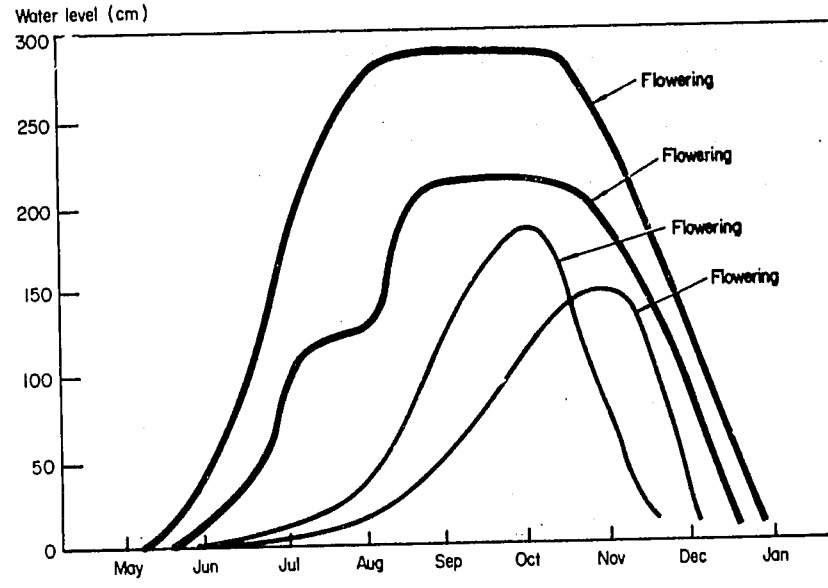
A 1978 study revealed that salt injury in rice depends not only on salt concentration in the soil but also on sodium adsorption ratio (Fig. 15), and that salt tolerance is associated with a high sodium adsorption ratio. This implies that salt injury will be more severe in soils low in calcium and magnesium than in others and that we must consider the sodium adsorption ratio in screening rices for salt tolerance.

We also investigated the role of manganese in iron-toxic soils, which are low in manganese. Our results suggest that iron toxicity may occur at water-soluble-iron concentrations as low as 5 ppm if the manganese concentration is very low. We also found that increasing the manganese concentration alleviates iron toxicity.

DEEPWATER AND FLOOD TOLERANCE

Modern semidwarf rice varieties cannot tolerate the flooding that occurs during the monsoon on more than a third of Asia's rice fields. We began intensive research on modern rices for deepwater areas in 1975. During 1976–77 breeding of photoperiod-sensitive rice for deepwater areas was speeded by rapid generation advance techniques. That breeding system became fully operational in 1978.

Initial emphasis was on the intermediate (21–50 cm) deepwater areas. Most of the modern high yielding rices cannot be used



16. Nodal tillers may contribute substantially to deepwater rice yields in fields where the water level increases for 6 weeks after planting and then remains nearly constant for 4–6 weeks, provided that time between tillering and panicle initiation is sufficient. Patterns where nodal tillering is important are shown by the heavy lines. In the other patterns continuous increase in water level does not give the plant time to produce nodal tillers. For such areas it is not important to breed for the nodal tillering characteristic.

in such areas because the seedlings are short and are liable to be submerged at transplanting time. To overcome the problem, farmers use tall, older seedlings and sometimes do double transplanting. We found that the longer-growth-duration varieties generally had higher grain yield when older seedlings (60 vs 20 days old) were used. But the yield of younger seedlings of the short-growth-duration varieties was higher than or similar to that of older seedlings.

During 1978 we capitalized on full use of facilities and improved techniques to greatly increase screening of breeding materials for submergence tolerance, internode elongation ability, kneeing ability, and ability to produce nodal tillers – traits required for increased yield from deepwater rice.

Our results indicate that the importance of nodal tillers (tillers from the upper nodes) in deepwater rice will depend on the flood patterns (Fig. 16). Unfortunately, few hydrological data for deepwater areas are available. Assembling of that data remains as a key step in assessing the importance of branching.

Thailand-IRRI cooperation

Research in our Thailand-IRRI Cooperative Deepwater Rice Project identified a critical role for fertilizer in survival of deepwater rice at an early growth stage and in rapidly rising water. A method for

Note the blank spots in these deepwater rice trials at Prajinburi, Thailand. They illustrate the combined adverse effects of rapidly rising water and lack of fertilizer when rice is planted on the acid sulfate soils of the area. Rice on plots treated with phosphorus and nitrogen fertilizer elongated rapidly and survived.

screening varieties for submergence tolerance in deepwater ponds and identifying breeding material outstanding for such tolerance was also developed.

Experimental plots receiving no fertilizer on low-fertility acid sulfate soil at Prajinburi, Thailand, were completely destroyed by rapidly rising water levels, but those given 37 kg each of nitrogen and phosphorus/ha, or 37 kg of phosphorus alone, showed good survival. At another site the unfertilized plot of a new deepwater-tolerant dwarf line was destroyed, but plots receiving 37 kg of nitrogen and phosphorus/ha had good survival. These findings have strong implications for judging breeding materials for ability to elongate and determining fertilizer responsiveness of varieties in deep water.

We found great difference in tolerance of genotypes for submergence in 115 cm of muddy water for 10 days. Two entries appear promising – FR13A from India and the line BKNFR76109-7, which has FR43B as a parent. The identification of entries with excellent tolerance should permit accelerated breeding work by countries that have simple deepwater pond facilities.

At a 1978 Deepwater Rice Workshop at Calcutta, which we jointly sponsored with the Indian Council for Agricultural Research (ICAR) and West Bengal state, more than 60 scientists agreed on a collaborative program to accelerate the development of the

varieties suitable for deepwater areas. The program covers screening for flood tolerance, use of rapid generation advance, screening for drought tolerance at seedling and early vegetative stages, trials on fertilizer efficiency, survey of stem borer incidence, and collection of germplasm from deepwater areas.

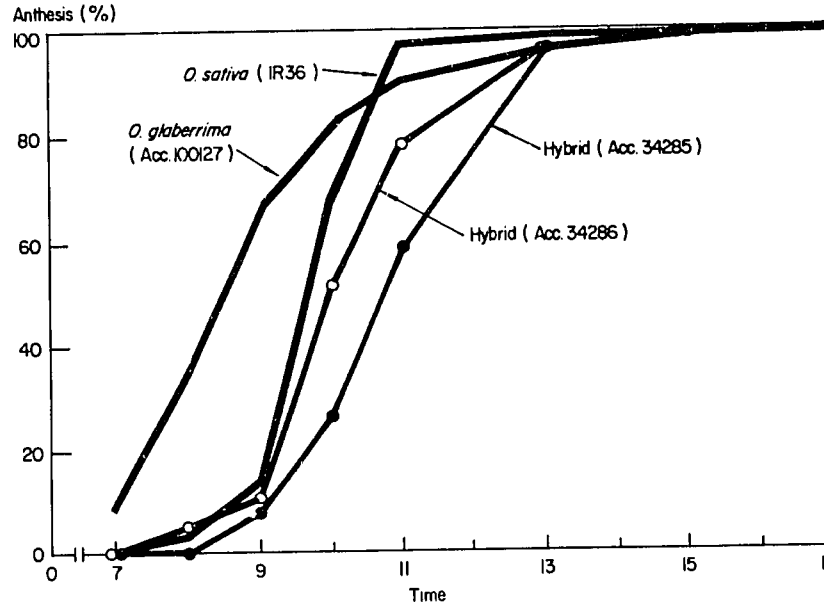
TEMPERATURE TOLERANCE

A combination of tolerance for high or low temperature and early maturity in the high yielding modern rice varieties gives farmers the potential to greatly increase yields in areas where high or low temperatures damage rice crops.

Heat tolerance

We tested 291 early-maturing rices at 35°C and identified several with heat tolerance. The best are listed in Table 11.

Flowering of a rice plant in early morning, before the temperature rises to a high level, allows the plant to avoid heat-caused sterility. In 1977 we found that *Oryza glaberrima* cultivars have the characteristic of early morning flowering. We tried breeding early flowering into improved rices so as to reduce losses from high-temperature sterility. But two crosses of *O. glaberrima* cultivars and IR36 *(O. sativa)* gave the opposite of what we had expected – the progeny flowered later than either parent (Fig. 17). We will



17. Flower opening time of IR36, *O. glaberrima*, and their hybrids.

Table 11. Among 291 early-maturing rices tested for heat tolerance at 35°C, the best selections were from 4 sources. IRRI phytotron, 1978.

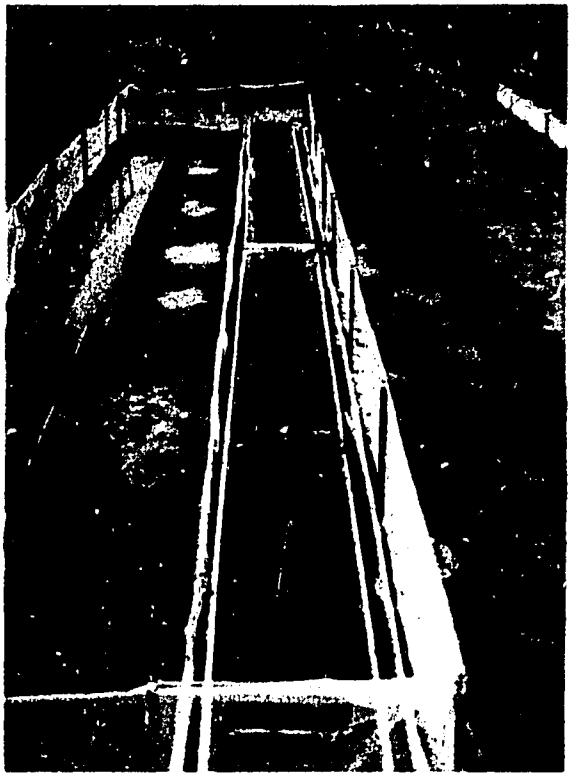
Designation	Origin	Designation	Origin
DNJ 126	Bangladesh	Pusa 2-21	India
IET 2684		Sathra 278	Pakistan
(OR34-16)	India	IR9208-22-2-2	IRRI
IET 3268 (C633)	India	IR9209-26-2-2	IRRI
IET 4094		IR9209-89-1-1	IRRI
(CR156-5021-207)	India	IR9209-181-3-5	IRRI
IET 4105		IR9403-3-1-1	IRRI
(CR148-60230215)	India	IR9403-96-2-3	IRRI

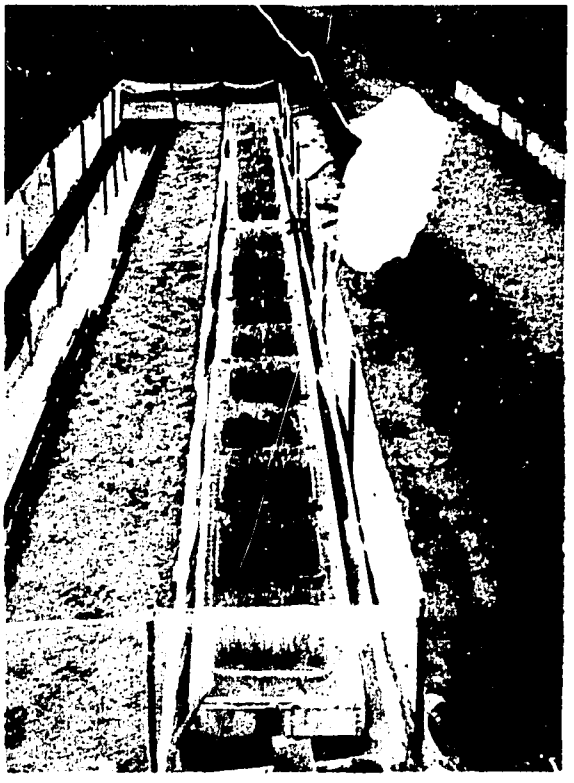
continue work to transfer early morning flowering to the improved varieties.

Low-temperature tolerance

In 1978 our first collaborative studies on rice cold tolerance were started in Korea. From the tests in Korea, at IRRI, and in countries that planted the International Rice Cold Tolerance Nursery

Collaborative IRRI-Korean testing of rices for cold tolerance started in 1978 in new facilities built by Korea's Office of Rural Development at Chuncheon. Shown here are the effects of cold water on seedlings in special field tanks. Seedlings on the left have just been placed in the test facility. Tolerant varieties maintain their green color; many seedlings in the photo at right show cold damage.





(IRCTN), the best varieties were selected for short growth duration (17 varieties), intermediate plant height (7), well-exserted panicle (8), flowering at 21°C (12), and cold water tolerance at seedling stage (9).

The Korean collaboration will definitely accelerate progress in our cold tolerance program. Most of those varieties were placed in the 1979 IRCTN and can be used by breeders working on cold tolerance. A large number of entries from the 1978 IRCTN were also included in the 1979 nursery, an indication of the improvement in the quality of entries and the nursery in general.

The first international workshop on rice cold tolerance was conducted at Suweon, Korea, in cooperation with Korea's Office of Rural Development. Forty-eight scientists from seven countries reviewed problems limiting rice production in low-temperature areas and discussed research methods best suited to solving the problems. Recommendations for collaborative work on rapid generation advance and screening of breeding materials for cold tolerance at different growth stages were implemented immediately.

INTERNATIONAL RICE TESTING PROGRAM

The scope and impact of our International Rice Testing Program (IRTP) continue to increase. The broad acceptance of the program and its impact on rapid improvement of rice varieties throughout the tropical rice-growing world have been astounding. IRTP also serves as the vehicle for institutionalizing the planning of national and international GEU work.

Two new test nurseries were initiated in 1978 – the International Rainfed Lowland Rice Observational Nursery (IRLRON) for the vast rainfed areas of Asia, and the International Rice Arid Regions Observational Nursery (IRARON) for the irrigated arid regions where adverse soils and temperature problems are common.

More than 900 test nurseries were dispatched from three central points in 1978: from IRRI, 800 nurseries to 50 countries; from CIAT, 114 nurseries to 18 Latin American countries; and from Egypt, the new IRARON to 12 countries.

During 1978 we analyzed 1977 IRTP nursery results from 41 countries. The data continued to reflect the improved quality and quantity of observations made on nursery entries.

- Our cooperators continue their increased use of the IRTP entries for national rice improvement work, through both hybridization and direct testing of promising lines.

Participants in the 1978 IRTP monitoring tour that looked at regional rice research in West Africa take notes on an upland nursery at IRAT, Bouake, Ivory Coast (left). Cold tolerance tour participants take notes in rice plots (right) at the Larnoo, Kashmir, India, high elevation station – about 2,200 m above sea level.

- Several varieties that mature in 110–115 days (especially IR36) continued to perform well in many regions of the world. Varieties from Bangladesh, India, Indonesia, and IRRI performed well in the 120–140 days group. Some semidwarf and tall varieties performed well in dryland yield tests in different countries.
- Varieties tolerant of diverse stresses were identified from entries in the International Rice Observational Nursery. Several indica varieties with moderate levels of cold tolerance at the seedling and flowering stages were found.
- Several potentially good varieties for use in blast resistance development were identified in nurseries at several sites where blast incidence was high.
- The reaction of rices to brown planthopper in South Asia appears distinct from that in East and Southeast Asia. The gall midge biotype in Thailand appears distinct from biotypes in India, Indonesia, and Sri Lanka, and differential reactions were evident within India.

In 1978 we made increased use of monitoring tours for planning the IRTP program. Four tours focused on regional rice research activities – South India and Sri Lanka, the southern region of South America, West Africa, and the Indus River Plains; six tours focused on specific program areas of rice improvement – rainfed, deepwater, cold tolerance, long duration, virus diseases, and collaborative drought resistance breeding. Besides observing and planning IRTP nurseries, tour participants discussed and planned collaborative research of mutual interest with scientists in national rice improvement programs.

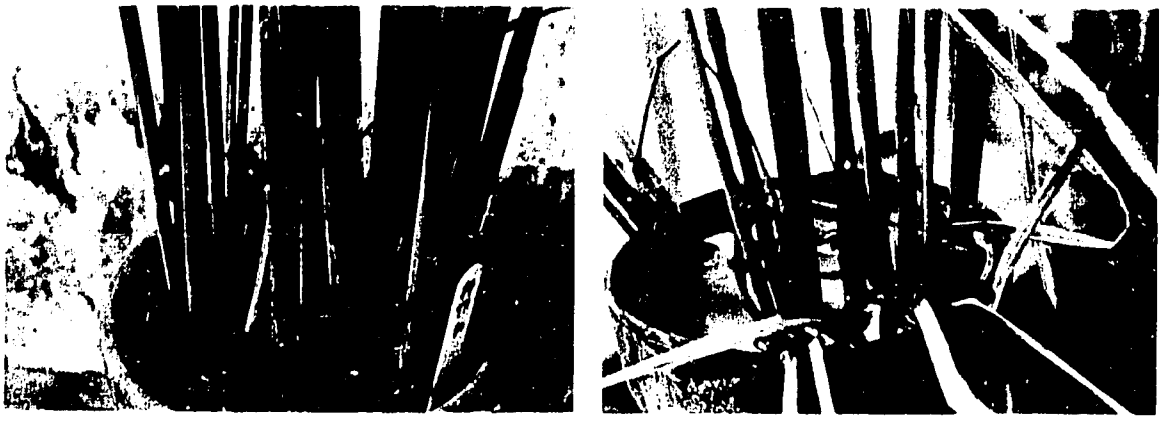
Control and management of pests

To supplement the host plant resistance resulting from our GEU program's research, we seek improved cultural, biological, and chemical means of managing pests – insects and diseases – and weeds as well. The aim is to develop simple, inexpensive, and environmentally acceptable techniques that will be attractive to the small-scale farmer with his limited financial resources.

RICE DISEASES

In the 12-year search for resistance to sheath blight, during which we tested more than 10,000 rice breeding lines and varieties, we found all were susceptible to the pathogen *Rhizoctonia solani.* Numerous studies have also shown that new pathogenic races of the blast fungus can occur in nature, and cause severe losses on varieties presumed to be resistant. Furthermore, all the rices we have screened for resistance to leaf scald have been found susceptible.

Devastation of the rice crop in small farmers' fields as seen here – by the brown planthopper (left), the caseworm (center), and the leaf folder (right) – underscores the continuing need for new efficient techniques to control rice pests.



18. The rice plants on the right display the symptoms of a bacterial disease in the IRRI yield nursery. Nondiseased plants are shown on the left.

Because there is need for alternative control methods for these diseases – and others – we increased the scope of chemical control research in 1978. Several fungicides were tested for inhibition of spore germination in the laboratory. We found that Hinosan TCP at 0.3% concentration and CGA 49104 at 0.25% concentration effectively inhibited spore germination of blast, *Cercospora* leaf spot, and leaf scald pathogens. For dryland, direct-seeded rice, CGA 49104 at the rate of 32 g/kg of seed provided excellent protection from the blast disease for a minimum of 5 weeks after seeding.

New bacterial disease

A new bacterial disease at IRRI was identified on IR129-192-2 plants in the 1978 yield nursery. The leaf sheath and stems of diseased plants appeared dark brown and water-soaked at the basal internodes, and the tissues later rotted (Fig. 18). Our initial study indicated the disease was caused by a bacterium of the *Pseudomonas* sp. Bacterial and pathological studies of the disease continued into 1979.

Kresek disease of rice

The percentage of incidence of the kresek phase of bacterial blight increased when the seedbed was infested with *Xanthomonas oryzae* close to transplanting time. Kresek incidence at the seedling stage was much higher when IR8 was transplanted than when it was direct seeded. This suggests that kresek infection may be associated with injury of seedling roots during transplanting and is related to survival of the pathogen in the seedling or field (Table 12).

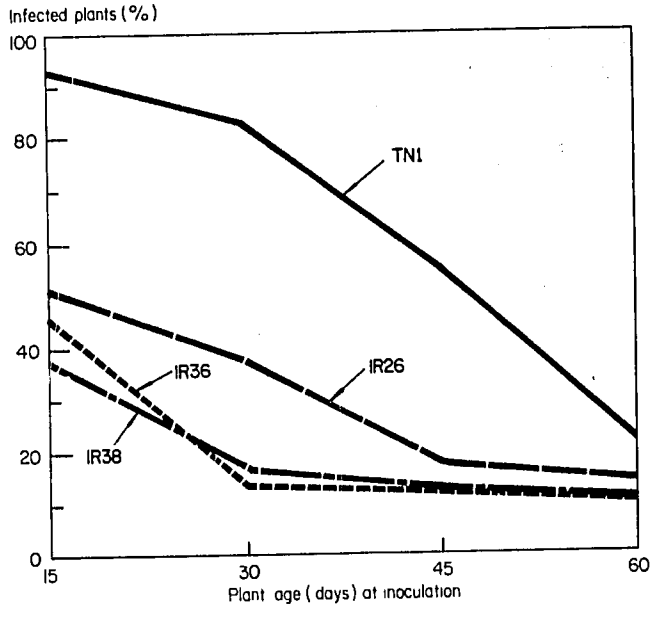
Table 12. Kresek incidence was examined on IR8 transplanted or direct-seeded in soil infested with *Xanthomonas oryzae* at different inoculum levels. The development of kresek appears to be directly related to seedling root injury

Inoculum dilutions	Kresek development (%)			
	Sterile soil		Unsterile soil	
	Transplanted	Direct-seeded	Transplanted	Direct-seeded
10^0	32.9	0.3	26.9	1.5
10^{-2}	17.4	0.5	23.2	0.8
10^{-4}	8.0	0.3	10.2	2.3
10^{-6}	1.4	0	1.3	1.5

Ragged stunt

We tested the pathogenicity of ragged stunt on several wild relatives of *O. sativa* by artificial inoculation in an IRRI greenhouse. *Oryzae barthii*, *O. glaberrima*, *O. latifolia*, *O. nivara*, and *O. spontanea* became infected with ragged stunt, but 41 inoculated plants of *O. australiensis* did not develop symptoms.

In inoculation tests of four varieties at various plant ages we found that, regardless of variety, the younger rice plants had higher susceptibility to rice ragged stunt disease (Fig. 19). In collaborative studies with Hokkaido University, Japan, we found similarities in



19. Ragged stunt infection of rice varieties decreases as rice plants grow older.

Table 13. Differences between rice black-streaked dwarf and rice ragged stunt indicated by collaborative studies with researchers at Hokkaido University, Japan.

