AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION

A. PRIMARY: Agriculture

B. SECONDARY: Cereal Crops

2. TITLE AND SUBTITLE

Research highlights for 1974: International Rice Research Insitute

3. AUTHOR(S)

(101) IRRI

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1975	90 p.	ARC 633.18.161k

7. REFERENCE ORGANIZATION NAME AND ADDRESS

The International Rice Research Institute, Box 933, Manila, Philippines

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

9. ABSTRACT

General conclusions drawn from research by the International Rice Research Institute (IRRI) in 1974 are as follows: 1) Farmers have adopated new varieties of rice on only about one fourth of the world's rice land. Even in some countries in which the new rices are grown widely, rice production has increased far less than anticipated; 2) on an estimated half to three fourths of the world's rice land, farmers cannot increase production greatly because no improved varieties and technology are available which are appropriate to these areas. To be more effective, the IRRI has decided on three steps. It must work closely with farmers to determine why they have not adopted the new technology, or if they have, why their yields are still so low. IRRI must organize its internal research and training programs to encourage interdisciplinary attacks on farmers' problems in the field. Lastly, it must coordinate more efficiently its research and development programs with those of cooperating scientists and educators in the rice growing countries. Results of and recommendations made from specific research projects are discussed and detailed in the report.

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-AAB-424	
12. DESCRIPTORS	13. PROJECT NUMBER
	14. CONTRACT NUMBER: AID/ta-G-1074 GTS
	15. TYPE OF DOCUMENT

AID 590-1 (4-74)

RESEARCH HIGHLIGHTS FOR 1974

Text also published as director's introduction, "Research Highlights," Annual Report for 1974, International Rice Research Institute.

THE INTERNATIONAL RICE RESEARCH INSTITUTE
LOS BAÑOS, LAGUNA, PHILIPPINES, 1975
MAIL ADDRESS: IRRI, BOX 933, MANILA, PHILIPPINES

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Sometime in 1975, a mother will give birth to a very significant child – our planet's 4-billionth human being. The earth's population will then be on its way to the 5-billion level, expected in the mid-1980s. Even if family planning programs cut the birth rate thereafter to two children per family, the 6-billionth person will arrive well before the year 2000.

The 4-billionth child will likely be born in Asia, where more than half of the world's people already live, and will probably eat rice, the region's staple food. Millions of others in Africa and Latin America also depend on this crop for much of their nutrition.

The exploding population rate grimly dictates the world's food requirements, especially for rice. For the rice-growing countries are already the most crowded in the world, and their rates of population growth are among the highest.

A truly formidable challenge faces those involved in the worldwide struggle to produce more rice. In Asia alone, farmers must produce 5 million more tons of rice in 1975 than in 1974, even to maintain the current meager per-capita consumption. This annual increase in demand is about *1½ times the total annual rice production of the world's largest exporter, the United States.*

Over the next decade, worldwide rice production must increase by at least 30 percent just to maintain current (and inadequate) levels of consumption. Otherwise, chances are high for widespread hunger and even famine.

Most of the extra rice must be produced without bringing more land into cultivation, because most arable land is already being farmed in the rice-growing nations.

To the casual observer, the change in the global food outlook is surprising. The new wheat and rice varieties in the 1960s seemed to many a panacea. The term "green revolution" was coined to describe how the new "miracle" seeds could free the world from ugly spectre of hunger. To many, man seemed well on his way to solving his oldest problem, food production.

But the droughts, floods, and pest epidemics of the early 1970s, combined with a steady increase in population, awakened the world to the fact that the struggle to produce food had just begun. Remarkable as the new rices were, they would not grow equally well under all growing conditions. In fact, these modern varieties were quite unsuitable for vast regions of deep water, drought, injurious soils, and cold temperatures. This partly explains why today, farmers use the improved seeds in only about a fourth of the world's rice-growing areas (fig. 1).

The major thrust of rice scientists in the next decade must be to develop improved rices and associated technology for small farmers in regions of adverse ecological conditions, to help them produce more food from limited land.