	Black-streaked dwarf	Ragged stunt
Distribution	Temperate regions	Tropical regions
Symptoms		
Stunting	Severe	Moderate
Tillering	Excessive	Not excessive
Leaves	Not ragged	Ragged
Swollen veins	Irregular	Narrow, elongate
Virus particles	Spherical, 60 nm diam	Spherical, 40 nm diam
Vector insect	*Laodelphax striatellus*	*Nilaparvata lugens*
Host plants	Barley, corn, oat, and wheat are infected	Barley, corn, oat, and wheat are not infected

symptoms – stunting, leaf twisting, and appearance of swollen veins – between rice black-streaked dwarf and ragged stunt; however, the diseases are not identical (Table 13).

Tungro forecast

Criteria such as an extremely low initial vector insect population during the dry season, limited time for its propagation, insufficient diseased plants as virus sources, few infective insects, and varietal resistance to tungro and to its vectors can be used for *negative prediction* of a tungro outbreak (Table 14).

We know that prevention of a tungro outbreak is practical if rice farmers learn to recognize tungro vectors, and frequently check for and kill tungro vectors in the seedbeds, particularly when adjacent fields are being plowed or harvested.

Table 14. A 6-year study of tungro vectors in Filipino farmers' fields from April to June and the incidence of rice tungro disease in the fields from June to October, provide a basis for establishing the predictability of tungro outbreak.

Year	Tungro vectors		Tungro disease	
	No./10 sweeps	Infective (%)	Fields (%)	Incidence (%)
1973	5.8	0	1	0.60
1974	11.0	1.77	45[a]	2.38
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

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

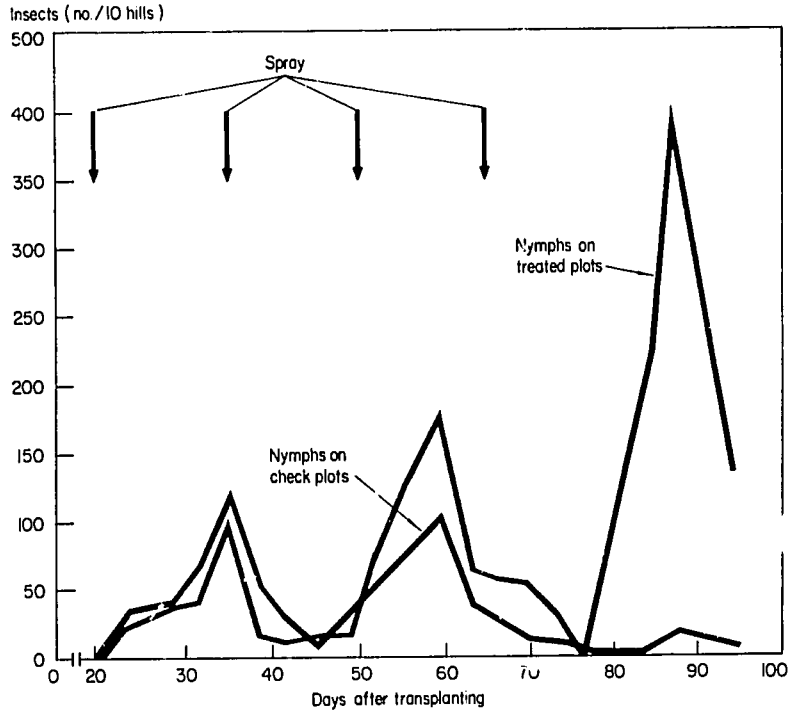
INSECTS

The brown planthopper remains a major threat to Asia's rice crop. Our research on biological control of the hopper intensified in 1978. At the same time we expanded testing of insecticides against the full range of rice insects.

Brown planthopper resurgence

We continued to seek the causes for an increase in brown planthoppers in a field after insecticide use. Greenhouse studies indicated that insecticidal effects that cause resurgence include stimulation of reproduction, increase in feeding activity, and longer adult life.

In 1978 greenhouse studies we found that 5 insecticides – methyl parathion, fenitrothion, decamethrin, diazinon, and fenthion – significantly increased the reproduction rate of brown planthopper females placed on sprayed plants. In field studies, four applications of methyl parathion after transplanting caused a distinct increase in the third generation of brown planthopper 85 days after transplanting (Fig. 20).



20. Four sprays of methyl parathion at 0.75 kg a.i./ha caused marked resurgence of the brown planthopper population on IR22.

Antifeedant for BPH

We cooperated with scientists from the International Centre on Insect Physiology and Ecology, Nairobi, Kenya, to study antifeedants for the brown planthopper. Emulsified 12% crude oil from the seeds of the neem tree sprayed on TN1, a planthopper-susceptible variety, reduced the hopper's feeding. Higher concentrations caused the hoppers to avoid the TN1 plant. The first-instar nymphs of all brown planthopper biotypes tested were highly susceptible to neem oil. Only 3 to 9% of nymphs matured on plants treated with 3% oil (lowest concentration), while 67 to 88% matured on plants sprayed with water. At neem oil concentrations of 6% or more, all nymphs died.

On neem-oil sprayed plants the fecundity of the three biotypes was greatly reduced; however, egg hatchability was not affected. In field trials, predators, such as spiders and mirid bugs, were not affected by neem oil sprays.

Insecticide evaluation

In 1978 we began evaluating insecticides for their effectiveness against the striped stem borer and leaf folder as well as against the brown planthopper and green leafhopper. New insecticides found effective were Miral, ethoprop, and cartap, as paddy-water application against the stem borer, and chlordimeform, A47171, and ethion, as foliar sprays against the brown planthopper.

For the first time in 1978 we tested insecticides for their fumigant effect in the greenhouse. Carbofuran and Perthane were highly toxic to the brown planthopper, but had no effect on the green leafhopper.

Methods of insecticide application

Farmers often cannot get enough water to the field for crop spraying with the ordinary knapsack sprayer. In 1978 we tested the efficiency of a hand-held, battery-operated ultra-low volume (ULV) sprayer that requires as little as 2 liters of spray solution/ha. Initial studies showed that droplet size and plant age affect the density of spray droplets on the plant (Table 15). The sprayer works best with young plants and a 65-μm droplet size.

Because the brown planthopper feeds on the leaf sheath at the base of the rice plant, we need spray techniques that allow droplets to penetrate the crop canopy.

With ULV, however, a low percentage of the droplets reached the leaf sheath even in a young crop. ULV application of carbo-

Table 15. Ultra-low-volume (ULV) sprays were tested on IR42 during the 1978 dry season. The deposit of spray on the plant is affected by ULV droplet size and plant age.

ULV droplet size (μm)	Droplets/cm² on plant[a]		
	11 DT	22 DT	60 DT
65	16.1 a	10.5 a	2.6 a
86	6.1 b	7.1 a	0.7 b
130	1.8 c	0.7 b	0.3 b
250	0.4 c	0.1 b	0.1 b

[a]Av of upper leaf, lower leaf, and leaf sheath. DT = days after transplanting. Means followed by a common letter are not significantly different at the 5% level.

furan gave whorl maggot control equal to that from use of a high-volume sprayer, paddy-water application, or soil incorporation.

Biological control of insects

We have identified the important predators and parasites of the brown planthopper. Both groups play critical roles in pest control. In the field we observed that total brown planthopper egg mortality was about 70%, with egg parasitism causing nearly half of that. The bug *Cyrtorhinus* kills some eggs as well. Mortality of planthopper nymphs was about 95%, caused mostly by predators such as *Microvelia* and spiders, and to a lesser extent, by strepsipteran and dryinid wasp *(Pseudogonatopus)* parasites. Such activity can reduce

The brown planthopper eggs shown (upper left) were damaged by the predator Cyrtorhinus, *seen on the rice stem (lower left). The small parasitic insect* Anagrus flaveolus *is shown on a rice leaf (upper right). The female adult finds a brown planthopper egg mass by drumming the rice plant with her antennae, bores into the leaf sheath, and parasitizes the eggs. Parasitized eggs are yellowish or reddish (lower right).*

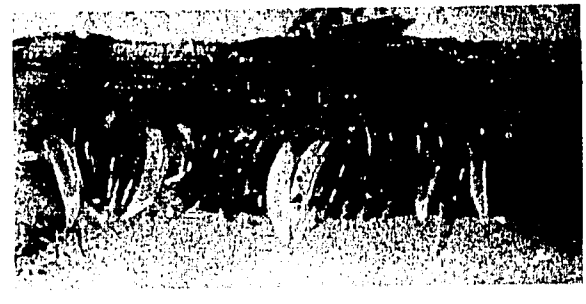


Table 16. Brown planthopper density was significantly reduced by 50 ducklings or 25 adult ducks feeding for 4 hours a day in 100-m^2 plots of transplanted rice at IRRI.

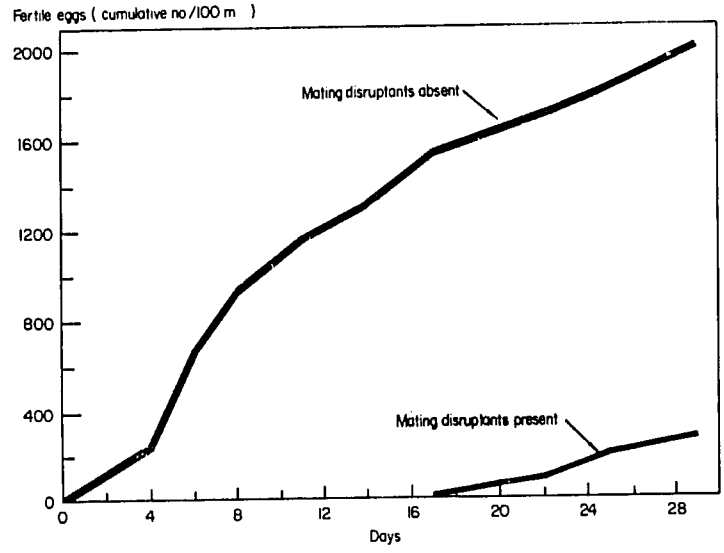
Treatment	Brown planthopper density (no./hill)			Reduction in density (%)
	Before introduction of ducks	After introduction	Difference[a]	
	Field 1 (38–43 days after transplanting)			
Ducklings (50)	534	54	480*	90
Adult ducks (25	459	63	396*	86
Control	335	319	16	–
	Field 2 (49–53 days after transplanting)			
Ducklings (50)	15	7	8*	53
Adult ducks (25)	.21	13	8*	38
Control	20	22	–2	–

[a]* = significant at the 5% level by LSD test.

brown planthopper density to negligible levels without use of insecticides.

Ducks in rice fields can also help control the brown planthopper. Fifty ducklings or 25 adult ducks feeding in a 100-m^2 area for only 4 hours greatly reduced hopper density in IRRI plots (Table 16). It should be possible to use ducks in a pest management system even though they also eat some beneficial insects in the rice fields.

Fifty ducklings such as these, feeding 4 hours in 100-m^2 plots at IRRI, significantly reduced the number of brown planthoppers per rice hill.



21. Fertile eggs laid by stem borer moths on susceptible plants in field cages decreased sharply when vials (8/m^2) containing 1 mg of mating disruptant were placed in the cages.

Sex pheromones

In a collaborative research with the Tropical Products Institute, London, U.K., we confirmed that chemicals that attract stem borer moths to pheromone traps also disrupt mating. No fertile eggs were laid for more than 2 weeks in cages containing a formate mating disruptant for *Chilo suppressalis* (Fig. 21).

WEEDS

Weeds hamper farmers' work and cut yields across the entire range of tropical rice and dryland crops. In terms of cost and effectiveness, herbicides do not always provide a good answer to the farmers' weed problem. Hand weeding, which remains the only sure way of completely removing weeds from a crop, is backbreaking, tedious, and often requires more labor than a farmer can muster.

Weeds in a dry-seeded rice

A 1978 experiment emphasized the dramatic change in the kind of weeds that grow in a bunded dry-seeded rice field as the ponding of water changed. We found 15 weed species in a paddy with very low ponding, 12 in land with low ponding, and 9 in land with high ponding. A well-drained dryland plot had 13 weed species. The major weed species and their relative importance varied from plot to plot (Table 17). There was little similarity between the weed

Table 17. Weed populations change as ponding of water changes in a dry-seeded rainfed rice crop. The data are from unweeded check plots of a 1978 wet-season dry-seeded rice crop.

Weeds in well-drained dryland	Relative importance	Weeds at very low ponding	Relative importance	Weeds at low ponding	Relative importance	Weeds at high ponding	Relative importance
Digitaria ciliaris	50.5	*Echinochloa colona*	28.3	*Echinochloa colona*	76.4	*Echinochloa colona*	59.3
Amaranthus spinosus	20.7	*Eleusine indica*	21.9	*Leptochloa chinensis*	11.1	*Cyperus iria*	18.1
Commelina benghalensis	9.0	*Digitaria ciliaris*	21.7	*Cyperus iria*	6.0	*Paspalum distichum*	18.1
Cyperus rotundus	5.7	*Cyperus rotundus*	12.8	*Calopogonium mucunoides*	3.5	*Leptochloa chinensis*	1.8

communities growing in each plot except between the plots with low and high ponding pontential. Only two weed species were common to the four plots. The results point out the difficulty of identifying a single herbicide suitable for all dry-seeded rice situations.

Weeds in transplanted rice

We examined the effect of tillage and weed control treatments on weed growth and the yield of transplanted rice. The weight of broadleaf weeds was significantly lower in zero-tillage plots, where the herbicide paraquat was applied 2 days before transplanting, than in plots with 1 plowing and 1 harrowing, or with 2 plowings and 3 harrowings. But the weight of grasses was significantly lower in the maximum-tillage plots than in the zero tillage plots.

The yield data indicate that as the degree of tillage and the rate of possible weed control treatment increased, the degree of weed control achieved also increased (Table 18).

Table 18. Effects of different methods of land preparation and weed control on the yield of transplanted IR36 in a 1978 wet-season trial at IRRI.

Treatment	Rate[a] (kg a.i./ha)	Yield[b] (t/ha)		
		Zero tillage	Minimum tillage (1 plowing, 1 harrowing)	Maximum. tillage (2 plowings, 3 harrowings)
Weeded twice	–	4.9 a	4.2 a	4.2 a
Pendimethalin	2	2.0 b	3.5 a	3.6 a
Butachlor	2	0.4 b	3.9 a	3.5 a
2,4-D	0.8	0.4 b	2.0 b	3.2 a
Unweeded	–	0.9 b	2.1 b	2.0 b

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

Control of *Scirpus maritimus*

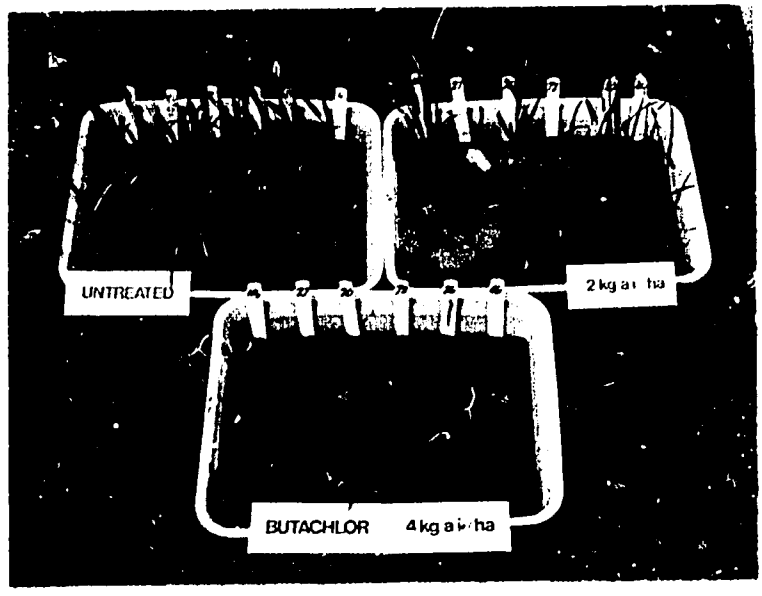
The perennial sedge *Scirpus maritimus* is increasing in importance in wetland rice fields. During 1978 we found that 2,4-D at the rate of 1.0 and 1.5 kg/ha applied 20 days after transplanting controlled *Scirpus maritimus* as effectively as bentazon and fenoprop, which are more expensive herbicides. Fosamine, a herbicide that is supposed to reduce tuber formation, had little effect on *S. maritimus* when applied 27 days before first tillage.

In another experiment, we found that 2,4-D at 0.5 kg/ha 15 days after transplanting and 1.0 kg/ha 20 days after transplanting greatly reduced the *S. maritimus* stand. The 2,4-D applied 20 days after transplanting was as effective as bentazon (1 kg/ha) and superior to the other treatments.

Cultivar tolerance for herbicides

We tested the entries in the 1978 International Rice Deepwater Observational Nursery for tolerance for preemergence application of pendimethalin, butachlor, and thiobencarb.

Herbicide injury was influenced by the location of the rice plant's first node in relation to the herbicide-treated soil surface. Cultivars with their first node near the soil surface tended to be susceptible to herbicides, whereas those with nodes farther from the soil surface tended to be tolerant.

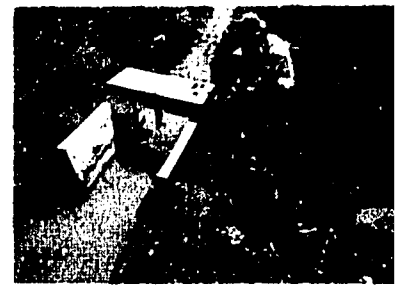


22. IRRI research scholar Modesto Madrid Jr. (left) shows differences in seedling herbicide tolerance. The three flats (right) show differences in cultivar tolerance for butachlor at two rates. The numbers on the tags are for BKN6986-147-2 (No. 20), BR118-3B-17 (No. 26), Nam Sagui 19 (NS), BR223-B-3 (No. 27), Baisbish (No. 46), and Sungwala (No. 72).

BKN 6986-45-1, BKN 6986-147-2, BR 188-3B-17, Yodaya, Kurkaruppan, and Nam Sagui 19 were tolerant of the herbicides at double the rate recommended for weed control (Fig. 22). Other cultivars such as BR 223-B-3, Baisbish, CN 539, Sulpan, and Sungwala were damaged by the herbicides.

Irrigation and water management

It is widely recognized that more efficient use of Asia's existing irrigation water resources is one key to a sizable increase in rice production. We continue to place major research emphasis on developing better techniques for managing irrigation systems, to obtain greater benefits from available water.



Senior research assistant Domingo Tabbal adjusts an IRRI designed flow measurement device in a farmer's field in Central Luzon, Philippines.

Integrated system management

We completed the first two crop seasons in a management study of a 2,500-ha irrigation system in collaboration with the Philippines National Irrigation Administration. Data were analyzed and compared with 1977 wet-season benchmark information.

Water-use efficiency was determined for selected weeks in both wet and dry seasons when most of the area had rice crop in the vegetative stage. The preexperimental wet-season water-use efficiency was 43%. That increased to 60% with our improved system management. Farmer interference in the system operation decreased as time passed and they were convinced of its improved performance (Table 19). The farmers' noninterference was a marked departure from preexperimental behavior standards.

Our first year's results suggest that application of simple and rational techniques of measurement, control, and monitoring to

Table 19. Farmers' behavior before and during land preparation in the Lower Talavera River Irrigation System, Upper Pampanga River Integrated Irrigation System-National Irrigation Administration, Nueva Ecija, changed markedly between the 1977 wet and 1977–78 dry season.

Season	Farmers (no.) exhibiting given behavior							
	Breaks embankment	Opens or closes gates	Destroys flumes	Checks canal	Breaks equipment	Makes illegal turnout	Does not follow schedule	Total
Wet 1977 (before experiment)	23	52	2	116	1	85	1	172
Dry 1977–78 (after experiment)	1	30	–	39	2	3	–	57

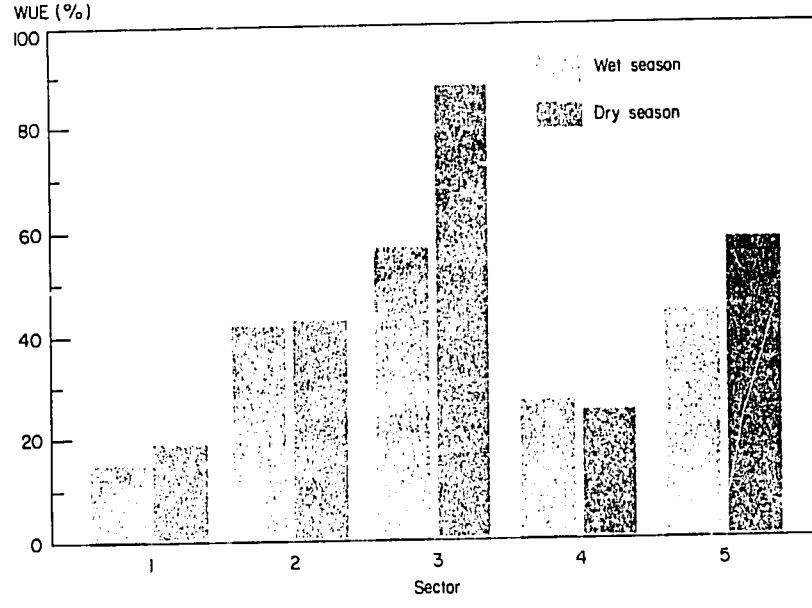
deliver irrigation water based on actual field requirements has tremendous potential for improving the overall performance of an irrigation system.

Water use in a communal project

Communal irrigation systems in the Philippines serve more than 800,000 ha, but little is known about the pattern of water use in such systems. We studied a communal system in Camarines Sur province for water availability at the source and water allocation and distribution in various parts of the system. The system used 3 concrete dams to divert water from small rivers into canals and irrigate about 500 ha.

The service area had five sectors. The water-use efficiency in sector 1, which is next to the main source of water, was 15% in the 1976 wet season and 19% in the 1976–77 dry season. The water-use efficiency in sector 2 (145 ha) remained at about 42% for both seasons; that in sector 3 (75 ha) was about 57% in the wet and 88% in the dry season.

Sectors 4 and 5 (most distant from main water source) each received water from an independent source in addition to the excess flow along the main canal from the first three sectors. Sector 5 received much less water and had a higher water-use efficiency than sector 4 (Fig. 23).