The role of science and technology

opposite page

Upper: *Participants in the Genetic Evaluation and Utilization (GEU) training program come to IRRI for specialized training in interdisciplinary rice improvement.*

Lower: *The ultimate goal of IRRI's programs is improvement of quantity and quality of worldwide rice production.*

During the past year, we at IRRI have given considerable thought to how we can more effectively help the world's small farmers increase their rice production.

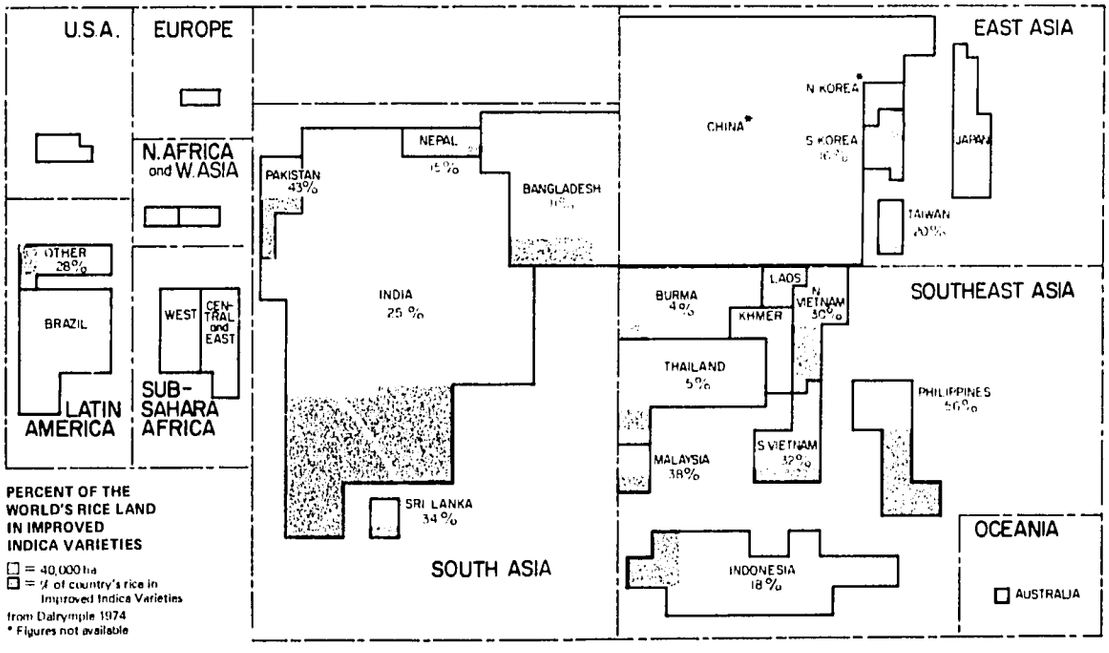
We know that farmers have adopted the new varieties on only about a fourth of the world's rice land. Even in some countries where the new rices are widely grown, rice production has increased far less than anticipated.

We also know that on a substantial portion of the world's rice land estimates range from half to three-fourths farmers can't increase production much because no improved varieties and technology are available that are suited to their areas.

We have concluded that to be more effective, we must take three steps:

First, we must *work closely with farmers to determine their constraints.* We must find out why they have not adopted the new tech-

1. About 25 percent of the world's rice land is now planted to improved rice varieties. Scientists hope to extend the Green Revolution by developing improved varieties and technologies for the other regions.



nology, or if they have adopted it, why their yields are so low;

Second, we must organize our internal research and training programs to encourage *interdisciplinary attacks on farmers' problems* in the field; and