23. Study of the water-use efficiency (WUE) in different sectors of the Harani-Malinao-Tugmad Communal Irrigation System, Camarines Sur, during the 1976 wet and 1976–77 dry season, indicated that increasing efficiency could provide water for additional areas.

Table 20. Total water supply, measured drainage, and drainage reuse in the Vaca Creek watershed, Nueva Ecija, Philippines, 1977–78 wet and dry seasons.

Season	Total water supply (million m^3) to watershed	Measured drainage flow (million m^3)	Drainage reused (million m^3)	
			Irrigation model	Drainage model
Wet	83.14	40.74	8.21	17.55
Dry	67.44	36.42	13.62	26.96
Total	150.58	77.16	21.83	44.51

The study indicated the potential of increasing the land irrigated by the system through better allocation of the available water. Attainment of 60% water-use efficiency in sectors 1 and 2 alone would generate water savings that would irrigate an additional 150 ha.

Reuse of drainage water

We did a water-balance study with the National Irrigation Administration on a 3,183-ha irrigated watershed to determine its drainage flow. That drainage, with supplemental irrigation from the Upper Pampanga River Integrated Irrigation System (UPRIIS), serves the 1,745-ha Vaca Creek Irrigation System (VCIS). The Vaca Creek Reservoir stores the drainage water for release into VCIS.

The reuse of watershed drainage in VCIS was calculated two ways (Table 20). The first way (irrigation model) considered the UPRIIS source as the main supplier of water to VCIS, with drainage water stored in the Vaca Creek Reservoir used only when supplementary water was needed. This model provides a measure of how much irrigation water is saved by scheduled release of UPRIIS water into the Vaca Creek Reservoir for VCIS use. The second way (drainage model) considered the watershed outflow as the main source for VCIS and use of the UPRIIS irrigation source as supplemental. The drainage model measured how much irrigation water could be saved if all watershed drainage went to VCIS.

The drainage model, as we expected, gave about two times higher values of drainage reuse than the irrigation model. This shows the potential of more efficient use of drainage water and reduction of irrigation water release from UPRIIS. Analysis of drainage water samples from the watershed and UPRIIS showed both to be suitable for irrigation.

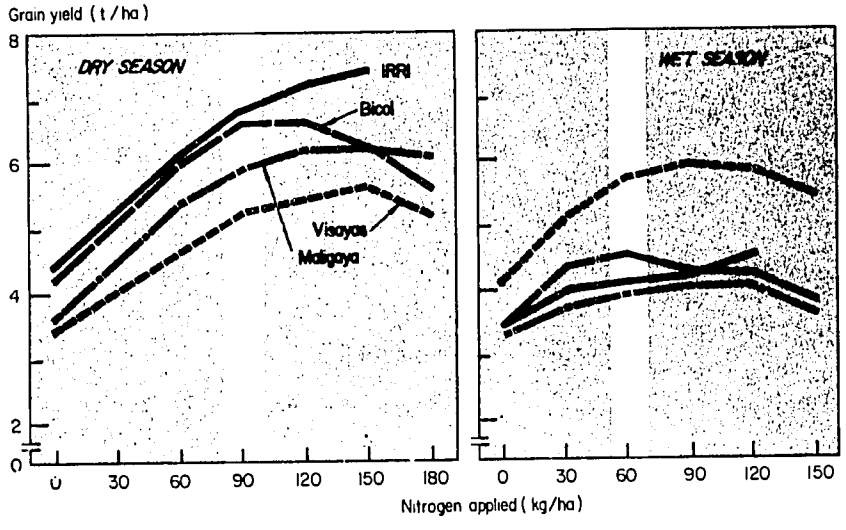
Soil and crop management

Low-cost nitrogen fertilizer is essential to the rice crop – and to the well-being of rice farmers -- in the tropics. But farmers face the continuing threat of fertilizer shortage and of a steady increase in fertilizer prices, both closely related to the world energy supply. Our soil and crop management research team seeks ways to increase the efficiency of nitrogen use by the rice plant. Its focus on ecological fixation of nitrogen has sharpened.

Rates of nitrogen and varieties

Since 1968, fertilizer experiments with 6 rates of nitrogen have been planted at 3 Philippine experiment stations. Figure 24 summarizes average yield data for the 5 rice varieties that produced the highest yield at the 120 kg/ha nitrogen rate for 1974–78.

A continuous cropping experiment at IRRI compares transplanting and broadcast planting of six improved varieties at four nitrogen rates. We harvested the 47th consecutive crop in September 1978. The average yield for the last 32 crops was 0.3 t/ha more for transplanted rice at the highest nitrogen rate. At lower nitrogen rates, differences were less or none (Table 21). The nitrogen rates of 100 kg/ha for the dry season and 60 kg/ha for the wet season appear best. Average yields in the long-term plots have declined since 1968. Figure 25 illustrates that decline for transplanted plots.



24. Summary of 1974–78 data for the 5 rices that produced the highest yield each season at 120 kg nitrogen/ha indicates that 90 kg of nitrogen is the best dry-season rate, and 60 kg the most practical wet-season rate. The IRRI dry-season yield increase from 120 and 150 kg nitrogen makes those rates impractical at current fertilizer and rice prices.

Table 21. Average yields for 32 crops of 6 varieties of transplanted or broadcast-seeded rice at 4 nitrogen rates in a continuous cropping experiment at IRRI, 1968–78.

Treatment	Nitrogen rate (kg/ha)		Yield (t/ha)	
	Dry season	Wet season	Transplant	Broadcast
N_0	0	0	3.7	3.7
N_1	50	30	4.5	4.4
N_2	100	60	4.9	4.7
N_3	150	90	5.1	4.8**

**Significant difference at the 1% level.

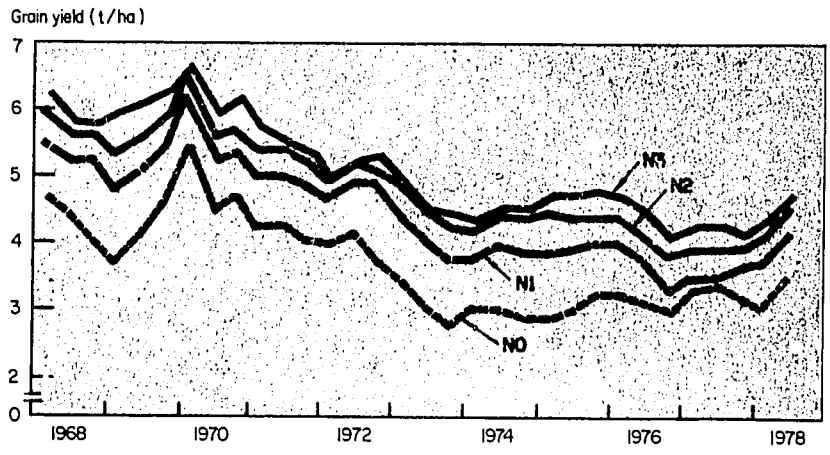
The differences due to nitrogen rates were consistent for both planting methods.

Dates of planting and rates of nitrogen

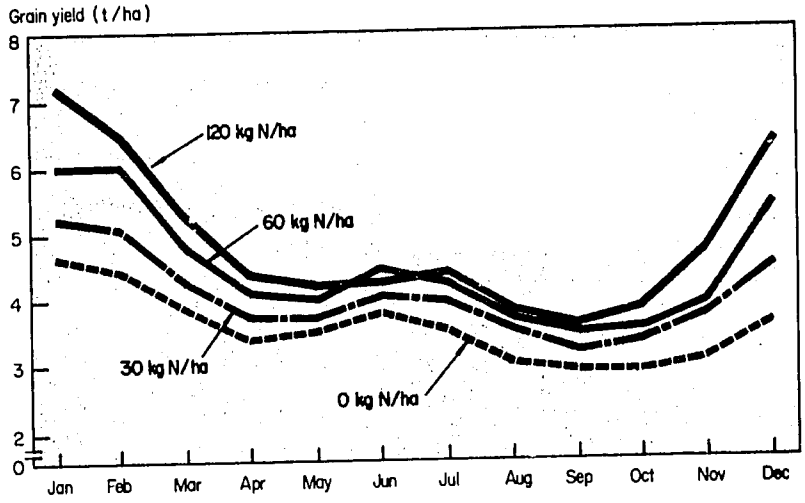
In a date-of-planting experiment started in 1968 four varieties were planted monthly at four nitrogen levels. IR8 and H-4 were always included; the two other entries were improved varieties that were changed regularly. H-4 had a negative nitrogen response in the wet season and IR8's yield declined because of its susceptibility to diseases. With the 10-year data we can array best planting dates as January, February, December, March, November, June, July, April, May, August, October, and September (Fig. 26). By IRRI data the best nitrogen rate in this long-term trial was 120 kg/ha in the dry season and 60 kg/ha in the wet season. Data for off-IRRI experiments indicated that lower nitrogen rates may be better (see Fig. 25).

Nitrogen fertilizer efficiency

The efficiency of urea can be dramatically improved by placing it in the root zone of the rice crop or by treating it to slow its release



25. Yield of the 16th to 47th crop for transplanted rice in a continuously cropped experiment (3-crop moving av) for 6 varieties. Broadcast-seeded plots followed a similar yield trend, but at a slightly lower level. Nitrogen rates are described in Table 21.



26. Average yields of the best two of four varieties planted each month at IRRI from 1968 to 1977. The change in best nitrogen rate from 120 kg/ha in the dry season to 60 kg/ha in the wet season is seen at the end of the curves.

of nitrogen to the rice plant. In 1978 urea supergranules and sulfur-coated urea gave an average return of \$6–7/\$1 extra cost (compared with ordinary urea) in 84 trials in the International Network on Fertilizer Efficiency in Rice (INFER).

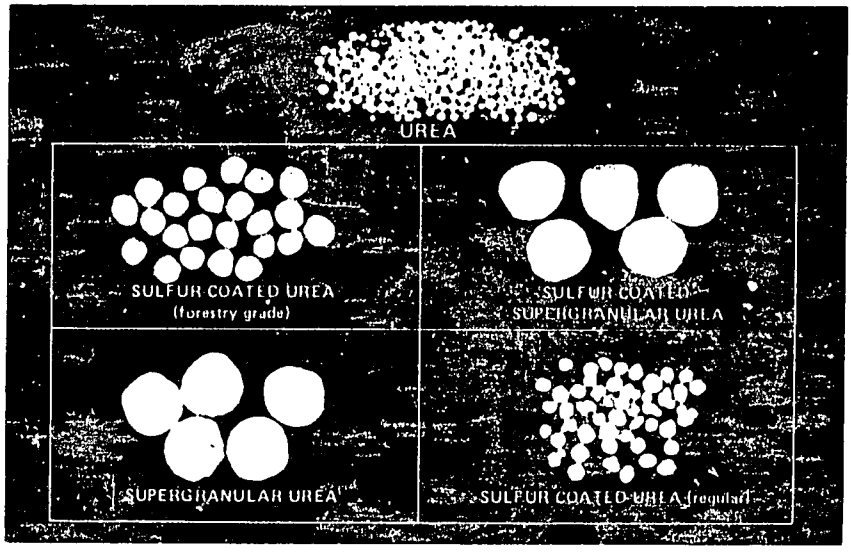
These encouraging results are being followed up through an intensified joint research program with the International Fertilizer Development Center, Muscle Shoals, Alabama. Our main objective is to develop ways to improve nitrogen efficiency through modification of nitrogen fertilizers or management practices. Preliminary results using experimental materials shown in Figure 27 are given in Table 22. Sulfur-coated *forestry grade* urea is promising as a fertilizer for transplanted rice. We will continue study of this and the other materials at IRRI and throughout INFER.

A second major objective of our nitrogen efficiency research is

Table 22. The 1978 wet-season yield of IR42 and apparent recovery of nitrogen show forestry grade sulfur-coated urea's advantage as a nitrogen fertilizer compared with the different experimental fertilizers shown in Figure 27.

Fertilizer material	Application method (58 kg N/ha)	Yield[a] (t/ha)	N recovery (%)
Split urea[b]	Broadcast	3.8	45
SCU (ordinary	Broadcast	4.1	53
SCU (forestry grade)	Broadcast	4.3	74
Supergranule	Root-zone	4.0	38
SC supergranule	Root-zone	4.1	39

[a]Yields were affected by typhoon damage. There were no statistically significant differences. [b]2/3 basal + 1/3 at panicle initiation.

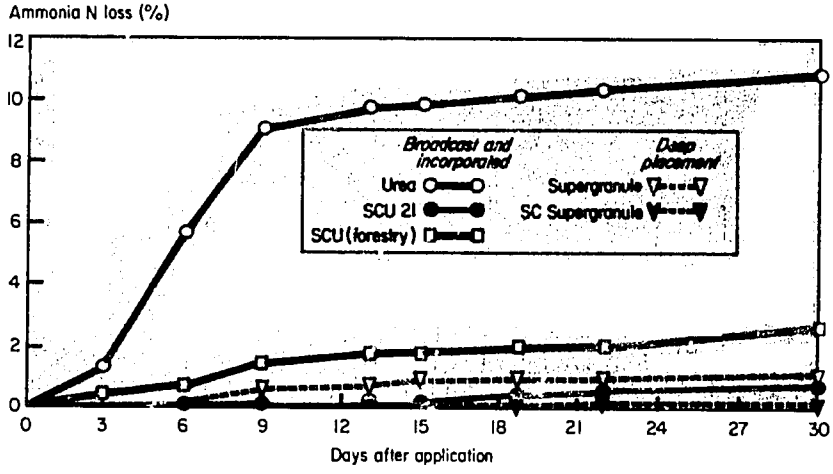


27. Urea-based experimental nitrogen fertilizers for root-zone placement or slow release of nitrogen to rice. Forestry grade sulfur-coated urea (SCU) and supergranules were developed by the International Fertilizer Development Center. The forestry grade urea granules are up to 10 times larger than the ordinary SCU (developed by Tennessee Valley Authority, USA) and are easier to incorporate into puddled soils.

to identify the cause and magnitude of applied nitrogen losses. Recent research on losses was designed to complement the agronomic research on fertilizer efficiency. Figure 28 shows nitrogen loss through ammonia volatilization from the fertilizers in Figure 27. Slow release and deep placement of nitrogen dramatically reduce ammonia losses.

Deep placement of urea fertilizer

Nitrogen fertilizer trials in IRRI fields during the 1978 dry season confirmed that deep placement of urea was more effective than the best split application (Table 23).

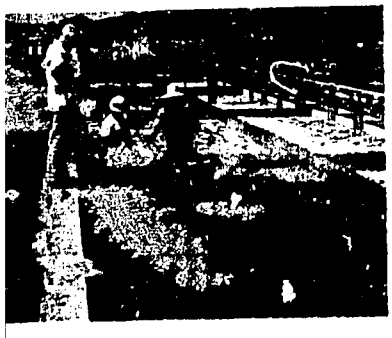


28. The advantages of deep soil placement or treatment of nitrogen fertilizers are seen in the differences in ammonia volatilization losses from the urea fertilizers applied to Maahas clay in an IRRI greenhouse, 1978.

Table 23. The effect of depth of placement of 56 kg N/ha as urea in mudballs or briquets on the grain yield of IR36 and IR42 was tested in the 1978 dry season. The advantage of placement at 5-cm or deeper is marked.

Treatment	Grain yield[a] (t/ha)				Treatment means
	IR36		IR42		
	Briquet	Mudball	Briquet	Mudball	
No nitrogen	2.7 d	3.0 c	3.4 d	3.1 c	3.0 d
Best split[b]	4.2 c	3.7 b	4.4 c	4.[illegible] b	4.2 c
5 cm deep	4.4 bc	4.9 a	5.2 b	5.4 a	4.9 b
10 cm deep	5.0 a	5.0 a	5.7 ab	5.4 a	5.3 a
15 cm deep	4.5 abc	5.2 a	5.7 ab	5.6 a	5.2 ab
20 cm deep	4.8 ab	4.7 a	5.8 a	5.8 a	5.2 ab

[a]In a column, means followed by the same letter are not significantly different at 5% level. [b]2/3 basal incorporated before transplanting plus 1/3 topdressed 5–7 days before panicle initiation.



J. T. Cope, IRRI visiting agronomist from Auburn University, Alabama, USA, watches deep placement of nitrogen fertilizer by machine in IRRI research plots.

Biological nitrogen fixation

Recommendations made during the Nitrogen and Rice Symposium call for priority to research increasing biological fixation of nitrogen through azolla, by blue-green algae, and by heterotrophic organisms in the rice root zone.

Nitrogen balance studies determined amounts of nonsymbiotic nitrogen fixation in flooded rice soils. After four and six continuous crops of rice, we detected nonsymbiotic nitrogen fixation by both photoautotrophic and heterotrophic microorganisms in planted pots, but not in pots with no rice plants. When phosphorus and iron were added in the pots, nonsymbiotic nitrogen fixation by the photoautotrophs almost equaled the nitrogen removed by the rice crop.

We grew rice plants in chambers containing heavy nitrogen (^{15}N) gas, and found that nonsymbiotic nitrogen fixation is associated with the rice root and the outer parts of the stem and that there is a transfer of a portion of fixed nitrogen to the growing rice plant.

More than 10 clones of *Azolla pinnata, A. filiculoides,* and *A. mexicana* were added to the IRRI azolla collection. In azolla field plots started in 1976 we grew 22 crops of *A. pinnata* for 335 days and produced 465 kg N/ha. In 1977 azolla nitrogen production was 330 kg/ha in 220 days from 14 crops.

In trials of fertilizer rates for azolla, an application of superphosphate at 15 kg P_2O_5/ha (3 kg every 2 days) gave the same yield as superphosphate at 30 kg P_2O_5/ha applied as basal dressing. That

IRRI soil microbiologist I. Watanabe (left) and International Network on Fertilizer Efficiency in Rice (INFER) trainees check azolla multiplication in IRRI plots. Azolla pinnata *plots produced an equivalent of more than 450 kg nitrogen/ha in 335 days.*

means it is possible to reduce the phosphate dose on azolla culture by split application. Phosphorus applied to azolla is later available to the rice plant.

Recommendations for research

Nitrogen and its essentiality to the rice crop were discussed by an international body of nearly 100 scientists during the 1978 symposium on nitrogen and rice at IRRI. A task force of the world's key rice scientists summarized recommendations for future nitrogen-related research and training. The nitrogen and rice symposium and its 1977 predecessor on soils and rice provide the rice-growing world a sound base for soil and crop management research.

SOIL CHARACTERIZATION

Knowledge of the character of problem rice lands makes it possible to recommend management techniques for higher rice yields. In 1978 we concentrated on characterization of soils on 4 major kinds of problem rice lands in the Philippines.

Saline soils

Philippine coastal saline soils vary widely. We identified four main types of saline soils.

- The first type is wet throughout the year, not excessively saline, and will grow two crops of salt-tolerant rice a year. We have such rices available.
- The second type is flooded with fresh water during the wet season and is saline during the dry season because of intrusion of brackish creek water. It needs flood-tolerant rices in the wet season and short-duration salt-tolerant rices in the dry season. Lines of both types are available.
- The third type is saline in the wet season because of upwelling or seepage of brackish water. Our present salt-tolerant lines do well on this type.
- The fourth type derives its salinity directly from tides, and salt injury of plants can be severe. Our lines will not tolerate this level of salt.

The salinity tolerance of 72 rices in the International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON) was observed in this IRRI field where salinity was maintained at an EC of 8–10 mmho/cm. Rices such as those identified for the first three salinity types listed were tested at 32 saline sites worldwide during 1978.

Peat soils

The Philippines' largest peat soil area (about 10,000 ha) is in Leyte. A Hydric Tropohemist, it is 0.5 to 8 m deep and is fed by surface runoff from surrounding hills. Where the land has been cleared and drained, the soil has subsided more than 2 m in some places, groundwater has been lowered to 20–60 cm below the surface, and the upper 15 cm compacted. Rice is grown as a dryland crop in the drained area and as a wetland crop in the undrained areas. The crop suffers from blast disease and deficiencies of zinc and copper.

Table 24. Draining a peat soil before reflooding and planting increases the concentration of nutrients in the soil solution.

Treatment	Nutrient (ppm)				
	Ammonium nitrogen	Potassium	Phosphorus	Iron	Manganese
Drained and reflooded	57	133	31	2.8	0.0
Not drained	6	12	3.0	7.0	0.0

Although peat soils contain more than 1% nitrogen, rice on undrained peats suffers from nitrogen deficiency. We found that a drained peat soil (and thus aerated) had a marked increase in available nutrients when subsequently flooded (Table 24). Lowering the water table in peat lands shortly before submergence and planting should increase the availability of both native and added nutrients.

Acid sulfate soils

Two types of acid sulfate soils were characterized: a saline Sulfic Tropaquept (pH 3.5–4.0), and a slightly saline Typic Sulfaquent (pH 3.2–4.1). Both will grow rice if kept submerged.

Zinc-deficient soils

Zinc deficiency appears to be the most widespread nutritional disorder of wetland rice in the Philippines. It affects more than 1 million hectare of current and potential rice lands. The soils exhibit a wide range of texture, pH, and organic matter content, and tend to have prolonged waterlogging, high organic matter content, pH higher than 7, a Mg-Ca ratio greater than 1, strong zinc adsorption, and low available zinc.

A combination of the above factors is lethal to the rice plant. In a trial on such a soil (a Hydraquent: pH 8.2; O.M. content, 17.5%; Mg-Ca ratio, 1.5; zinc adsorption capacity, 99%; and available zinc content, 0.04%) in Tiaong, Quezon province, only 2 of 698 varieties survived.

METHODS OF APPLYING ZINC TO RICE. In field experiments at Tiaong, we evaluated the effect of zinc oxide and zinc sulfate applied by different methods and at different rates to transplanted and direct-seeded rice.

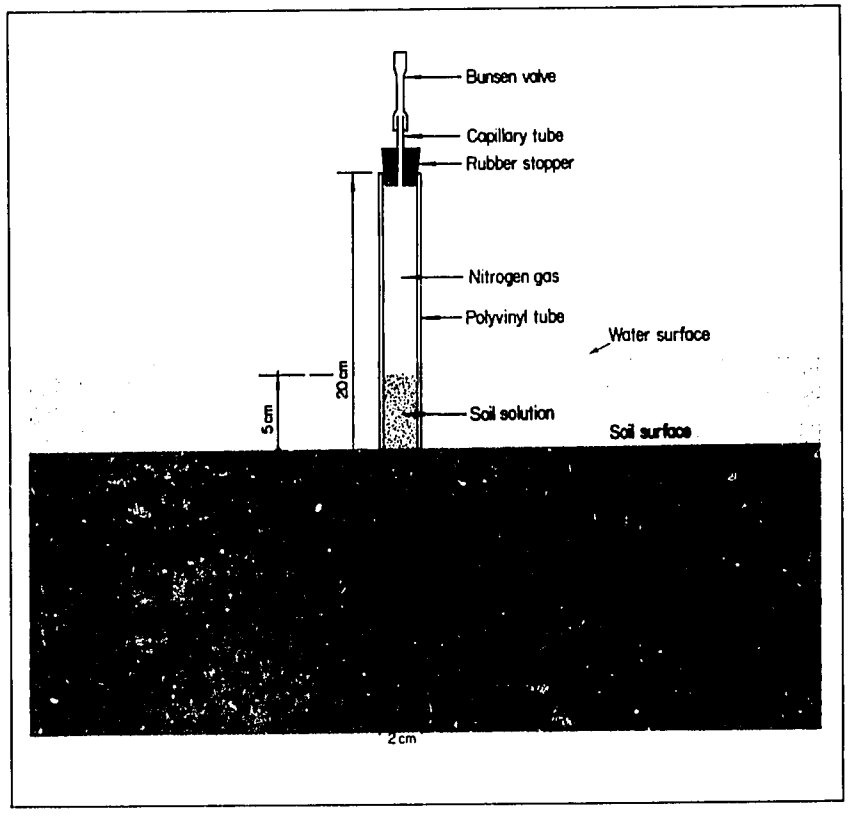
Where we added no zinc the rice plants did not produce grain. Dapog seedlings – seeded on banana leaves, no soil – raised in zinc oxide suspension and regular wetbed seedlings dipped in 2% zinc

oxide solution, or transplanted where 11 kg zinc sulfate/ha was incorporated in the soil, produced more than 3 t/ha. Applying zinc oxide suspension to dapog seedbeds is a satisfactory method of applying zinc. It requires little labor and is preferred by farmers to dipping seedlings after they are pulled from wet seedbeds.

For direct-seeded rice, field application of zinc sulfate (4.5 kg/ha) or coating pregerminated seeds with zinc oxide (1.6 kg Zn/ha) produced more than 3 t/ha.

Monitoring soil salinity

We developed a simple improved way of measuring salt dynamics in saline experimental fields. Low-cost piezometer tubes were made by sealing 1-bar porous cups to narrow polyvinyl tubes (Fig. 29). When the tubes are pushed into the mud the soil solution passes through the porous cup and collects in the tube. Conductivity readings for the solution were similar to the conductivities of saturation extracts of the soils.



29. Porous-cup piezometer for collecting interstitial solutions of flooded soils.

Rice grows under environmental conditions more diverse than those for any other major food crop. Amount of sunlight and wide ranges of temperature affect crop yields. In vast areas the rice plant is subject to drought at the seedling stage and to water as deep as 3 m at the flowering stage.

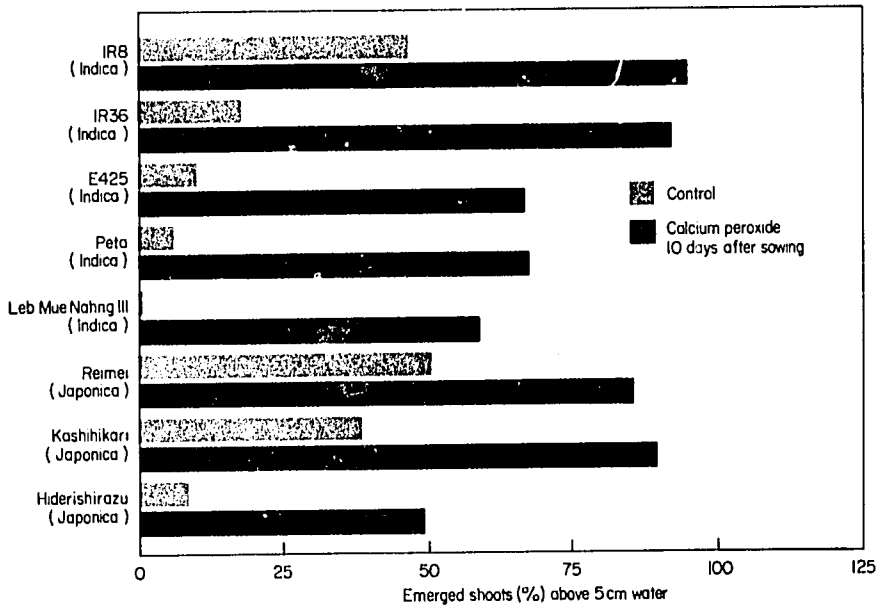
Environment and its influence

Vast areas where rice is grown suffer from water shortage, but many other areas suffer from excessive flooding. Our 1978 research on the environment for the rice crop focused on the physiological mechanism of drought and flood tolerance of rice plants.

Deeper rice root system

Drought tolerance of rice is related mainly to the plant's root system. A deeper root system taps the water in deeper soil layers, and thus helps the plant tolerate longer dry spells. Dryland rice has a deeper root system than wetland rice, and also develops a deeper root system in the dry season than in the wet.

During a drought we traced the course of water absorption from different soil layers by a dryland variety. The roots absorbed water almost exclusively from the upper soil layers during the early stage of drought and then gradually, water from the lower layers. The roots of dryland varieties went to the 80-cm depth. In contrast, a wetland variety sent no roots into soil layers below 50 cm.

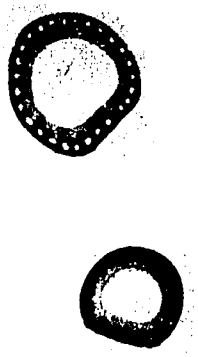


30. The effect of seed treatment with calcium peroxide shows in seedling emergence of 8 rices from floodwater. E425 and Hiderishirazu are dryland varieties, Peta is a traditional wetland rice, and Leb Mue Nahng III is a deepwater rice.

Oxygen requirement

Some rice varieties suffer from oxygen shortage as seedlings in flooded fields. That presents problems for farmers who practice direct seeding in wetland soils.

Figure 30 shows seedling emergence from 5 cm water for different rice varieties, and the effect of calcium peroxide (an oxygen-releasing agent) on emergence ability. Calcium peroxide used to coat seeds releases oxygen slowly, and supplies oxygen to seedlings under water.



These cross sections of rice stems show the difference in development of air spaces when IR36 is grown as a wetland (top) and dryland (bottom) crop. The white areas near the outer edge are air spaces.

Air space in the rice culm

The rice plant is more tolerant of flooding than other cereal crops because it has air spaces in its culm that transport oxygen from the aerial parts to the plant's roots.

Dryland varieties generally have less and smaller air spaces than wetland varieties. Deepwater rices develop relatively larger air spaces. Growing conditions also affect the development of air space. We have found that rice plants grown in a wetland field have more and larger air spaces than the same variety grown as a dryland crop.

In 1976, a sudden wilting of Yushin, a high-yielding variety, was reported in Korea. In studies of the cause of this newly reported physiological disorder, we found it related to size of culm and air spaces. Yushin has comparatively less and smaller-sized air spaces than its sister variety, Tongil.

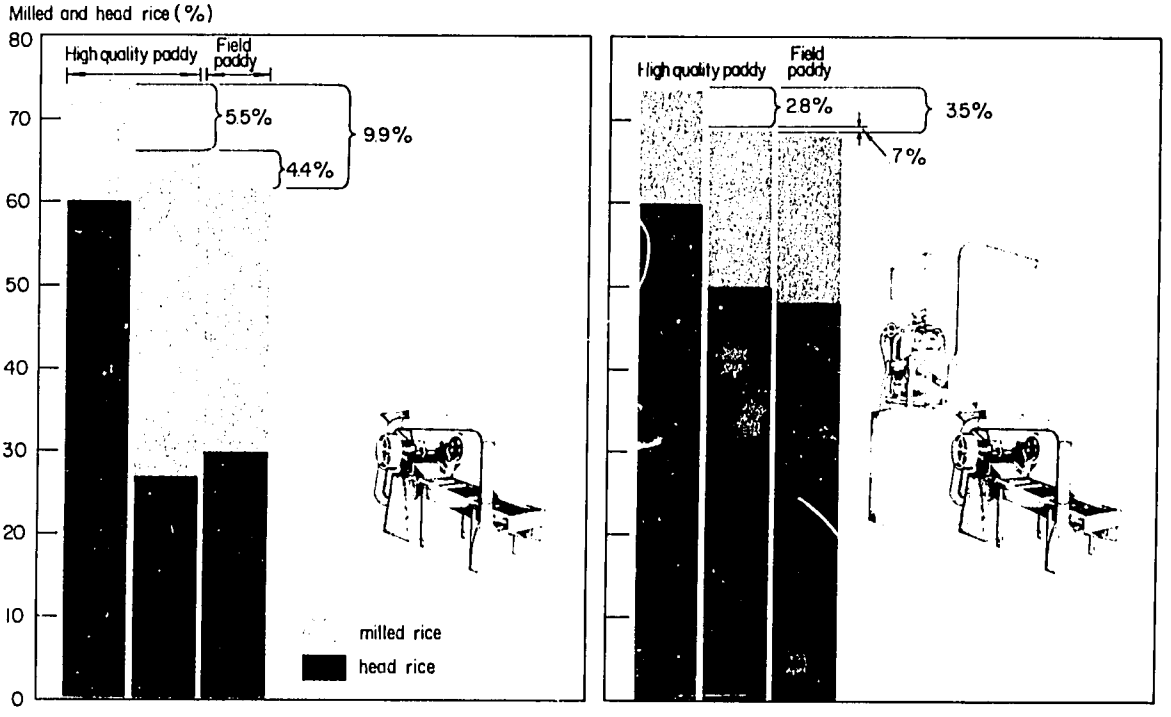
Postproduction technology

Losses of rice in the milling process can run as high as 10% of input. In a field study of village-level milling units two technical constraints that limit output of milled and head rice were highlighted.

First, paddy coming from farmers' fields contained a high percentage of fermented, immature, and cracked kernels and considerable quantities of rocks, straw, and dirt that caused a 4.4% gap between actual and potential yields (Fig. 31).

The second constraint resulted from technical limitations in the machine. When clean, high-quality paddy was processed in the same mill, recovery increased, but a 5.5% gap remained between realized and potential milling recovery.

We found that separating husking and polishing operations by adding a separate dehulling unit and using the steel huller for polishing greatly reduces the gap between potential and actual recovery rates, even for field grade paddy. In addition, the small husking unit did not increase overall power requirements or reduce work space. Our study showed that the husker can be retrofitted to existing mills at relatively low cost. For normal village operation, it can recover initial investment costs in 2 years.



31. Recovery of milled rice from the village system increases when a separate dehulling unit is added to the single-pass steel huller, which is common in villages. Studies in 1978 confirmed that adding the dehuller (right) could give a saving of enough rice to pay off machine costs within 2 years.

Constraints on increased yields

Since 1974 a number of rice scientists – working as teams composed of agronomists, economists, and statisticians – have identified constraints to high rice yields in farmers' fields in six Asian countries. We coordinated the six-country network and an IRRI team did constraints research at four Philippine sites.

Yield gap

The yield gap between what farmers obtained by using their levels of inputs – fertilizers, insecticides, weeding, etc. – and what could be obtained with high levels of those inputs in the same farmers' fields varied by season and by country. Table 25 shows the dry-season gap for 372 trials since 1974. The wet-season gap was generally lower; it ranged from 1.8 t/ha for Laguna, Philippines, to 0.4 t/ha for Yogyakarta, Indonesia, and averaged 0.9 t/ha for 410 sites.

Figure 32 summarizes the economics of the yield gap. The modest gap of the wet season often did not make it economically attractive for farmers to use high rates of fertilizer and insecticides. When they did, their return was low or often negative. In most cases, however, they found reduction of the gap in the dry season profitable.

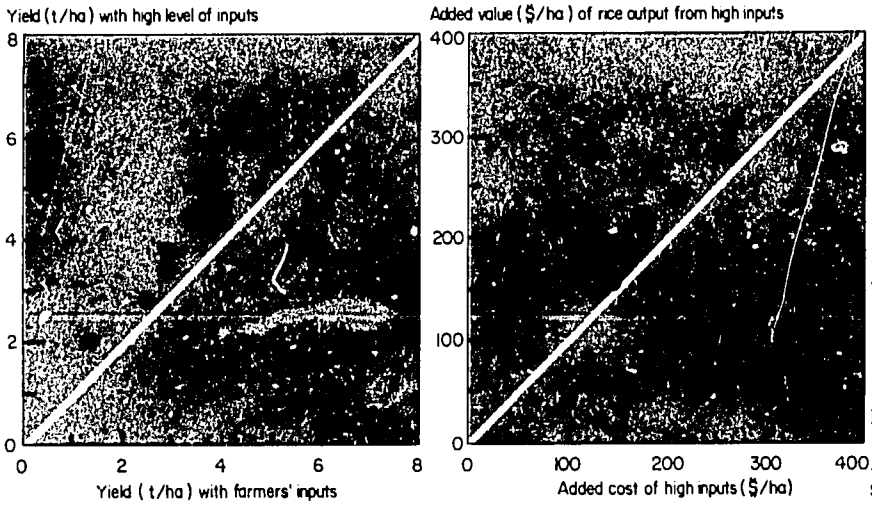
Price incentives

Prices of rough rice and urea fertilizer provide the relative incentive for farmers to use modern rice technology, especially at high levels. The prices varied greatly among countries (Table 26). Table

Table 25. Average dry-season yields and the difference (yield gap) between those at farmers' and at high levels of inputs, 1974–77.

Site	Dry-season trials (no.)				Av yields (t/ha)		
	1975	1976	1977	Total	Farmers'	High	Gap
Dry zone, Sri Lanka		11	20	31	2.5	2.9	0.4
Subang, Indonesia		24	40	64	3.8	4.4	0.6
Taiwan, China		3	34	37	6.6	7.3	0.7
Joydebpur, Bangladesh		6	23	29	3.6	4.6	1.0
Yogyakarta, Indonesia	2	2	35	39	4.8	6.1	1.3
Iloilo, Philippines		2	17	19	3.9	5.3	1.4
Central Plain, Thailand	7	6	26	39	4.2	6.1	1.9
Camarines Sur, Philippines	3	5	20	28	4.0	5.8	1.8
Laguna, Philippines	9	12	19	46[a]	4.5	6.5	2.0
Nueva Ecija, Philippines	3	9	28	40	4.6	6.8	2.2
All	24	80	262	372[a]	4.3	5.6	1.3

[a]Includes 6 trials in 1974.



32. Yield gap and its economics in the wet and the dry season. Each point represents the average result from each of 10 sites in 6 Asian countries, 1974–77. On the left, the yield with high-level inputs (circles) is plotted against the yield with farmers' inputs (line). The vertical distance above the line is the yield gap, which is positive for each site. On the right, the points below the line are sites where farmers' practices were more profitable than those with *high* inputs. A modest wet-season gap shows.

27 shows how much rice is needed to buy a kilogram of urea under five systems of credit. The high effective price of urea in many areas – 2 kg or more – is a strong disincentive to adoption of the modern rice technology.

Production inefficiency as a rice yield constraint

Yield gaps occur because farmers who face the same production function fail to achieve the same level of efficiency. The gap is due to technical inefficiency and to failure to apply inputs at levels that maximize profits (allocati inefficiency). Figure 33 shows a basic model to conceptualize technical and allocative efficiency as a constraint to rice production. With the model, if a farmer used X_1 units of inputs, the total yield gap is $Y\,max\text{-}Y_1'$.

Table 26. Prices and interest rate on credit, distribution of farms by tenure, and share-tenancy conditions prevailing in the areas where constraints studies were conducted, 1977.

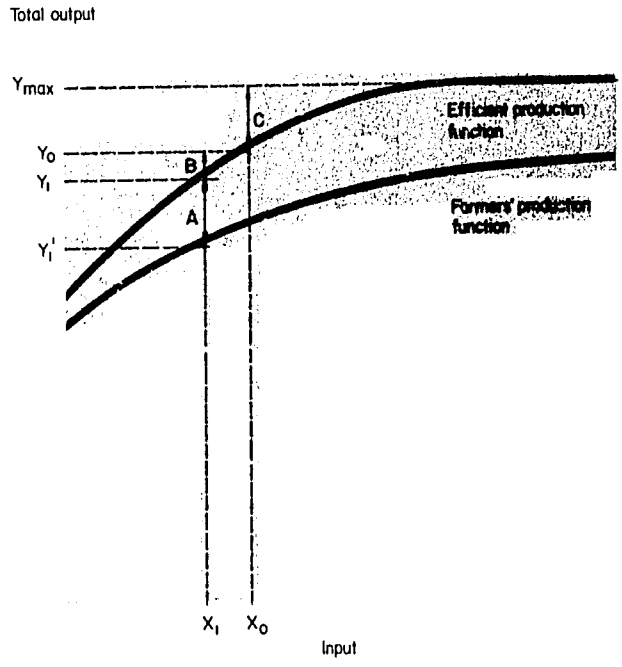
Site	Prices ($/kg)		Prevailing interest rate on loans (%/yr)	
	Paddy	Urea	Private	Institutional[a]
Joydebpur, Bangladesh	0.15	0.11	100	9
Yogkarta, Indonesia	0.15	0.18	n.a.[b]	12
Subang, Indonesia	0.14	0.18	n.a.	12
Dry zone, Sri Lanka	0.19	0.13	n.a.	10
Taiwan	0.32	0.16	13	12
Central Plain, Thailand	0.11	0.16	24	12
Laguna, Philippines	0.14	0.24	50	13
Nueva Ecija, Philippines	0.15	0.24	50	13
Camarines Sur, Philippines	0.14	0.24	50	13

[a]Government credit programs.
[b]Information not available; or credit not generally available from source.

Table 27. Effective real price of urea in kg of rice for farmers at different prevailing institutional arrangements in areas with constraints studies, Asia, 1977.

Site	Kg of rice needed to pay for 1 kg of urea with the stated conditions				
	Owner self-financed	Owner institutional credit	Owner private credit	Share-tenant institutional credit	Share-tenant private credit
Joydebpur, Bangladesh	0.73	0.77	1.09	1.53	2.19
Yogyakarta, Indonesia	1.20	1.27	n.a.[a]	2.54	n.a.
Subang, Indonesia	1.29	1.37	n.a.	2.73	n.a.
Dry zone, Sri Lanka	0.68	0.72	n.a.	0.72	n.a.
Taiwan	0.50	0.53	0.54	n.a.	n.a.
Central Plain, Thailand	1.45	1.54	1.62	2.30	2.43
Laguna, Philippines	1.71	1.82	2.14	1.82	2.14
Nueva Ecija, Philippines	1.60	1.70	2.00	1.70	2.00
Camarines Sur, Philippines	1.71	1.82	2.14	2.43	2.86

Technical inefficiency is the difference between the highest possible yield for a given level of input and the yield attained by the farmer. Allocative inefficiency occurs when the farmer does not use the quantity of fertilizer, or other inputs, that would maximize profits were he technically efficient.



33. Basic model used to measure constraints imposed by technical and allocative inefficiencies. Yield gaps below *Y max* are A (technical inefficiency), B (allocation inefficiency), and C (profit seeking). X_1 represents the level of inputs actually used by a farmer; X_0 represents the level of inputs that would maximize profits for the technically efficient farmer.

Table 28. Estimated yield gap and contribution of profit-seeking behavior, allocative and technical inefficiencies, Nueva Ecija, Philippines, 1974 wet season to 1977 dry season.

Source	Grain yield (t/ha)			Av contribution[c] (t/ha)		
	Farmers' behavior[a]	High input high efficiency[b]	Gap	Profit-seeking behavior	Allocative inefficiency	Technical inefficiency
			Wet season			
Experiments	2.4	3.3	0.9	–	–	–
Function	2.6	3.5	0.9	0.1 (11)	0.1 (11)	0.7 (78)
			Dry season			
Experiments	4.4	6.4	2.0	–	–	–
Function	4.6	6.2	1.6	0.1 (6)	0.5 (31)	1.0 (63)

[a]For the experiments, the farmers' input plots; for the function, farmers' input level with farmers' efficiency. [b]Maximum yield, disregarding input costs, and with researchers' efficiency. [c]Figures in parentheses are percentage contributions.

In Figure 33, gap *A* is caused by technical inefficiency. Gap *B* is due to allocative inefficiency. Gap *C* occurs because a farmer seeks maximum profit rather than maximum yield.

We applied the model to 1974–77 data from Nueva Ecija, Philippines. We found that the contribution of technical inefficiency to the yield gap was major (Table 28).

- In the dry season the farmers were not using enough inputs and those they were using were not resulting in the yields they should have. This reflected in the high percentages of contribution of allocative and technical inefficiency.
- In the wet season the inputs used were about right in relation to the return, but the inputs did not give the payoff they should. Thus the high percentage contribution of technical inefficiency.

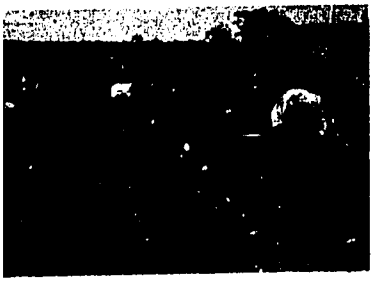
Consequences of new technology

Our study of the consequences of adoption of the new rice technology focuses on the impact – or the potential impact – of the changes at all levels. The changes may be in the efficiency of small farms at the low level, or in government policy on rice pricing at the high level.

Most Philippine barrios have no farms larger than 5 ha. In 1978 we studied a barrio in Laguna province, Philippines. The barrio is unusual because it has 3 large farms, averaging 45 ha each. Two of the large farms had leasehold tenants and 42 small farms were

Table 29. Earnings of factors of production for 2 large and 42 small farms in a barrio in Laguna province, Philippines, during the 1977–78 dry season.