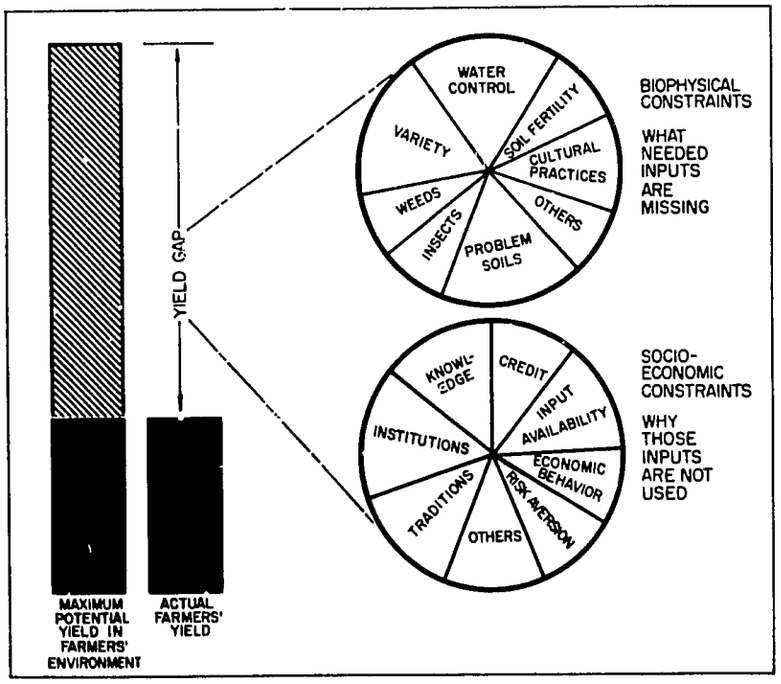
Third, we must better *couple* our research and development programs with those of cooperating scientists and educators in the rice-growing countries, *for theirs is the ultimate task of developing and adapting the technology needed to feed a hungry world.*

We made some progress in each of these areas in 1974. These efforts complemented the traditional flow of new varieties and technology from the fields, greenhouses, and laboratories of the Institute.

IDENTIFYING FARMERS' YIELD CONSTRAINTS

In 1974, we intensified and expanded our research to better understand what prevents small farmers from producing yields as high as we know are attainable with new technology.

We are concerned with both bio-physical and socioeconomic factors (fig. 2). The bio-physical aspect of the yield gap indicates *what*



2. The "yield gap" between potential and actual farmers' yields is due to both bio-physical and socioeconomic constraints.

inputs are missing. It measures the extent to which yields would increase if farmers would use improved varieties, apply optimum levels of fertilizers and pesticides, correct soil problems, and use the best cultural practices. The socioeconomic analysis indicates *why* the farmer may not be using the bio-physical technology. Reasons may include input costs, market prices, inadequate knowledge, inadequate credit, or traditional beliefs.

Because the yield-gap factors differ from area to area, an important aspect of our program is developing and sharing reliable research methodology to help local scientists in many nations identify local production constraints, so they can then overcome them.

Our research shows that diseases and insects are obviously major constraints to rice yields. In six experiments on farmers' fields in Laguna province, Philippines, for example, insect damage reduced yields by an average of almost 1.7 t/ha (table 1).

Other major constraints are inadequate water and weed control, and inadequate fertilizer use.

Table 1. Comparative yield constraints from each of three inputs when the other inputs were held at farmers' level or at a high level (average of 6 locations). Laguna province, Philippines, 1974 dry season.

Level of other inputs	Increase (t/ha) from		
	Insect control	Weed control	Fertilizer
Farmers' level	1.68**	0.23	0.91**
High level	1.04**	0.50	0.66**

**Highly significant increase.

INTERDISCIPLINARY RESEARCH

We continued to develop and formalize *interdisciplinary* team attacks on rice production problems in 1974. Our reasoning is simple: the problems that face small farmers are varied and complex. No single discipline – nor any single research institution – has the ability to tackle them. Only a team effort, each scientist contributing his specialized knowledge and skills, can produce the wide range of varieties and technology needed to really intensify food production.

Our two largest teams are those concerned with the Genetic Evalution and Utilization (GEU) program and with the Cropping Systems program. Together, they account for more than half of IRRI's total research and training efforts. The GEU program illustrates how the approach is being used.

Genetic Evaluation and Utilization (GEU) Program

The GEU program is an interdisciplinary rice improvement effort, linked with similar national programs in Asia, Africa, and Latin America, to jointly develop and evaluate improved rices and technology for all rice-growing areas. The GEU program builds on the success of the semidwarf varieties that have so remarkably increased production in those areas where farmers are assured of water control and adequate chemical inputs.

Despite these productivity increases, the Green Revolution technology has bypassed many other less prosperous areas. The semidwarf rices developed at IRRI are unsuitable for many vast "deep water" regions of Thailand, Bangladesh, India, Burma, Indonesia, and Vietnam. Similarly, high-yielding rices are needed for the salty soils of coastal marshes and of irrigated land in arid regions, and for the drought-prone regions where upland rice is grown. The improved rices developed for all areas must be resistant to major insects and diseases.

The GEU teams

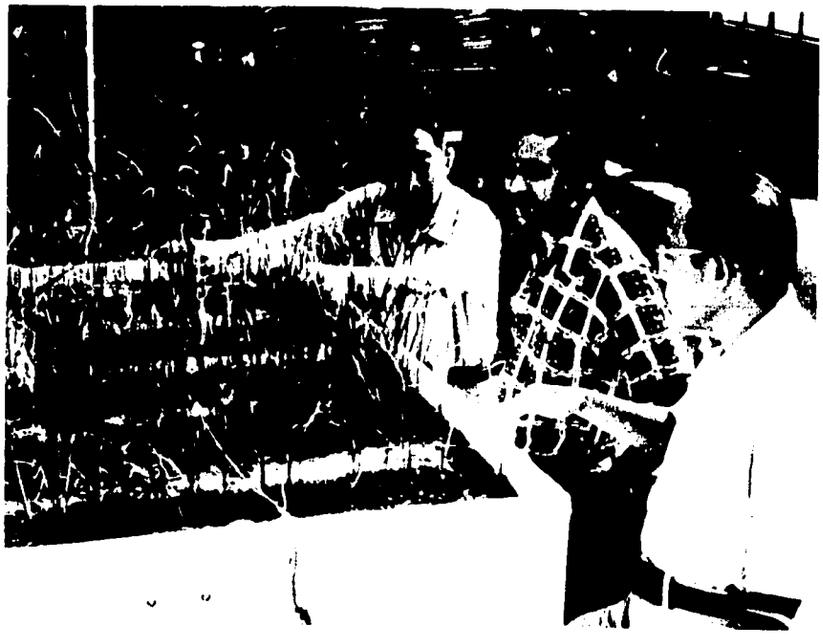
Through the GEU program, nine interdisciplinary teams of plant breeders and problem-area scientists, such as pathologists, entomologists, agronomists, and soil chemists, are working together to develop rices that are genetically adapted to each of the major types of growing conditions in which rice is produced.

The problem areas for which GEU teams are seeking improved rices are:

- agronomic characteristics;
- resistance to insects;
- resistance to diseases;
- resistance to drought;
- tolerance to adverse soils;
- tolerance to deep water and floods;
- tolerance to extreme temperatures (cold or hot);
- grain quality; and
- higher levels of protein.

To develop improved rices, each team first identifies varieties that can withstand the major constraints to rice production within its specific problem area. Through crossbreeding, they develop large numbers of experimental lines that are resistant or tolerant to these constraints, and that have other favorable characters as well (particularly high and stable yield potential and pest resistance).

Each team member brings his specialized background knowledge into the breeding and evaluation program.