Factor	Earnings (kg/ha)		
	Large farms	Small farms	
	leasehold	Leasehold	Subtenant
Rice yield	4400	4400	4295
Current inputs	600	530	605
Land (paid to landlord)	775	970	735
Land (paid to sublessor)	–	–	1200
Labor	1270	1205	1350
Capital	590	370	425
Operator's surplus	1165	1365	–20



Contract harvesting of rice prevails in Philippine barrios. The workers get a share of the harvest.

operated by leaseholders. Our study compared the two large farms with the 42 small ones.

All 44 farms grew modern varieties and used about the same rates of fertilizer. The large farms used 123 days of labor/ha (98% of it hired), and the small farms used 105 days of labor/ha (65% of it hired). Use of capital was similar for both types of farm. Average yield was 3.8 t/ha for the large farms and 3.7 t/ha for the small.

We distributed total rice production among the factors of production according to the actual or imputed costs of each factor (Table 29). A few of the small farms were subleased by tenants with legal rights to the land to barrio residents who had no land rights. The rate of use of current inputs, such as fertilizer and pesticides, was nearly identical on both types of farms. The earnings of labor and capital were also similar. The land that was subleased received a much higher return than land that was operated under leasehold, but the landowner received about the same rent under all three arrangements. On subleased farms, the sublessor received a high rental. As a result, no operator's surplus remained.

Two forms of harvesting contracts were prevalent in the barrio – *gama* in which both weeding and harvesting activities are carried out by laborers who in turn receive a fractional share of output, and *hunusan* in which laborers do only harvesting and threshing for a share of output. The *hunusan* share varies depending on the arrangement, degree of kinship, and other factors. However, a careful accounting shows very little difference between the actual amount paid and the amount that would have been paid using strictly cash wage rates.

The crop in the foreground was dry seeded by a Filipino farmer who adopted a new two-crop pattern – a dry-seeded crop followed by a transplanted crop – in 1978. Planting of the crop in the field in the background was delayed because the farmer elected to wait for enough rainfall that would allow a transplanted first crop.

Cropping systems

There is solid evidence that Asian rice farmers will rapidly adopt new cropping patterns built around rice. The keys to farmer adoption of such patterns are profitability and simplicity, and therein lies the demand placed on our cropping systems research. We seek farmer-acceptable technology – profitable and simple – that encourages increased cropping intensity by rice farmers.

Our 1978 work indicated continuing progress toward better cropping systems:

- The Asian Cropping Systems Network had 17 sites in full operation with 23 other cropping systems research sites complementing them in network countries. Highly acceptable cropping patterns became obvious through work at our Philippine sites.
- Farmer acceptance of a two-rice crop pattern in Iloilo province, Philippines, was so rapid that a pilot production program we helped initiate late in 1976 required almost no IRRI input in 1978.

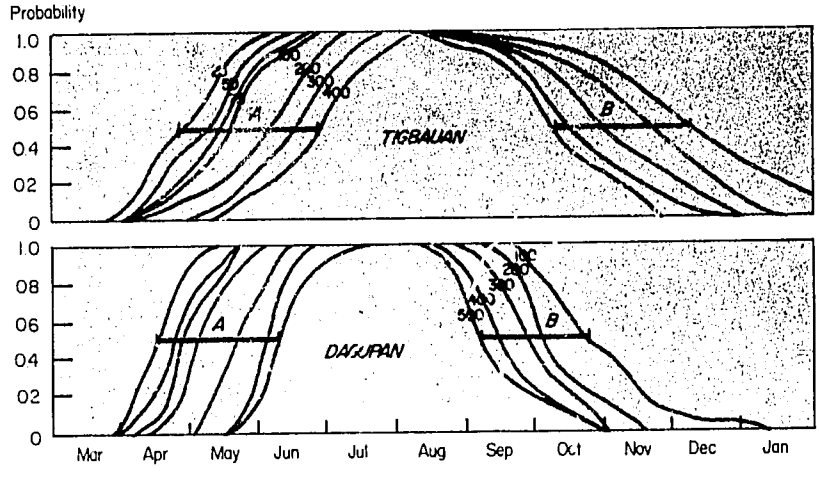
- Research results on use of older seedlings to reduce field time for the rice crop were successfully put into practice in Filipino farmers' fields after a crop-destroying typhoon late in 1978. When they used 35-day-old IR36 seedlings the farmers got a loss recovery harvest 75 days after transplanting.
- The validity of a labor-intensive continuous rice production system was clearly shown. It efficiently used twice as much labor as a 2-crop system, kept land in rice throughout the year, and more than tripled rice production per hectare. Farm family earnings also tripled.

We build cropping systems research around five areas: description of the environment in which the farmer must work, cropping pattern design, cropping pattern testing, component technology, and preproduction testing.

ENVIRONMENTAL DESCRIPTION

Establishing planting dates by rainfall probability

The time when rains start and finish decides when a first rice crop can be established – or if a late-season crop should be planted. To provide farmers an alternative to guessing the start of rain, we evaluated the probability of a site's receiving a certain amount of rain before or after given dates. Rainfall accumulation criteria used for onset were 25, 50, 75, 100, 200, 300, and 400 mm; for termination, 500, 400, 300, 200, and 100 mm. From rainfed records we ranked and plotted the dates when the criteria were satisfied (Fig. 34).



34. Empirical cumulative probabilities for the onset (25–400 mm cumulative rain) and termination (500–100 mm remaining rain) of rains in Iloilo (Tigbauan) and Pangasinan (Dagupan) research sites. The expected onset (at 100 mm) is 13 days earlier in Pangasinan than in Iloilo; termination (100 mm remaining) occurs an average of 25 days earlier in Pangasinan. The Iloilo onset and termination are substantially more variable than those of Pangasinan.

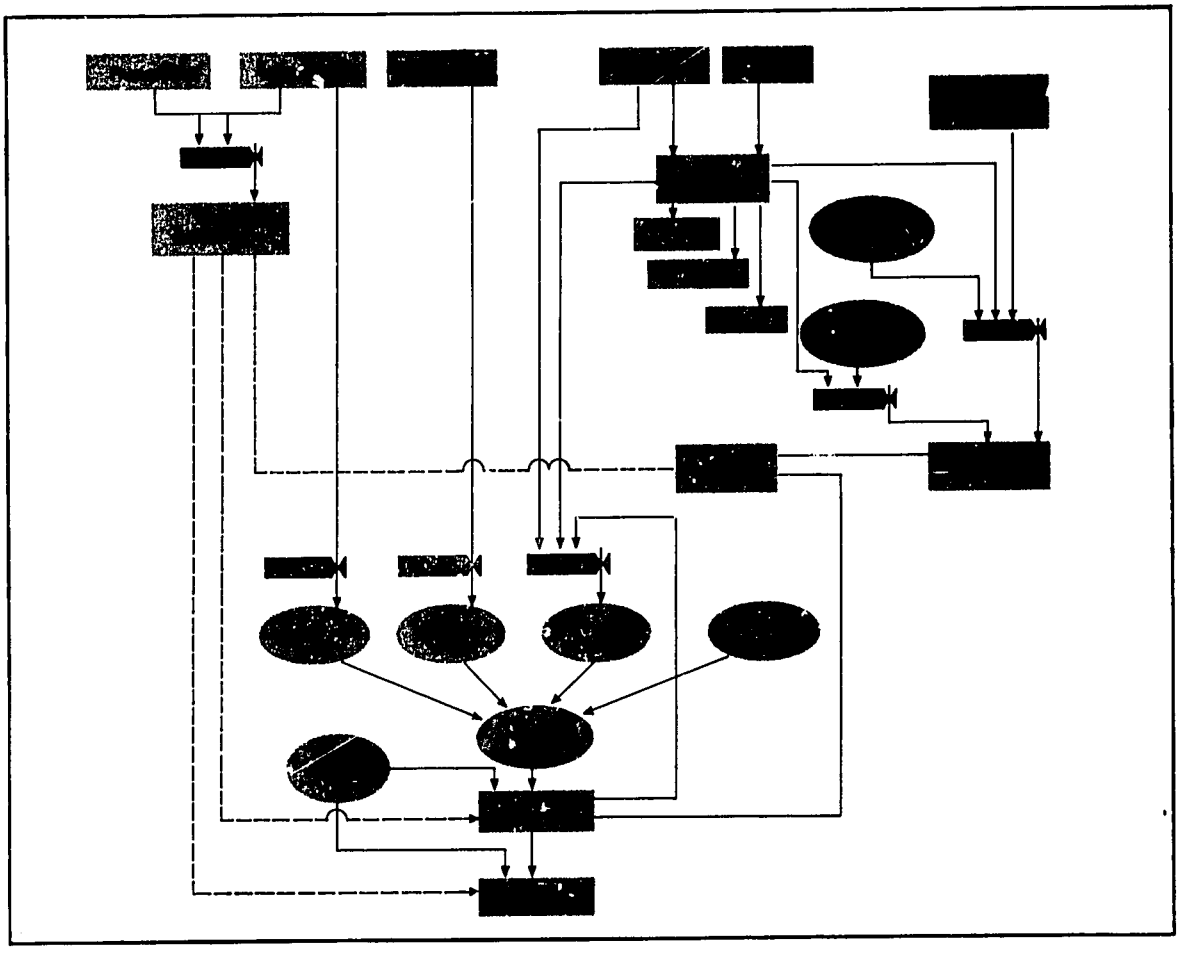
The probability of this Iloilo farmer's getting enough rainfall to allow an early dry-seeded crop is good. In 4 out of 5 years he can plow under the stubble from the dry-seeded crop and transplant before 30 September.

The average range of date of rainfall onset is obtained by observing the distance between the 25 and 400 mm criteria at the 0.5 probability (bar A of Fig. 35). It is about 55 days in Pangasinan and 60 days in Iloilo. Among several Philippine sites tested, this period ranged from 35 to 90 days. A similar analysis of range of termination of the rains from 500 to 100 mm of rain still to be received (bar B) shows that termination is considerably more rapid in Pangasinan than in Iloilo. Among the several sites studied, this period ranged from 37 to 75 days.

The rainfall probability curves were used to set cutoff dates for purposes of crop scheduling. We assumed that an 80-day transplanted rice crop requires about 400 mm of water. Rainfall probabilities show that this requirement can be met 4 out of 5 years by transplanting rice before 30 September in Iloilo and before 30 August in Pangasinan. For double rice cropping the first crop would have to be transplanted before 25 June in Iloilo and before 25 May in Pangasinan, or direct seeded (wet or dry) before the end of May in Iloilo and by 1 May in Pangasinan. That assumes a 15-day turnaround period between crops.

We found that 75 mm of accumulated rain is generally sufficient to obtain emergence and sustain early growth of dry-seeded rice. The chances of satisfying this requirement before the end of May (latest practical date for 2-crop system) in Iloilo are 10 to 1; in Pangasinan the 75 mm rainfall before the 25 May latest date can be expected in 3 out of 5 years.

Wet seeding was not favored. Because land preparation is slow, wet seeding on puddled fields over a wide area requires about 300 mm of accumulated rainfall. That means wet seeding can be



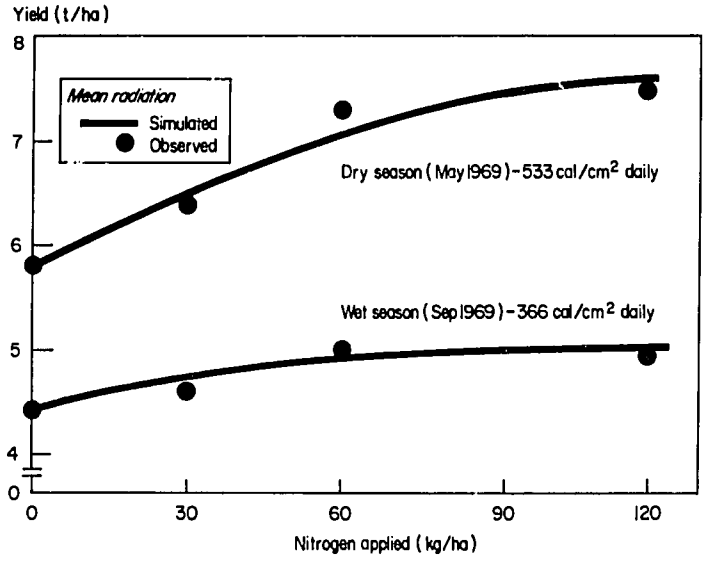
35. Flow chart of a simulation model for a single crop of rice grown in a puddled soil. When the model was tested using 1969 data the simulated yield agreed closely with actual yield (see Fig. 38).

practiced before the end of May in less than 1 out of 2 years in Iloilo. In Pangasinan wet seeding would be possible before 25 May only in 1 out of 9 years.

Crop simulation model

A central need in cropping systems research is to match cropping systems to regional weather patterns and local soil conditions. Techniques of systems analysis can speed that matching.

In 1978 we started development of a simulation model for a rice-based cropping pattern. Its core is the single-crop model shown in Figure 35. The model requires daily inputs of the weather elements shown in the top row of boxes. Soil management characteristics are included as parameters. With actual weather data, the adequacy for growth of each input of temperature, radiation, water, and nitrogen is compared daily with the requirement for unconstrained growth, and actual growth is estimated in relation



36. Yields simulated by the single-crop model (Fig. 37) and actual yields for irrigated rice at IRRI (from 1969 data).

to deficiencies in inputs. Computed indexes are with zero representing no growth and unity representing unconstrained growth. The *growth index* – the product of the indexes – reflects the effects and interactions of the four factors.

We tested the model with yield data of irrigated rice at IRRI and found good agreement for a range of levels of nitrogen nutrition in both the wet and dry season (Fig. 36).

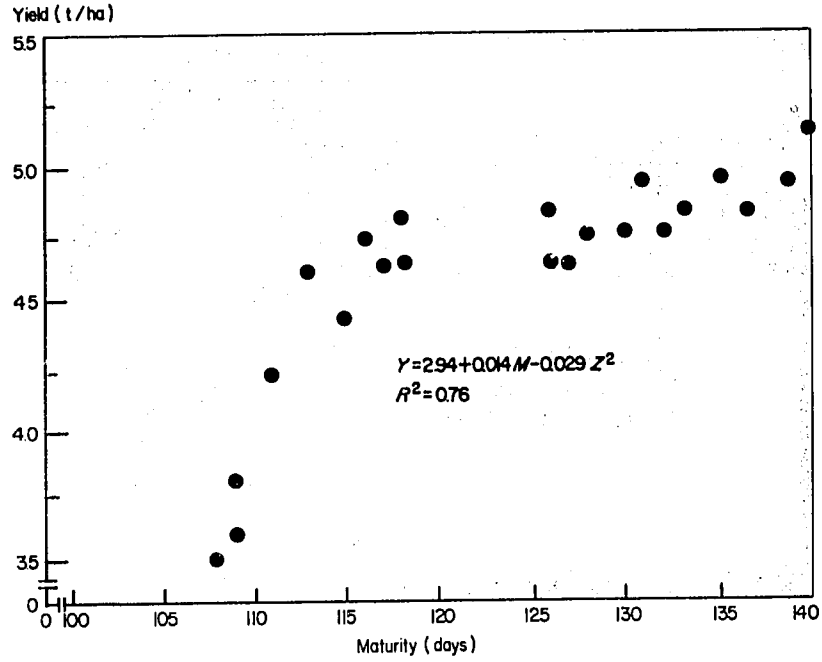
CROPPING PATTERN DESIGN

Influence of crop duration on rice yields

Major considerations in the selection of a rice for double-rice-crop patterns are yield potential and crop duration. To explore the relationship between yield and maturity, we selected 22 cultivars – representing the highest yielding rices for each interval of maturity in the range from 105 to 140 days – from the fifth international yield nurseries (early and medium).

A model $Y = a + bM + cZ^2$ was used to associate maturity with yield, where Y is yield (t/ha), M is maturity (days), and $Z = M\text{-}C$ when M is less than the fixed value C, but zero otherwise.

The model was fitted by incrementing C over a range of maturity values to minimize the residual sum of squares; the value obtained for C was 114 days. The model is graphically presented in Figure



37. Mean grain yield and maturity of 22 selected entries from the fifth international yield nurseries. As a reference point, IR36, which is used extensively in cropping systems studies at IRRI, had a mean maturity of 118 days and yield of 4.8 t/ha in the yield nursery.

37. The model suggests that in the near future, rice with maturities of 112 to 118 days are likely to best fit the many environmental situations for which rice-based patterns are being designed. Earlier maturing varieties have lower yield potential but require about the same production costs; later varieties add only 14 kg grain/ha for each day beyond 114.

Tillage for transplanted and wet-seeded rice

For rainfed rice, a time lapse between harvest of the first crop and planting of the second can adversely affect the second-crop yield because the delay increases the risk of drought. Intensive tillage may be unnecessary for the second crop if the soil was puddled for the first crop.

To determine yield effects from reduced tillage intensity and shortened intervals between crops, we compared five land preparation methods and two planting techniques. Mean yields were not significantly affected by either land preparation or planting treatments (Table 30).

Labor required for the full conventional preparation method was much greater than that required for the other methods. We found that reducing the intensity of land preparation can shorten the

Table 30. The effect of land preparation techniques and planting methods on grain yields and tillage labor inputs. The data are based on 4 replications of 100-m^2 plots at IRRI in the 1978 dry season.

Land preparation technique	Grain yield (t/ha)		Tillage labor[a] (h/ha)
	Transplanted	Wet-seeded	
Conventional, 1 plowing and 2 harrowings over 11 days	5.0	3.8	146 a
Vaned roller, 2 passes over 3 days	5.5	3.7	86 b
Vaned roller, 3 passes over 5 days	4.3	4.1	105 b
Rotovations, 2 passes in 3 days	5.3	4.7	89 b
Stubble cutting and paraquat application, in 1 day	3.8	4.6	56 c

[a]Values followed by a common letter are not significantly different.

time interval between successive rice crops without greatly affecting rice yield.

Old seedlings to shorten rice patterns

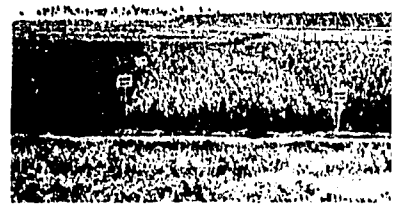
Farmers who grow rainfed or partially irrigated rice often delay transplanting because of lack of water. In such a case the use of 40-day-old seedlings can shorten the growth duration in the field. Even though yields may be reduced, the risk of drought damage is reduced, particularly for a second crop of rainfed rice.

Two IRRI trials in 1978 evaluated the reduction in yield and growth duration with old seedlings. We also checked the extent to which an increased number of seedlings per hill compensated for the yield loss.

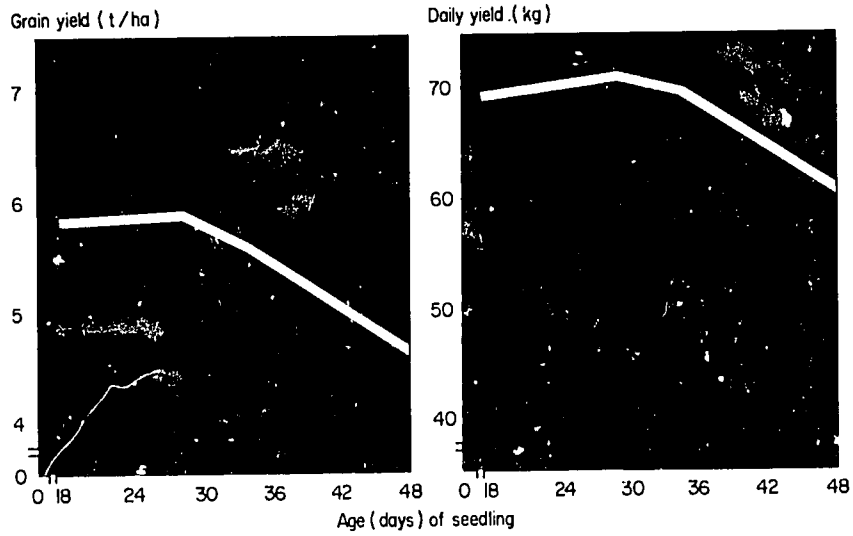
In the first trial, yields and days from transplanting to harvest were affected by seedling age, but not by the number of seedlings per hill. The average grain yield was significantly reduced when 48-day-old seedlings were used – 21% less than that from 18-day-old seedlings (Fig. 38). Reduction in field duration was significant at all seedling ages beyond 18 days but the difference between the oldest and youngest seedlings used was only 9 days. Only the 48-day-old seedlings gave a significantly lower yield per day than the 18-day seedlings.

In the second trial, increasing the number of seedlings from 3 to 9 per hill had no significant effect on grain yields of the 18-day-old seedlings, regardless of the variety (Table 31). The early-maturing IR36 appeared to be more sensitive than IR38 and IR32 to the use of old seedlings with only 3 seedlings to a hill.

The varieties differed slightly in their relative time gain from transplanting to maturity. The time gain from the use of older



Early in 1978 trials on the effect of use of older seedlings on growth duration and yield of rice were started. Shown are plots of IR36 with 18-day-old seedlings (left) and 48-day-old seedlings (right). The reduction in field duration by use of older seedlings is obvious. Yields are given in Figure 38.



38. Effect of seedling age on the yields of IR36. IRRI, March–June 1978.

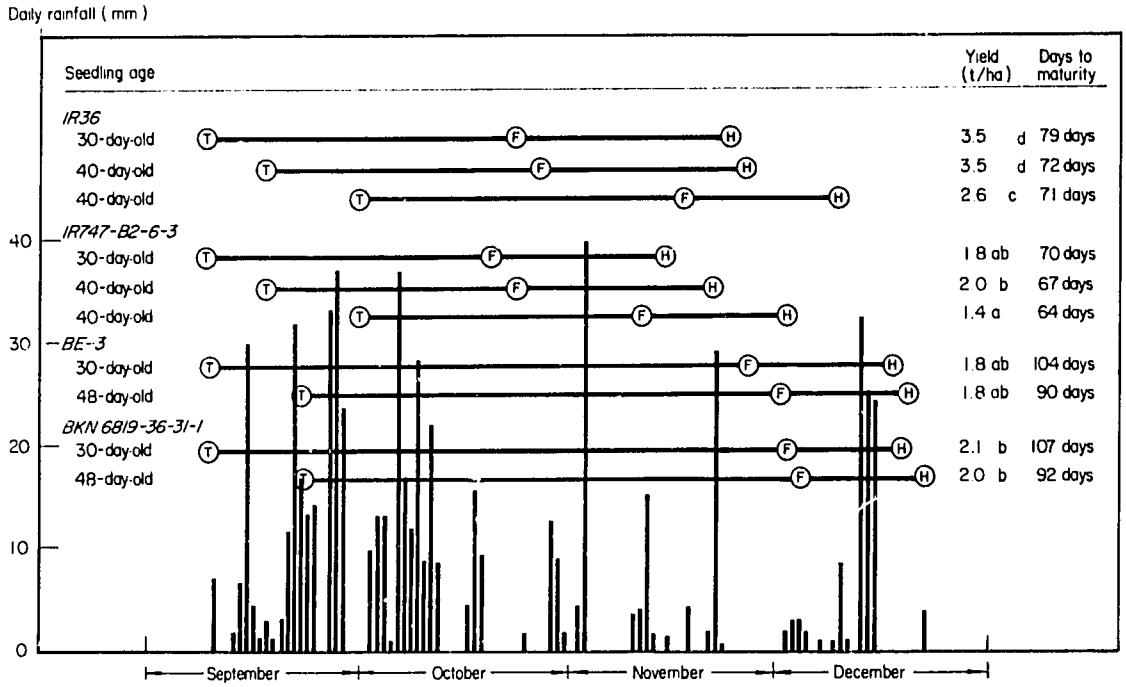
seedlings appeared to be limited by the slow (about 2 weeks) seedling recovery after transplanting, particularly in IR38. Increasing the number of seedlings per hill did not substantially reduce field duration. The use of 40-day-old seedlings did not significantly reduce yield per day for any of the varieties studied.

We tested the effect of seedling age and planting date with IR36 and three other cultivars on a rainfed field in Iloilo, where the

Table 31. Effects of age and number of seedlings per hill on the grain yields of three rice varieties (maturity period in parenthesis) at IRRI, March–June 1978.

Age (days) of seedlings	Grain yield[a] (t/ha)		
	3 seedlings/ hill	9 seedlings/ hill	Difference
	IR36 (110 days)		
18	5.92a	5.87a	0.05
40	4.87 b	5.31abc	–0.44
	IR38 (125 days)		
18	6.00a	6.04a	0.04
40	5.93a	5.48ab	0.45
	IR32 (140 days)		
18	5.24ab	4.83 bc	0.41
40	5.45 ab	4.52 c	0.93**

[a]In a column, means with similar letters are not significantly different at the 5% level. **Significant difference at the 1% level.



39. In a trial with seedlings of different ages in a rainfed field, Iloilo, each hill had 3 or 4 30-day-old seedlings, or 7 or 8 40- or 48-day-old seedlings. Dates of transplanting (T), flowering (F), and harvesting (H) are indicated. All varieties received 75 kg of nitrogen/ha split into 3 applications. Note the flexibility of IR36 with regard to seedling age and planting dates.

period for a second rainfed rice crop is relatively short. The cultivar designations, planting date, harvest date, and yield obtained from each treatment are shown in Figure 39. The three IR36 treatments had highest yields. The last transplantings of IR36 and IR747-B2-6-3 experienced drought during the late grain-filling period. Both transplantings of BE-3 and BKN6819-36-31 experienced drought at flowering and during early grain filling.

The experiment demonstrated that older seedlings of IR36 will give an 80-day second crop with yields 60–70% of the first crop's.

Yield loss to insects in dry-seeded rice

Where rainfed rice is direct seeded we see few insect pest problems because the crop is planted immediately after a 2–6 month rice-free dry season and insect numbers are low. In 3 years of tests in Batangas province we detected no yield differences between insecticide-treated and untreated plots with a relatively low-yielding local variety. But, with the introduction in 1978 of a new high-yielding variety, we saw a significant yield increase for the first time (Table 32).

Similar trials in Iloilo and Pangasinan provinces resulted in large yield differences due to insecticide in three out of four trials with

Table 32. Yield response increased for a modern variety (IR36) after insecticide was used on direct-seeded rice in the Philippines in dryland (Batangas province) and wetland (Iloilo and Pangasinan provinces) rainfed environments.

Year	Variety	Yield (t/ha)[a]		
		Insecticide	Untreated	Difference
		Dryland environment		
1976	Dagge	3.1	3.0	0.1
1977	Dagge	2.8	2.6	0.2
1978	Dagge	2.7	2.9	0.2
	C171-136	3.7	3.3*	0.4*
		Wetland environment		
1977	IR36 (Iloilo)	5.5	3.9*	1.6*
	IR36 (Pangasinan)	6.3	5.5*	0.8*
1978	IR36 (Iloilo)	4.9	4.0*	0.9*
	IR36 (Pangasinan)	3.5	3.6	–

[a]* = significant difference at the 5% level.

IR36. We have noted the following pattern of yield responses to insecticide use on dry-seeded rice:

- the differences cannot be attributed to any known rice pests,
- they occur in both dryland and wetland environments,
- they appear only when the yield potential is high,
- when they occur, they become manifest only with the insecticide carbofuran applied in seed furrows.

A next step is to determine if the often dramatic yield increases are due to insect control of an unknown pest or are a direct growth response to the insecticide.

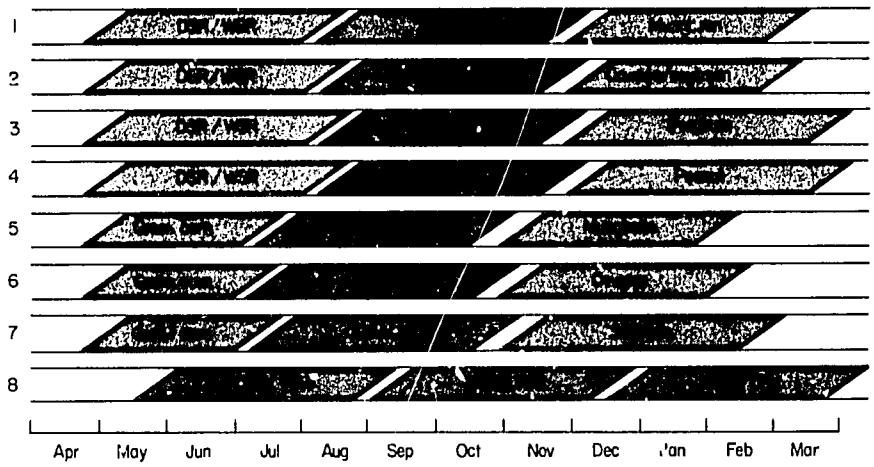
CROPPING PATTERN TESTING

Cropping pattern testing in Iloilo and Pangasinan provinces finished its third year as a cooperative project with the Philippine Bureau of Plant Industry. In 1978 we concentrated on retest of patterns that gave the best results in 1976–77.

Pangasinan cropping patterns

In Pangasinan, we retested the 8 patterns in Figure 40. Deviation in duration of monthly rainfall from the previous year and in the long term rainfall pattern added to the decision-making problems facing Pangasinan farmers.

Fourteen of 17 farmers completed the green corn-rice-upland crop patterns (5 to 7), and 8 of 9 farmers (near free flowing wells) completed the rice-rice-rice pattern (8). Our retests generally indicated that these patterns were adapted to the field conditions in



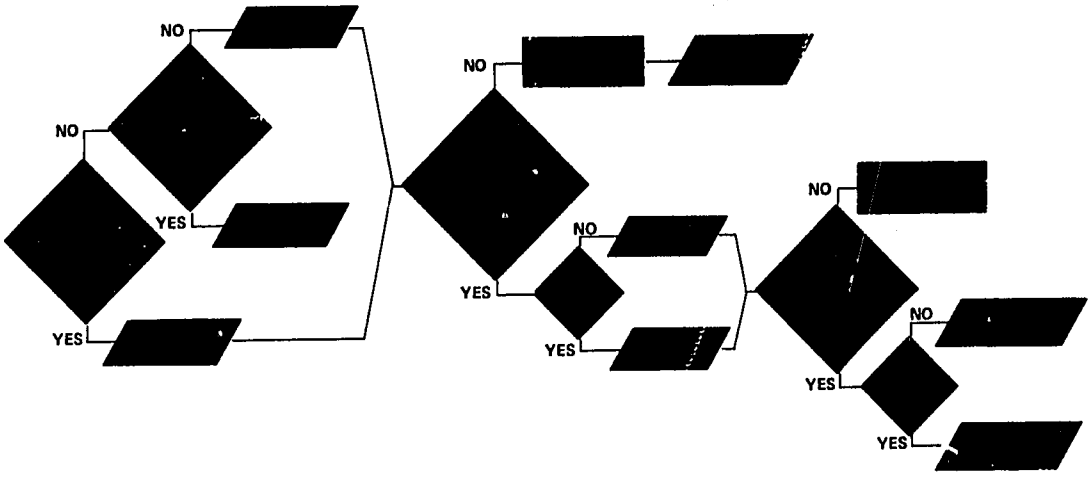
40. Eight 1976–77 cropping patterns were retested in Pangasinan during the 1977–78 crop year. The WSR (wet-seeded rice) in patterns provides farmers a chance to shift seeding systems depending on soil moisture supply.

which they were tested and farmers could meet the cultural requirements of the patterns.

The dry-seeded rice (DSR) – transplanted rice (TPR) – upland crop (UC) patterns (1 to 4) were retested because comparisons of the two crops' water requirements with historic rainfall data indicated that an early planted DSR crop was necessary for successful second rice and dryland crops. IR36, which our previous tests had shown to be well adapted as both DSR and TPR, was used as the first and second rice crop. Of 48 farmers who agreed to test the pattern, all established a first DSR crop and 32 a second TPR crop. Of the 32 only 16 planted a following upland crop. There were several reasons for that:

- the DSR crop was delayed because land preparation could not be started until after the rains began,
- the TPR crop was delayed because of nonviable seeds and nursery replanting.
- other activities competed for labor,
- risk of water shortage for the TPR and upland crops, and
- draft animals had no access to the fields because intervening fields contained rice crops in advanced growth stages.

Considering the reasons given for noncompletion of intended patterns, but assuming availability of viable TPR seeds, a simple decision diagram, which leads to DSR-TPR-UC, DSR-TPR or DSR-UC patterns, was prepared (Fig. 41).



41. This schematic diagram can help determine which pattern a farmer should plant in a rainfed or partially irrigated Pangasinan field. The rice yields shown are means obtained from 1977–78 crop year pattern tests. For upland crops relative yields (RY) are based on our project variety trials.

Iloilo cropping patterns

In Iloilo, three pattern groups were retested. The first group consisted of two rice crops followed by an upland crop. In that pattern, the first crop could be either DSR or wet-seeded rice (WSR) and the second crop could be either WSR or TPR. The second group had a single rice crop (WSR or TPR) followed by an upland crop. In the third group, green corn was the first crop, WSR or TPR was the second, and an upland crop was the third.

The three pattern groups were grown by 88 farmer-cooperators as rainfed crops on four landscape positions: plateaus, plains, side slopes, and bottomlands. The rainfall had a delayed abrupt onset, an extremely high peak, and an early termination – substantial deviations from the preceding year's and the long-term means – and underscored the decision-making problems faced by rainfed farmers. The delayed, abrupt start of the monsoon prompted farmers to shift from green corn to rice because of ponding of the water in paddies, or because a corn crop would delay the planting of a following rice crop and make it vulnerable to drought.

Over all landscape positions, 70% of the first crop was established as WSR, although the proportion of TPR was greater within the side slope position. Differences in first rice crop yields were in accord with differences in water regimes among the landscape positions, as shown by the number of flooded days during the time the crop was in the field (Table 33). First crop yield averages were 6.1 t/ha for bottomlands, 5.1 t/ha for plains, 4.9 t/ha for plateaus, and 4.6 t/ha for side slopes.

Because of low October rainfall, 42% of the second rice crops

Table 33. The landscape positions of rainfed rices govern the water regimes. The effect is seen in the breakdown of proposed, unplanted, and actual crop component patterns during the second crop at Iloilo, 1977–78 crop year.

Landscape position	Average week		Number of fields					Average yield first crop (t/ha)
	First crop establishment	Field last held standing water	Proposed		Actual			
			Rice	Upland	Rice	Upland	Unplanted	
Bottomland	25	46	8	–	8	–	–	6.1
Plain	27	45	16	9	16	5	4	5.1
Plateau	27	41	15	14	4	20	5	4.9
Side slope	28	41	9	17	1	21	4	4.6

proposed for plain, plateau and side slope positions were shifted to upland crops. But a few rice fields in those positions, which were harvested early, were shifted from upland crops to rice. Most of the upland crops were concentrated on the side slopes and plateaus. Because of the unusually dry weather, no dryland crops were attempted after two rice crops.

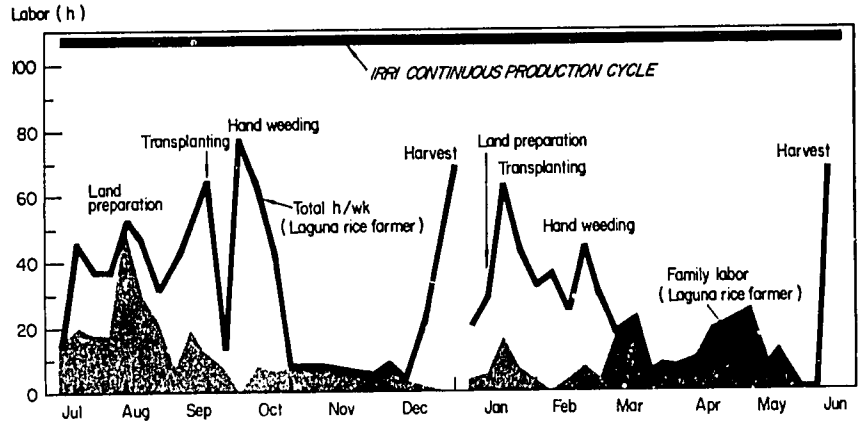
A schematic diagram similar to Figure 42 was made for Iloilo farmers. The schematics for Iloilo and Pangasinan showed the decision-making processes farmers follow. The diagrams also suggest component technology research that is needed to improve pattern adaptation. For rice-rice-upland crops patterns a critical point is the planting date of the first crop. Practicable tillage techniques and planting methods are obviously essential to the success of the second and third crops.

Labor-intensive continuous rice production system

The continuous rice production model we have tested since 1976 shows a remarkable ability to use labor and land to the fullest. With small plots (100 to 750 m^2) planted and harvested daily, three times a week, or weekly, the continuous system productively uses twice as much labor as conventional double-cropped rice and generates enough income to pay that labor a market wage.

Table 34. Land and labor use and rice production by the IRRI continuous rice production system and by seven Laguna province rice farmers, 1976–77.

	Continuous rice production system	Two-crop rice farmers
Land area	1 ha	1 ha
Time land is used	12 mo	7 mo
Family labor used	4898 h/yr	1360 h/yr
Hired labor used	0	1207 h/yr
Total labor used	4898 h/yr	2567 h/yr
Rough rice production	23.6 t/yr	6.5 t/yr



42. Weekly family labor and total labor per hectare for the two-crop Laguna province rice farmers show a series of peaks during the year. The IRRI continuous rice production model maintains a steady demand.

Table 34 compares the land and labor use intensity in the continuous rice system with that on conventional two-crop farms. The continuous system permits a family of three fulltime workers to accomplish all the necessary activities without hiring labor (Fig. 42).

The capital requirements for a continuous system are somewhat higher than those for conventional systems because of the need for farmer-controlled irrigation, a tiller for land preparation, and a crop dryer. Thus, the earnings of capital are substantially higher than in conventional systems (Table 35). Despite this, the earnings for a farm family that adopts the system on rented land could be more than twice as high as family earnings from a conventional two-crop system.

In 1978 studies we found the continuous rice production system gave stable yields whether or not insecticide is used. This alleviated earlier fears that the presence of rice in all stages of production might intensify insect pest problems.

Table 35. Value of output, factor earnings, and farm family earnings of the IRRI continuous rice production system and of seven Laguna province rice farmers, 1976–77.

	Continuous rice production system (US$/ha per yr)	Two-crop rice farmers[a] (US$/ha per yr)
Value of output	3,217	875
Cost of purchased inputs	1,096	142
Gross margin	2,121	733
Earnings of land[a]	323	226
Earnings of capital[a]	871	30
Return to farm family labor	927	477
Earnings of labor[a]	737	274
Farm profit	190	203

[a]Imputed using market rates of return.

Whole-farm test of pattern productivity

To test the acceptability of new cropping patterns we compare their profitability with that of farmers' patterns. If a new pattern consistently – for 3 years – shows at least 30% higher net return than the farmers' pattern, we consider it likely to be accepted by farmers.

Thirty percent is a *rule of thumb* that gives us sufficient margin of safety in case a pattern's productivity is less under farmers' management than in trials. To compute profitability, market prices are used to value labor, power, fertilizer (only variable costs are considered), and various crop products. We apply the market prices to the average levels of inputs and products across replicates of the experimental patterns, or across observations of each cropping pattern commonly grown by farmers.

Our method is reliable where farmers can easily buy and sell resources such as land, labor, and power. But in cases where resources are not freely exchanged, it is useful to find what combinations of cropping patterns can maximize farmers' income, given their particular fixed resources. This involves whole-farm analysis.

We used a linear programming (LP) method of whole-farm analysis to identify promising types of multiple cropping techniques for certain farms in Pangasinan and Iloilo.

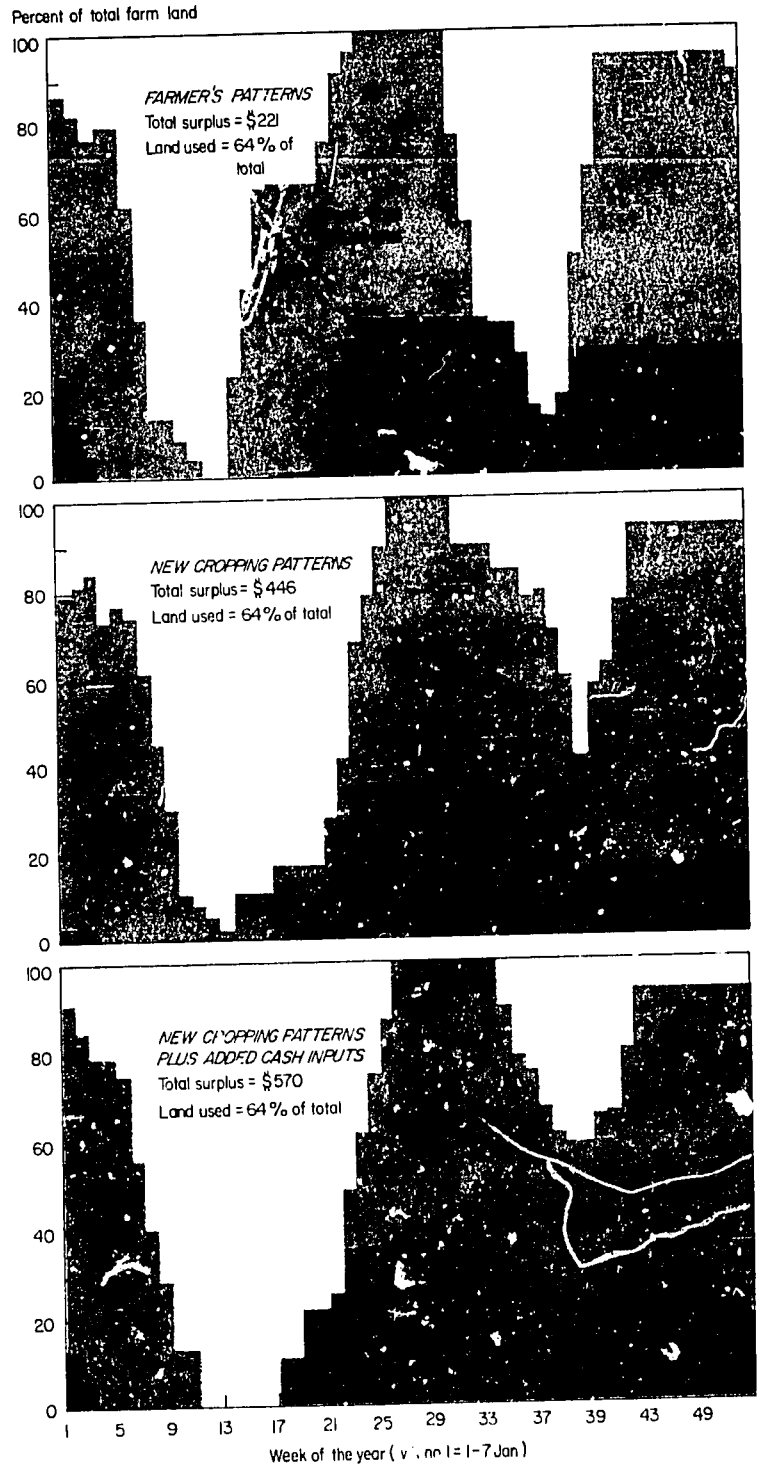
Mamerto Bañares (a pseudonym) is a relatively poor farmer in Iloilo who operates 1.0 ha of dryland and 0.6 ha of wetland, 0.2 ha of which he owns. Our LP model of his farm is shown in Figure 43.

We concluded that it is relatively more profitable for a poor Iloilo farmer to allocate limited cash reserves to our new upland crop patterns than to the wetland rice patterns. The new multiple rice cropping patterns are more suited to a wealthier farmer with his larger cash reserves. Nevertheless, even on the poor farm, the new technology for multiple rice cropping contributes directly to higher income. Through less labor-intensive direct seeding, it allows simultaneous expanded production of upland crops.

Our LP model can be used to analyze different farm resource situations and aid us in testing or redesigning new cropping patterns.