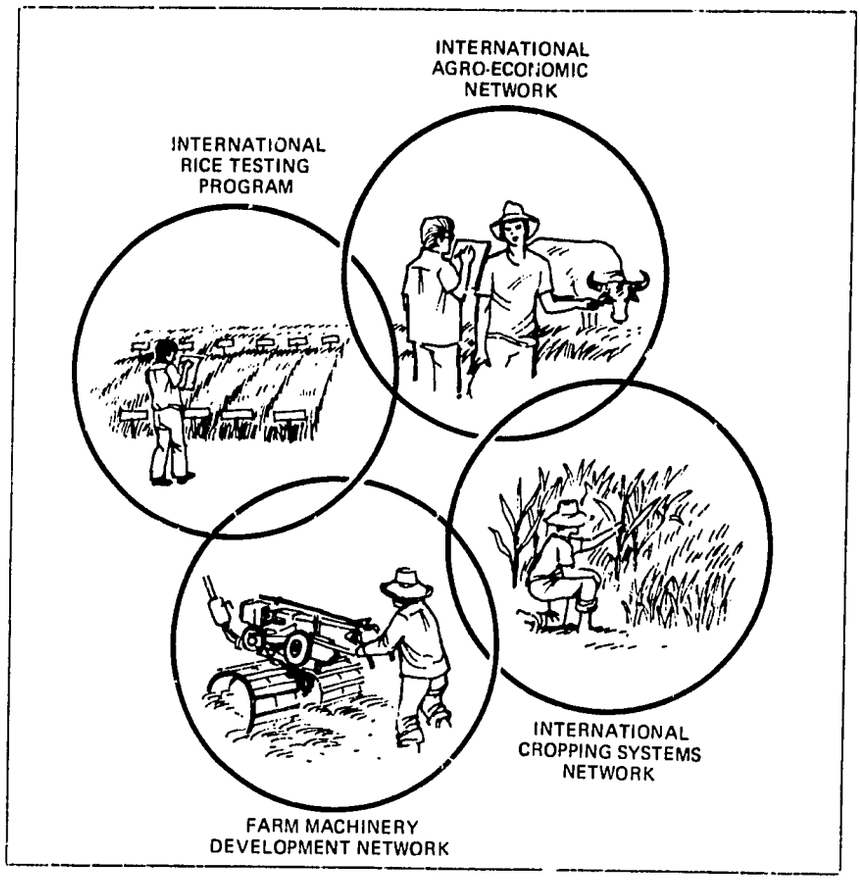
3. Three members of the GEU drought tolerance team inspecting rice varieties grown at constant water levels. Left to right are: Dr. Shouichi Yoshida, plant physiologist; Dr. Surajit K. De Datta, agronomist; and Dr. Te-Tzu Chang, geneticist (not pictured, Dr. John O'Toole, associate agronomist).

The drought-tolerance team, for example, consists of geneticists, plant breeders, agronomists, and plant physiologists (fig. 3); it works closely with the disease- and insect-resistance teams. In much the same manner that pest-resistant varieties were developed, the drought team is now screening, breeding, and testing to develop rices that can withstand moisture stress. They determine the abilities of traditional Asian and African varieties to survive drought, and cross them with other rices of higher yield potential. They promptly make promising lines available to cooperating scientists in regions of drought to evaluate in rigid screening trials.

NETWORKS

The third major thrust at IRRI is to initiate and expand international networks, uniting the research and development efforts of scientists from a number of cooperating countries.

Four such collaborative networks have been established among cooperating biological and social scientists across the rice-growing world: (1) the International Rice Testing Program, which is the evaluation component of an international GEU effort; (2) the International Agro-Economic Network; (3) the International Cropping Systems Network; and (4) the Agricultural Machinery Development Network (fig. 4).



4. Four collaborative networks have been established among cooperating biological and social scientists across the rice-growing world.

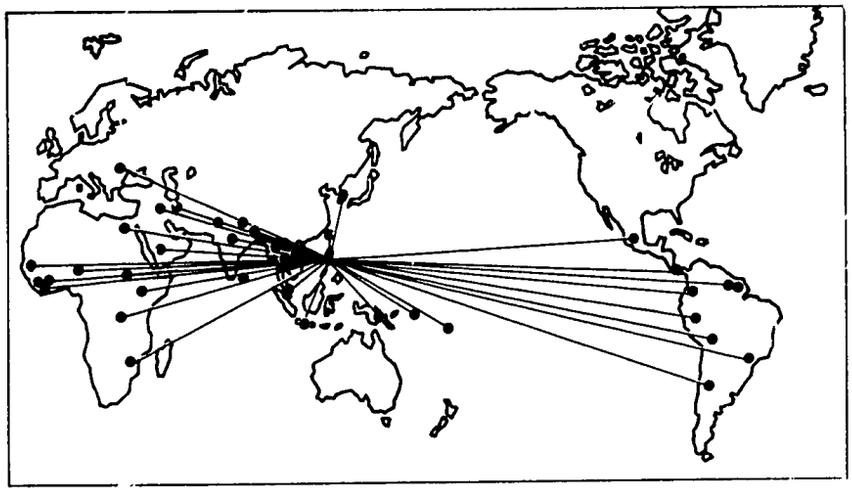
International Rice Testing Program (IRTP)

Elite rices generated by the GEU program and by national rice improvement programs are evaluated under a worldwide range of environmental conditions through the International Rice Testing Program (IRTP) (fig. 5).