Three-year comparison of farmers' and experimental cropping patterns

Multiple cropping suggests complementarities in fertilizer use, tillage, weeding, and insect control and more efficient use of a farmer's current resources. But wetland rice-based multiple cropping, as



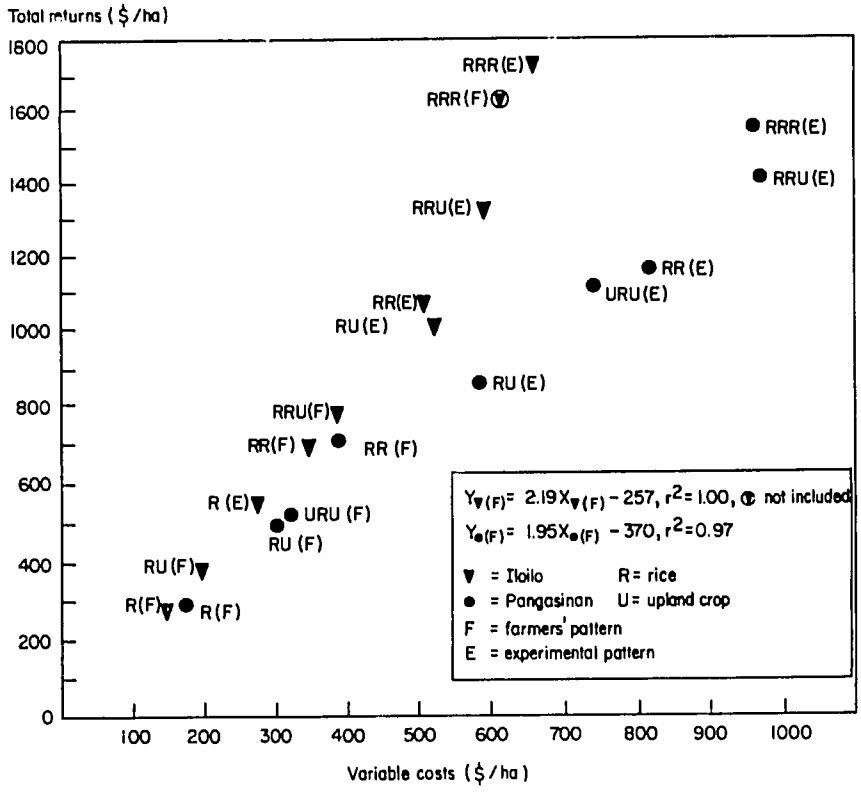
43. A linear programming model was used to compare a poor Iloilo province farmer's use of old and new cropping patterns. The top model shows optimal land use without new cropping patterns, the middle model shows optimal land use with the new cropping patterns, and the bottom model shows optimal land use when some extra cash reserves support use of the new patterns. Note that the profit (total surplus) is more than doubled by using the new patterns.

developed at IRRI and adopted by farmers, is also a way of using added resources equally efficiently.

A three-year test of wetland rice-based cropping patterns in rainfed and partially irrigated areas of Iloilo and Pangasinan provinces is represented in Figure 44. Farmers quickly adopted some of the experimental techniques while still being tested. Hence rice-rice-upland crop and rice-rice appear as farmers' patterns along with single crop rice and rice-upland crop, although only the latter two were practiced before our tests began.

The Pangasinan and Iloilo farmers received about $2 return for every $1 invested in variable inputs. With relatively high levels of management, experimental cropping patterns in Pangasinan can increase farmers' income, but do not offer as high a rate of return as less intensive technology. When adopting more intensive patterns such as rice-rice, farmers in Pangasinan reduce input levels, but improve their rates of return on current inputs. In Iloilo, farmers also reduce input levels, but with high management their returns are as good as or better than those with low management.

The more favorable rate of returns on current inputs achievable



44. Cost and returns of farmers' and experimental cropping patterns in Pangasinan and Iloilo during 1975–78. Each point is a simple mean of the average performances of patterns in each crop year. Farmers managed the experimental trials in their fields, with researcher supervision. Information on farmers' patterns was taken from daily records kept by 95 farmers in Iloilo and Pangasinan.

in Iloilo has been a strong inducement to adopt intensive cropping. The divergence in resource productivities between Iloilo and Pangasinan is greater at high than at low levels of cropping intensity. For example, the rice-rice-upland crop pattern produces a return of about $1,360 at $272 less cost in Iloilo.

COMPONENT TECHNOLOGY

The effect of crop rotation on weed growth

The effect of weed control practices for a dry-seeded rice crop on the weeds growing in a subsequent transplanted rice crop was studied. Significantly higher grain yields from dry-seeded rice were obtained from all the weeded plots (Table 36). No weeding was done in the transplanted rice crop, and previous weeding treatment did not affect yields.

Seventeen different weed species grew in association with the dry-seeded rice crop; only five occurred in the transplanted crop. In the dry-seeded rice crop the dominant weed species was *Echinochloa colona;* its weight was 38.7% of that of the weed flora. In transplanted rice, *Monochoria vaginalis* was by far the most important weed – 83.6% of the weight of the weed flora.

We also studied weeds in a rotation of upland crops. In the unweeded plots in the first crop, the major weed species were *Amaranthus spinosus, Eleusine indica,* and *Cyperus rotundus.* Minor weed species were *Digitaria* sp., *E. colona, Trianthema portulacastrum,* and *Phyllanthus niruri. A. spinosus* dominated the weed flora in all plots.

In the second crop, the weed flora changed dramatically. Where rice had previously been grown *Ipomea triloba* became the dominant weed species and *A. spinosus* became unimportant. In the other cropping sequences, *A. spinosus* still dominated and *I. triloba* and the other weeds comprised a relatively small proportion of the weed flora. *E. colona* was much more important in the corn-corn rotation than in the other rotations. *C. rotundus* tended to build up in the corn-corn and mung bean-mung bean rotations. *Digitaria* species were more important in the corn-corn rotation than in the rotations with rice as a first crop and in the mung bean-rice rotation.

In another dryland crop rotation the number of weed species growing in association with the different upland crops decreased gradually as the length of cropping increased. In the first crop, 21 different weed species were observed. By the fourth crop, the

Table 36. A 1978 trial at IRRI showed the effect of method of seeding and weed control on weed weight and yield of dry-seeded rice and a following transplanted rice crop. The transplanted rice was not weeded.

Method of seeding and weed control for dry-seeded rice[a]	Weed wt[b] (g/0.25 m^2)		Yield[b] (t/ha)	
	Dry-seeded rice	Transplanted rice	Dry-seeded rice	Transplanted rice
Dibbled – no weeding	149.7 b	7.4 a	0.2 c	4.0 a
Dibbled – weeded 14 and 35 DE	6.4 a	8.4 a	4.6 a	4.3 a
Dibbled – weeded 14, 35, and 56 DE	6.4 a	5.8 a	4.4 ab	3.7 a
Dibbled – weed free	–	5.1 a	4.8 a	3.8 a
Row seeded – no weeding	158.6 b	8.4 a	0.3 c	4.4 a
Row seeded – weeded 14 and 35 DE	23.2 a	11.1 a	3.5 b	3.8 a
Row seeded – weeded 14, 35, and 56 DE	1.9 a	7.7 a	4.3 ab	3.9 a
Row seeded – weed free	–	6.5 a	4.9 a	4.1 a

[a]DE = days after rice emergence. [b]In a column, means followed by the same letter are not significantly different at the 5% level.

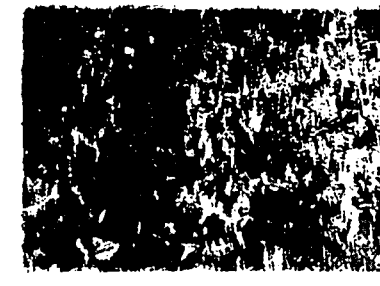
number had decreased to 13. The number of sedge species remained unchanged (Table 37).

Paspalum dilatatum was the dominant weed species in the first dry-seeded rice crop; in the second dry-seeded rice crop grown 1 year later, the dominant species was *Digitaria ciliaris*. In terms of number of weeds/m^2 *C. rotundus* was the dominant weed species in green corn and mung bean; in terms of weight, the dominant species were *D. ciliaris* and *E. indica*.

The unweeded plots gave no yield for dry-seeded rice in both years. Differences between the weeding treatments were not significant. For corn and mung bean, weeding gave no significant yield increase.

Weeds in upland crops planted after rice

In several trials in Pangasinan province, upland crops planted after rice did not respond to weeding. In a trial where different degrees of land preparation were used, no yield increase in mung bean was obtained from hand weeding or paraquat (2 kg a.i./ha) 14 days after rice emergence or from butachlor (2.0 kg a.i./ha) applied at preemergence. The initial land preparation activity was either one plowing plus one harrowing or paraquat applied to the rice stubble (0.75 kg a.i./ha) and a furrow opened for planting. In another trial with mung bean, cowpea, and soybean the only land preparation was the opening of a furrow for seed placement. There was no significant yield increase in plots that were weeded once, weeded twice, or had paraquat applied as a postemergence application.



In 1978 trials, upland crops such as mung bean following a rice crop did not show significant yield increase from weeding or herbicide use.

In a third trial paraquat was applied to one-half the plot before

Table 37. The effect of crop and season on change in the number of weed species, their total number, and weight per m^2 at maximum flowering in the unweeded plots in a well-drained upland soil.

Crop and seasons	No. of species				No./m^2	Wt (g/m^2)
	Grasses	Sedges	Broad-leaf weeds	Total		
1st: dry-seeded rice, 1977 wet season	8	1	12	21	399	373
2nd: green corn, 1977 wet season	5	1	12	18	191	173
3rd: mung bean 1978 dry season	4	1	9	14	194	69
4th: dry-seeded rice, 1978 wet season	5	1	7	13	202	408

planting and no herbicide was applied to the other half. A furrow was opened for planting. No yield increase in sorghum, soybean, asparagus bean, cowpea, and mung bean resulted from the preplant herbicide application or from one hand weeding in all crops 21 days after emergence.

Rice stubble management and cowpea insects

Minimum tillage systems are popular for fast establishment of grain legume crops after flooded rice. Farmers broadcast or dibble seed in the rice stubble. These traditional methods have resulted in natural control of early season insect pests. Thus, any new tillage or crop establishment technique must try to incorporate the farmers' method of controlling insects without sacrificing crop yield.

A cowpea crop grown in rice stubble (right) has significantly less insect pests than a clean tilled crop. Short stubble is better than long stubble.

A change came to the system with the introduction of rice varieties that produce a short stubble (10–20 cm tall) compared with the 30–60 cm height of traditional plant types. We compared three rice stubble heights and straw mulch in minimum tillage systems with a high tillage system (stubble plowed under) for effect on preflowering insect pests of cowpea.

Three insect pests were dramatically suppressed by rice stubble 15–30 cm tall (Table 38). The 30-cm stubble shaded young cowpea plants; thus, cowpea yields were low even with insecticide protection. The 15-cm stubble was best for the combination high yield and insect control.

Corn establishment after rice

A series of 1978 studies sought management techniques to improve upland crop production after wetland rice in heavy textured soils.

Our major findings were that corn production after puddled wet-

Table 38. Rice stubble management affected preflowering insect pests of cowpea planted after rice at IRRI, 1978. The shorter stubble of short-statured rices improved yields over those of rices with the traditional longer stubble.[a]

Rice stubble management	Insect pests (no./15 plants)			Yield (t/ha)	
	Bean fly larvae + pupae 13 DE	Thrips 20 DE	Leafhopper 20 DE	Insecticide	No preflowering insecticide
Plowed under	17 a	83 a	36 b	0.69 ab	0.32 d
Straw mulch	15 a	8 b	13 c	0.57 bc	0.35 d
Rice stubble					
2 cm high	15 a	82 a	83 a	0.48 c	0.53 bc
15 cm high	9 b	6 b	13 c	0.82 a	0.62 b
30 cm high	6 b	1 b	6 c	0.63 b	0.36 d

[a]DE = days after crop emergence. Means followed by a common letter are not significantly different at the 5% level.

land rice was significantly lower than after unpuddled wetland rice or dryland rice because of differences in soil water availability and soil compactness. Although soil compactness was similar at high moisture contents, a previously puddled soil, when dry, becomes more compact at 5 and 10 cm depth than the unpuddled soil.

The grain yield of corn after puddled wetland rice responded significantly to nitrogen and phosphorus fertilizer (Table 39). Application of 8 t rice straw mulch/ha increased the soil moisture available to the corn and rendered shallow placed (5 cm) fertilizer more available. This led to increased yield and root growth. Deep fertilizer placement (20 cm) also allowed corn to better utilize applied fertilizer; that apparently increased root growth in the lower zones, allowed better extraction of subsoil moisture, and thus greatly increased yields.

Soybean after wetland rice

Establishment of soybean after wetland rice was evaluated in rainfed fields. Rice and soybean yields were highest when the rice field was drained near the time of rice harvest.

Table 39. The effect of fertilizer rates, mulching, and fertilizer placement (5- and 20-cm depths) on the yield of corn grown after puddled wetland rice.

Fertilizer (NPK) rate (kg/ha)	Corn grain (t/ha)[a]			
	No mulch		Mulched	
	5 cm	20 cm	5 cm	20 cm
0–60–60	0.38 f	0.63 f	0.55 f	1.02 e
60–60–60	1.14 e	2.05 e	1.84 cd	2.82 b
120–0–60	1.03 e	1.99 cd	2.00 cd	2.07 c
120–60–60	1.74 d	2.85 b	2.64 b	3.15a

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

Table 40. Grain yield of soybean as influenced by planting methods and mulching.

Planting methods	Grain yield[a] (t/ha)	
	No mulch	Mulch
Drill – relay planting	0.52 e	1.09 c
Dibbling – no tillage	1.38 b	1.90a
Seeding in furrow tillage	0.38 f	0.77 d
Row drilling – 1 rotovation	1.64ab	1.97a

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

The best soybean establishment methods were no-tillage and dibbling of seeds immediately after rice harvest, and row drilling of seeds after a single rotovation (Table 40). The addition of a rice straw mulch immediately after planting increased bean yields.

Variety testing for cropping systems

We have tested promising varieties of dryland rice for three wet seasons at our Tanauan, Batangas, research site. C171-136 was the outstanding variety, giving a 69% yield advantage over Dagge, the farmers' variety. After two seasons of tests, IR1529-430-3 proved better than C171-136. Both varieties had yields higher than 4 t/ha in 30% shade in a coconut plantation.

We distributed C171-136 to 30 farmers to compare it with Dagge. Management was by the farmers using our recommended practices. The average on-farm yield of C171-136 was 36% higher than Dagge's at 5.4% less nitrogen fertilizer, but Dagge matured earlier. Net 'urn over variable cost was 66% more for C171-136.

An intercropping experiment showed that C171-136 as a sole crop yielded an average of 1.5 t/ha more than Dagge. Intercropped with green corn, C171-136 yielded 1.3 t/ha more than Dagge. The low labor requirements for harvesting C171-136, combined with its increased gross returns, gave an average increase in net returns (over Dagge) of 143% as a sole crop and 80% as an intercrop with corn.

Elite cultivars of upland crops screened after rice by the University of the Philippines at Los Baños were evaluated in replicated yield trials at IRRI and the three Philippine outreach sites.

- Georgia Red was the most promising sweet potato in IRRI, Jewel in Iloilo, and Karja 381 in Pangasinan.
- CES 55, CES IT2, and CES U-1 are the most promising mung bean varieties for upland conditions.

- After two seasons of evaluation, UPLB SG5 sorghum was the best yielder in dryland tests at IRRI and Batangas and with high tillage after wetland rice in Iloilo.
- Yield levels of corn at all sites were low because of prolonged drought, but the most promising at all the test sites was Indonesian Early DMR x TC#1 DMR(s) C_3F_1.
- M10 peanut from Burma and Mocket from Vietnam were again the most outstanding as a dryland crop and after wetland rice.
- The most promising cowpea for dryland conditions was TVx 66-2H. Pelungga was the highest yielder with zero tillage after rice in Pangasinan. TVu 1502-1C was best with high tillage after wetland rice.
- Yield levels of soybean were low except for the IRRI trial, which was planted earlier. The best yielder was CES 70-68.

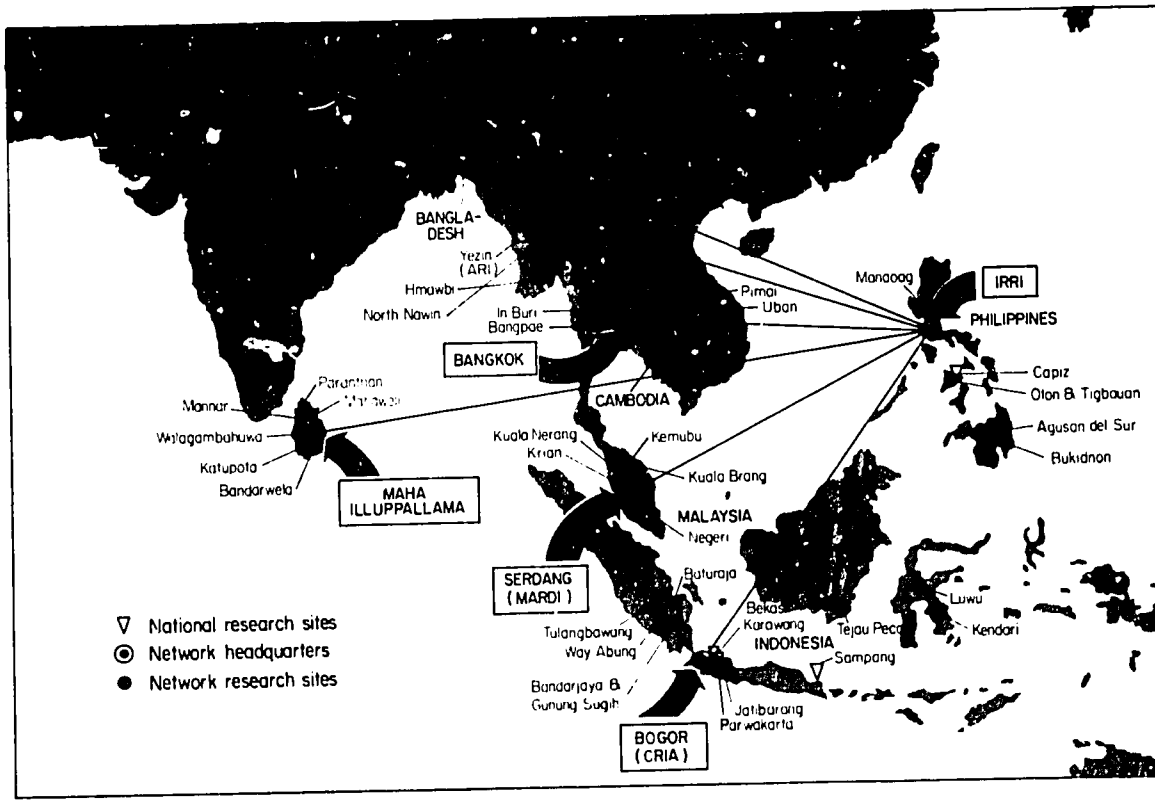
PILOT PRODUCTION PROGRAMS IN RAINFED RICE AREAS

During 1976–77, pilot production programs with rainfed rice were established in the Philippine provinces of Iloilo and South Cotabato. The Iloilo program was code named *KABSAKA*, that in South Cotabato, *KASATINLU*.

The *KABSAKA* program's growth and success were exceptional in 1978. Because of the severe drought in 1977, only 204 ha in *KABSAKA* were planted to second-crop rice. Yields were low and profit for the whole year averaged about $460 for the two crops. Nevertheless, in 1978 we had 317 – an increase of 229 over 1977 – farmers direct seed the first crop rice in May–June. The second crop rice for 1978 was planted by 267 farmers – an increase of 141 farmers and 223 ha over 1977. All second crops in 1978 were self-financed, suggesting strong acceptance of the two-crop rice system by rainfed rice farmers in Iloilo. Equally important is the fact that nearly 100% now practice direct seeding. We expect the project to continue unassisted by IRRI. Indications are that the *KASATINLU* program will be equally successful.

CROPPING SYSTEMS NETWORK

Much of the work reported in preceding sections of cropping systems has been by IRRI researchers on Philippine sites. The multiplier effect in the tremendous amount of cropping systems research done across Asia is, however, found in the Asian Cropping



45. Asian Cropping Systems Network sites, 1978.

Systems Network. Its reports, sometimes more exciting than ours in terms of results, are made in national programs.

The network had 17 research sites in the Philippines, Indonesia, Thailand, Malaysia, Nepal, Sri Lanka, and Bangladesh by the end of 1978. The test sites cover a broad range of climate, soil type, soil texture, and socioeconomic conditions in the major rice-growing countries in Asia. In addition to the 17 sites, we work with 23 other cropping systems research sites in countries involved in the network (Fig. 45).

The cropping systems working group, composed of program leaders from countries involved in the network, supports and guides network activities. At its seventh meeting at IRRI in 1978, the group agreed to start collaborative work on pest management and cropping systems economics in addition to varietal testing and cropping pattern monitoring.

Machinery development

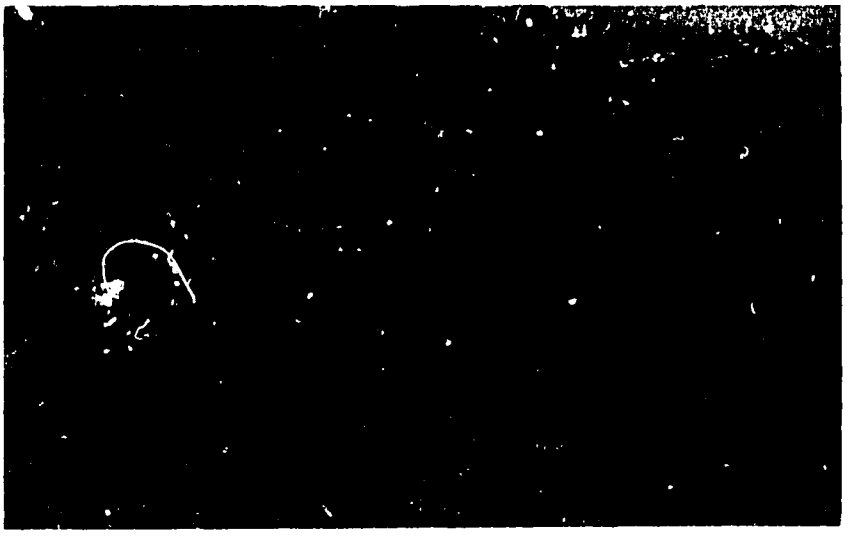
Agricultural engineers analyzed data gathered by our Cropping Systems Program in Iloilo province and found that cropping intensity there is limited by power availability. The Iloilo rainfed area has an average of 1 carabao, about 3 farm workers, and 1.4-ha farms.

The study showed that in years of average rainfall the introduction of IRRI power tillers and portable threshers – in numbers economically competitive with traditional practices – could increase the double-cropped area by 49% and the second rice crop yield by 370 kg/ha. The increases would come from reductions in crop establishment time for the first crop and in the turnaround time between the first and second crops. Labor requirements per crop would also be reduced, but total labor requirements would drop only 41 hours/year per worker because of the increase in double-cropped area.

The findings indicated that machines can be important to rainfed rice farmers, even on small farms with comparatively high work animal and farm labor densities.

Dryland crop seeder

Rice farmers often have the opportunity to plant a dryland crop after a rice crop, but they often use traditional seeding methods and plant limited areas. During 1978 we completed development of a seeder that can be pulled by a power tiller or a carabao. The



46. The new IRRI dryland crop seeder has metering plates for seed and fertilizer under each hopper. When the furrow openers are lifted, seed and fertilizer flow stops to prevent waste during turning at row ends and during transport from field to field. Seed plate changes and other adjustments can be made without tools.

seeder has the potential to increase yields by establishing more uniform crop stands. Weeding with animal or tractor-drawn weeding implements will be easier because the rows will be more uniformly spaced than when manually planted.

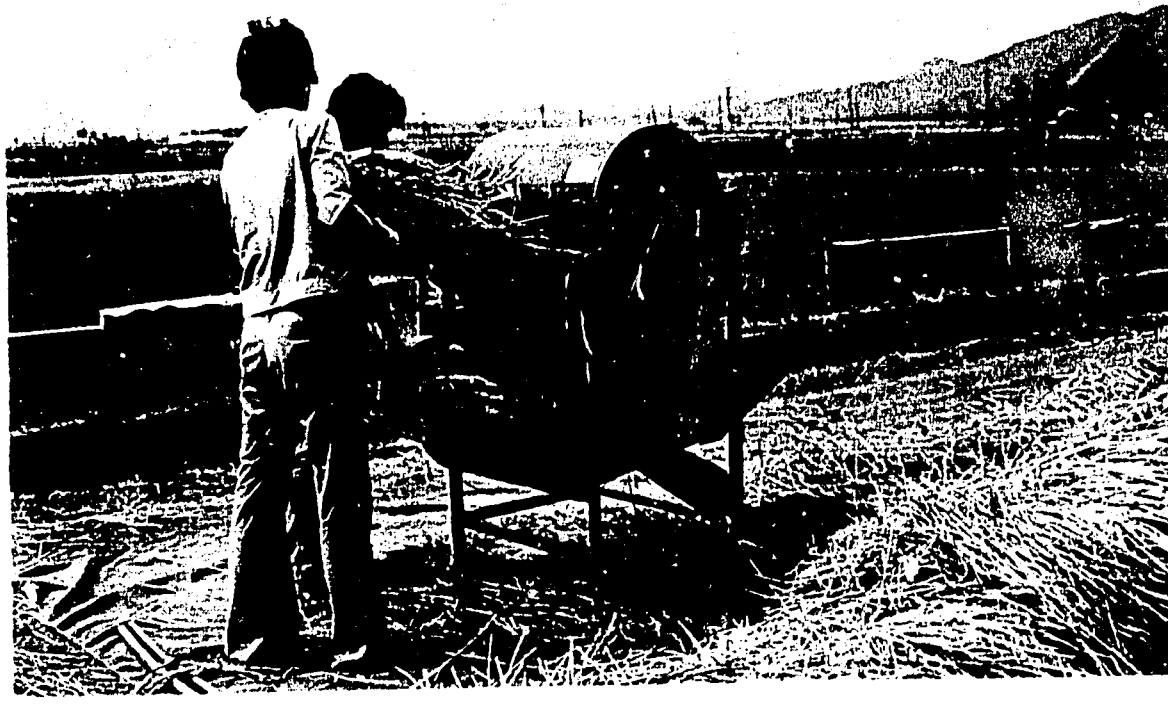
The multihopper dryland seeder has five individual seed and fertilizer hoppers (Fig. 46). Row spacing can be varied from 10 to 100 cm. Seed and fertilizer pass alternately through a common seed tube to the furrow, and the seed follows immediately after the fertilizer is dropped.

In our tests with rice, soybean, peanut, and corn, the seeder gave uniform placement of seed and fertilizer. Seeding a hectare takes 3–5 hours when the seeder is pulled with a power tiller.

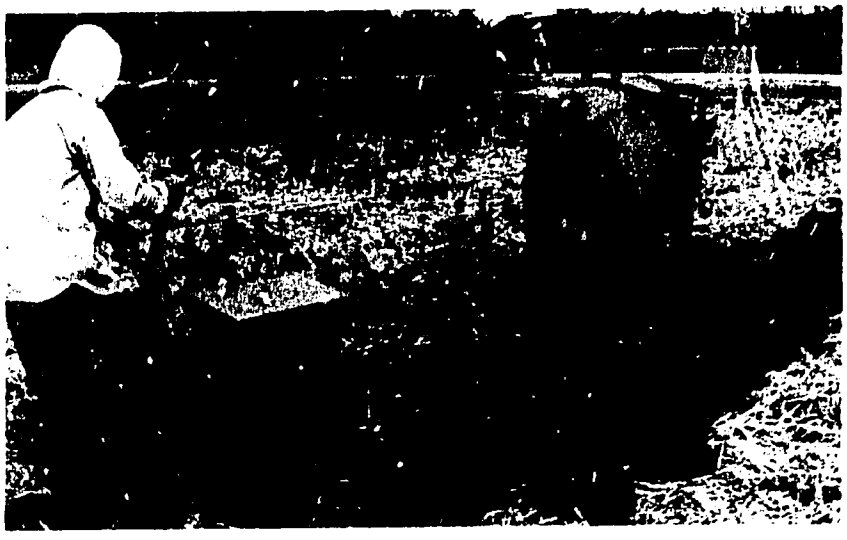
Portable thresher

The portable axial-flow thresher we developed in 1976 is popular among farmers. About 3,000 machines are now in use by rice farmers in the Philippines.

Feedback in 1978 from cooperating thresher manufacturers and users indicated a preference for a machine with a built-in cleaning system. In response, we developed and field tested a thresher with an oscillating screen and blower under the threshing cylinder-



47. The IRRI-designed axial-flow thresher was modified to add a cleaning system in 1978. A low-speed, large-diameter blower was added (bottom left). Costs were reduced by using the blower shaft to directly drive the oscillating cleaner screen.



The plow-sole fertilizer applicator (left) was adapted to the wooden plow in 1978. Fertilizer flow is metered by the large wheel.

The manual transplanter (right), designed by IRRI engineers, performed well in 1978 field trials at IRRI.

concave assembly (Fig. 47). When powered by a 7-hp engine, the machine can thresh and clean 450 to 500 kg of grains/hour with grain purity of 92–96%.

Plow-sole fertilizer applicator

Continued development of the plow-sole fertilizer applicator aimed at making it adaptable to power tiller or carabao-drawn plows. Limited field trials confirmed the advantages of applying fertilizer to the bottom of the plow furrow with the plow-sole applicator instead of traditional broadcast methods.

Five-row transplanter

We developed a manually operated 5-row rice transplanter that gave promising results in preliminary trials. The transplanter gave a low number of missing hills and damaged seedlings and the number of seedlings transplanted per hill was fairly consistent at 4–5. In 1979, trials will be extended to different soils and depths of water.

Machinery extension in Asia

Our industrial extension program for small machines was expanded in 1978 to include Indonesia. Progress continued in ongoing extension projects in the Philippines, Pakistan, and Thailand. Exceptional progress was made in Thailand, where the number of IRRI axial-flow threshers produced by cooperating manufacturers rose from 446 machines in 1977 to 1,574 in 1978.

International activities

The ultimate measure of IRRI's success is the increase that the research methodology and technology our scientists develop – on their own or in collaboration with other scientists – gives as rice production in national programs. Our international activity is the mechanism through which we ensure that IRRI contributes in a significant way to the efforts of different national programs.

Our international work has three basic objectives:

1. Complement location-specific research that cannot be done at IRRI headquarters.
2. Provide assistance to national programs.
3. Encourage strong national programs to work jointly with us on problems of mutual interest.

The activities to attain these objectives are seen, in addition to our training activity, in cooperative country projects, international research networks, collaborative research, and general services to national programs – workshops, conferences, symposia, and distribution of rice literature.

Cooperative country projects

Our cooperative country programs include work in Bangladesh, Indonesia, Pakistan, Philippines, and Sri Lanka and IRTP work in Latin America.

Dr. J. R. Cowan, IRRI liaison scientist (right), looks at research plots of the Central Research Institute for Agriculture (CRIA), Bogor, Indonesia, with Dr. Rusli Hakim, CRIA director (left), and Dr. B. H. Siwi, CRIA plant breeder.

- *Bangladesh.* A consortium of donors (Ford Foundation, Australian Development Assistance Bureau, and Canadian International Development Agency) agreed to fund an extension of the Bangladesh project from 1 January 1978 through 31 December 1980. Research efforts continued on varietal development for deepwater rice, rice production training and applied research, rice-based cropping systems, and machinery development and evaluation. The collection of rice germplasm was intensified along with the development of a Bangladesh rice testing network to include other institutions in the country. Six IRRI scientists worked with scientists of the Bangladesh Rice Research Institute to implement the cooperative program.
- *Indonesia.* Ten IRRI scientists were assigned to work with scientists of the Central Research Institute for Agriculture at Bogor, Sukamandi, and South Sulawesi. The emphasis of the cooperative work was genetic evaluation and utilization, rice-based cropping systems, insect and disease management, and machinery development and evaluation.
- *Pakistan.* Our cooperative work with Pakistan is on rice production training and applied research and on the development and evaluation of farm machinery. An agricultural engineer and a rice production specialist from IRRI are assigned in Pakistan.
- *Philippines.* An IRRI crop production specialist was assigned to the National Food and Agriculture Council to assist in the implementation of the Masagana 99 national rice production program.
- *Sri Lanka.* Three IRRI scientists worked with scientists from Sri Lanka's Department of Agriculture. They worked on rice-based cropping systems, rice breeding, and applied research trials.

During 1978 cooperative work was initiated in Burma and progress was made toward formalization and expansion of cooperation with scientists from the People's Republic of China and the Socialist Republic of Vietnam.

- *Burma.* One IRRI scientist was assigned to a cooperative project with emphasis on rice variety improvement, rice-based cropping systems, and development of machinery for small farms.
- *China.* Excellent progress was made in formalizing and expanding cooperation with scientists of the People's Republic of

China. Through the Chinese Academy of Agricultural Sciences, arrangements were made to collaborate in IRTP rice germplasm collection and conservation, and biological nitrogen fixation.

- *Vietnam.* In May 1978 a memorandum of agreement between the Ministry of Agriculture, Socialist Republic of Vietnam and IRRI was signed. We agreed to exchange germplasm, exchange visits of scientists, participate in conferences and workshops and in training programs, and collaborate in research on azolla and adverse soils.

Liaison operations

During 1978 IRRI liaison scientists assisted in developing cooperative national program-IRRI projects, and helped coordinate IRTP activities, in Southeast Asia, Africa, Latin America, and India. Assignment of the liaison scientist for Africa, based at the

Dr. Manuel Rosero (second from right), IRRI liaison scientist for Latin America, makes notes on a blast nursery in Brazil during a 1978 IRTP monitoring tour.

International Institute for Tropical Agriculture, Nigeria, was made in late 1978.

Collaborative research and network coordination

Our collaborative work on rice extends far beyond formal projects. We likewise continued collaborative work with scientists in developed countries. Among the more important collaborative projects with scientists in developed countries were those on:

- the sex pheromone of rice stem borers, with the Tropical Products Institute, U.K.;
- the brown planthopper, with the Center for Overseas Pest Research and Cardiff University College, U.K., and the Tropical Agriculture Research Center and Hokkaido University, Japan;
- the bacterial leaf blight, with Kyushu University, Japan; and
- cropping systems budgeting, with the Australian National University.

IRRI scientists continued to work with scientists in national programs in the implementation of a number of research networks serving Asian rice research. The networks are:

- Cropping Systems Network,
- International Rice Agroeconomic Network on Constraints to High Yields in Farmers' Fields,
- International Network on Fertilizer Efficiency in Rice, and
- Farm Machinery Development and Evaluation Network.

International meetings

Five hundred and thirty-three scientists participated in ten conferences, workshops, and symposia sponsored or co-sponsored by IRRI in 1978.

Title	Date	Attendance
Workshop on international cooperative project on national rice programs	14–16 March	25
IRTP Advisory Committee meeting	21 April	18
International rice research conference	18–22 April	124
Farm-level rice yield constraints conference	24–26 April	62
Deepwater rice workshop	17–19 August	79
Workshop on consequences of small rice farm mechanization in Asia	11–13 September	27
Rice cold tolerance workshop	18 September	49
Nitrogen and rice symposium	18–21 September	93
Cropping systems working group meeting	2–5 October	27
Workshop on the chemical aspects of grain quality	23–25 October	29

Associated formal training

The availability of properly trained and highly motivated scientists is essential to strong national rice research and extension programs. To help meet that need, we sponsor a resident training program in which scientists and extension workers from rice-producing countries study and gain experience in rice culture and rice-based cropping systems.

In 1978, we trained 380 scientists from 29 countries. Together, they represent 1,979 training months or about 65 training years – about 39 training years more than in 1977.

Among our research-oriented training participants, we had 31 postdoctoral fellows, 65 research (post-MS) fellows, and 112 research scholars (Table 41).

Table 41. Distribution by country of IRRI research fellows and scholars, 1978.

Country	Postdoctoral fellows	Research fellows			Research scholars		Total
		PhD	MS	N.D.[a]	MS	N.D.	
Bangladesh	1	4	14	1	5	–	26
Burma	–	–	–	–	4	–	4
Colombia	–	–	–	–	–	1	1
Cuba	–	–	–	–	–	2	2
England	–	1	–	1	–	1	3
Germany	2	1	–	–	–	–	3
India	12	7	–	–	1	–	24
Indonesia	1	6	–	–	12	14	33
Japan	6	3	–	5	–	1	15
Kenya	–	–	–	–	–	1	1
Korea	2	1	–	–	3	6	12
Malaysia	1	–	–	–	1	1	3
Mexico	–	1	–	–	–	–	1
Nepal	–	–	–	–	2	–	2
Netherlands	1	1	–	–	–	–	2
Nigeria	–	–	–	–	–	2	2
Pakistan	–	2	–	–	1	1	4
People's Republic of China	–	–	–	–	–	4	4
Philippines	1	6	–	–	12	–	19
Senegal	–	–	–	–	–	1	1
Sri Lanka	2	–	–	1	2	5	10
Taiwan	–	–	–	–	2	–	2
Thailand	–	3	–	1	12	3	19
USA	1	4	–	–	–	1	6
Venezuela	–	–	–	–	1	–	1
Vietnam	1	1	–	1	–	–	[illegible]

[a]Nondegree.

A 6-month rice production training course started in March 1978 for 38 participants from 9 countries. All participants except one – a Liberian – were from developing countries of Southeast Asia.

During 1978 139 scientists participated in training programs supportive of international rice research networks. The courses in this category were a 6-month cropping systems training program, a 4-month genetic evaluation and utilization (GEU) training course, a 2-month mechanization consequences training course, a 5-week irrigation and water management course, and a 2-week agricultural engineering training course.

Another 152 trainees attended the 2-week rice production course, which was given 6 times in 1978: 4 as part of the GEU, mechanization, and irrigation courses, and 2 for IRRI staff.

The mechanization and irrigation courses were offered for the first time in 1978. Our GEU course – given only once in 1977 – was given twice during the year. The second GEU course included four participants from the People's Republic of China, the first time that scientists from that country had participated in IRRI training.

These photographs reflect the wide range of field activities of our 1978 training groups. At top left, GEU 4-month trainees look at cold-tolerant rices near Banaue, Philippines. Later (top right) they work on deepwater rices in IRRI's special deepwater tanks. At lower left, irrigation and water management trainees work on a problem along a canal in Central Luzon. At lower right 6-month rice production training participants prepare their research plots for a trainee-organized field day.

Finances

IRRI received cash grants amounting to $13,814,747 during 1978.

The Ford Foundation gave $449,425, of which $100,000 was for core operations and capital expenditures and the remainder was to support rice research and development programs of the following countries:

- Bangladesh – $269,800 for the expansion of technical assistance and collaborative relationships with the Bangladesh Rice Research Institute,
- Pakistan – $66,938 as part of a 2-year grant to the Agricultural Research Council of Pakistan for support of research and training related to rice and agricultural mechanization, and
- Thailand – $12,687 as part of a 2-year grant to the Government of Thailand Royal Irrigation Department for support of water management research and training in northeast Thailand.

The Rockefeller Foundation contributed $267,500, which included $250,000 for core operations and capital needs. The Foundation also gave $17,500 toward the stipend and miscellaneous expenses of a postdoctoral appointee at IRRI.

The United States Agency for International Development (USAID) released a total of $4,107,719. IRRI received $3,100,000 of a $3,380,000 grant for core operations; $44,105 for expanding, strengthening, and further institutionalizing the National Applied Research and Extension Program for Transplanted Rice; $274,009 for industrial extension of small-scale agricultural equipment developed at IRRI; and $12,473 for the rice postproduction project in the Bicol River Basin.

Since October 1977, a contract between IRRI and USAID has supported a 2.5-year project for the accelerated development and use of improved rice technology in Indonesia with a total budget of $860,000. In 1978, USAID released $279,604 to IRRI.

Since February 1977, a contract between IRRI and USAID has supported a 2-year project in collaborative rice research in Pakistan with a budget of $258,000, plus Rp 1,110,000 managed by the USAID in Pakistan. In 1978, USAID released $112,246.

Since September 1977, a contract between IRRI and the Food and Nutrition Research Institute and USAID has supported a Philippine project titled "Protein quality of milled rice in preschool children" with a budget of $16,705. In 1978, $7,250 was reimbursed.

Since May 1977, a contract between IRRI and the Government of Sri Lanka has provided assistance in implementing a rice and cropping systems research project. Funds were provided by a loan from the USAID of a dollar budget of $3,125,130, plus Rp 2,006,560 managed by the USAID in Colombo. In 1978, $270,367 was released to the Institute.

USAID contributed to IRRI's training program by supporting scholars and trainees from countries where USAID has active programs. IRRI received $7,665 for this purpose in 1978.

The Ministry of Overseas Development, United Kingdom, released $835,400 toward the support of IRRI's core program.

The International Development Research Centre (IDRC), Canada, granted IRRI $707,960. Of that, $627,020 was part of a 2-year grant to the Institute for cropping systems research in the Philippines. The IDRC grant also included

- $50,130 as part of a 4-year grant to enable the University of the Philippines at Los Baños to conduct, in support of IRRI's multiple cropping

program, varietal screening for corn, sorghum, mung bean, eggplant, tomato, and sweet potato;

- $30,430 as part of a 4-year grant to support a multiple cropping research project at the Bangladesh Rice Research Institute; and
- $380 as the final release on a 2-year grant for research in Indonesia in cooperation with the Central Research Institute for Agriculture, and to develop cropping patterns for rainfed and partially irrigated rice areas and to adapt them through trials in farmers' fields.

The Japanese government gave $2,300,000 in 1978 for purchase of equipment for research and training, for partial support of cropping systems research, for the direct and indirect expenses of the plant physiology and soil microbiology departments, and for partial support of the genetic evaluation and utilization program.

The European Economic Community released $840,000 of a $1,120,000 grant toward the direct and indirect costs of water management, scholarships offered to candidates from developing countries, and partial support of the genetic evaluation and utilization program.

The International Development Association gave $100,000 toward core operations and capital expenditures of the Institute.

The Government of the Federal Republic of Germany gave $498,863 toward core operations.

The Australian government gave $758,230 in 1978. Of that, $588,730 was for core operations, including travel of Australian scientists; $158,200 supported expansion of technical assistance and collaborative relationships with the Bangladesh Rice Research Institute; and $11,300 supported a project at the Australian National University.

The Canadian International Development Agency gave $1,051,200 toward core operations and $221,150 toward a cooperative program for research and development between the Bangladesh Rice Research Institute and IRRI.

The Government of New Zealand gave $26,155 to support the core program.

The United Nations Environment Programme gave $70,000 toward research for developing rice varieties with low pesticide and fertilizer requirements.

The Government of Denmark gave $85,888 to support the core program.

The Government of Sweden gave $57,990 toward the core program.

The Government of Indonesia, using a World Bank loan, released $107,714 to IRRI as part of a 7-year contract for development of research facilities at the Sukamandi Branch of the Central Research Institute for Agriculture and for scientific and technical assistance to rice research at Sukamandi.

The Netherlands government gave $314,895 as part of a 5.5-year grant for a project to develop regional rice research stations in Indonesia.

The United Nations Development Programme gave $431,194 as part of a 5-year grant for the International Rice Testing Program; $282,097 as part of a 5-year contract to study nitrogen fixation associated with lowland rice; and $99,454 for a regional rice training program.

In 1976, IRRI entered into a cost-reimbursement contract with the United States National Institute of Health to study ways of increasing protein and essential amino acids in the rice grain through plant breeding. In 1978, $15,553 was reimbursed.

Since July 1976, funds from the Australian government have supported a contract between IRRI and the International Centre of Insect Physiology and Ecology for a joint program of ecological research on rice planthoppers. In 1978, $64,685 was released to the Institute.

The other donors, the areas they supported, and the amount they contributed are listed below.

- National Food and Agriculture Council, Philippines, for training government extension technicians $37,551
- Philippine Council for Agriculture and Resources Research, cooperative applied research project on rainfed rice 44,794
- Stauffer Chemical Company, weed control 3,000
- Potash Institute of North America and International Potash Institute, soil fertility 13,500
- Shell Chemicals Company, research grant to IRRI 6,803
- Hoechst, research grant to IRRI 4,277
- Ciba-Geigy, pest management 3,000
- Cyanamid, pest management 3,000
- East-West Center, research expenses of a research scholar 750
- Monsanto, herbicide research 2,000
- Montedison, rice research 3,000

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*On part-time
**Left during the year.
***On study leave.