Each national program can nominate its best parent materials, breeding lines, and varieties for global evaluation in the 12 yield and screening nurseries (table 2). Additional problem-area nurseries may be initiated as the need arises.

Worldwide testing shows how different rices react to diverse pests, diseases, and environmental conditions, and speeds up the identification of rices with yield stability. It spreads new germ plasm to broaden the genetic base of the world's rice crop.

The operation of the program is quite simple. IRRI, as IRTP coordinator, receives seeds of varieties or lines that cooperators in national centers have nominated for inclusion in the program. We



5. Elite rices developed through national programs and through IRRI's Genetic Evaluation and Utilization program are evaluated in about 40 nations through the International Rice Testing Program.

Table 2. Nurseries in the International Rice Testing Program (IRTP).

YIELD:
International Rice Yield Nursery – early-maturing (IRYN-Early)
International Rice Yield Nursery – medium-maturing (IRYN-Medium)
International Upland Rice Yield Nursery (IURYN)

SCREENING:

Observation:
International Rice Observation Nursery (IRON)
International Upland Rice Observation Nursery (IURON)

Disease:
International Rice Blast Nursery (IRBN)
International Rice Sheath Blight Nursery (IRSHBN)
International Rice Tungro Nursery (IRTN)

Insect:
International Rice Brown Planthopper Nursery (IRBPHN)
International Rice Gall Midge Nursery (IRGMN)

Other Stresses:
Inernational Rice Salinity Tolerance Observation Nursery (IRSTON)
International Rice Cold Tolerance Nursery (IRCTN)

multiply the seed and then compile it into sets, which are distributed to cooperators in country programs. The field tests are run by scientists in national programs who are familiar with local environmental conditions and with the habits, customs, and resources of local farmers.

These scientists evaluate and record how each rice yields and how each reacts to adverse biological factors, such as diseases, drought, or cold. Results are used within each national program, and duplicate

sets of data from all locations are sent to IRRI to be rapidly analyzed, compiled, published, and distributed. Rice scientists around the world then study the information, select the best materials for their programs, and request seed.

The program's effectiveness is largely determined by the way that cooperators use the germ plasm and test information to strengthen their national programs.

International Rice Agro-economic Network (IRAEN)

IRRI is collaborating with scientists in several rice-growing countries to develop methodology to monitor problems that slow down the farm adoption of improved rice varieties and technology through the IRAEN.

Economists and agronomists in Indonesia, Thailand, and the Philippines are coordinating research through the IRAEN. Other nations are expected to participate in future research. They conduct experiments on farmers' fields, survey farmers to determine biological and socio-economic constraints, analyze markets and input prices, and relay their findings back to scientists in national research programs and at IRRI.

The agro-economic teams are trying to determine answers to such problems as why rice production has substantially increased in many regions where the new varieties are planted, but not in others (fig. 6).

Or, why many farmers who have accepted the new rice varieties do not use accompanying chemical inputs and cultural practices. These farmers' yields may have increased, but they still lag far behind potential yields proved possible in experiments.

Once answers are determined, the scientists can then tailor research to develop the varieties and technology to overcome the production constraints.

The network is a step toward an international system through which scientists can continuously monitor the adoption of improved rice technology, and can devise strategies to speed adoption. From the knowledge gained through the network, scientists will evaluate the probable impact of alternative research and development strategies.

The International Agro-Economic Network has the following objectives:

- to develop and use procedures to identify the physical, social, and economic factors that influence the adoption and efficient use of improved rice technology;

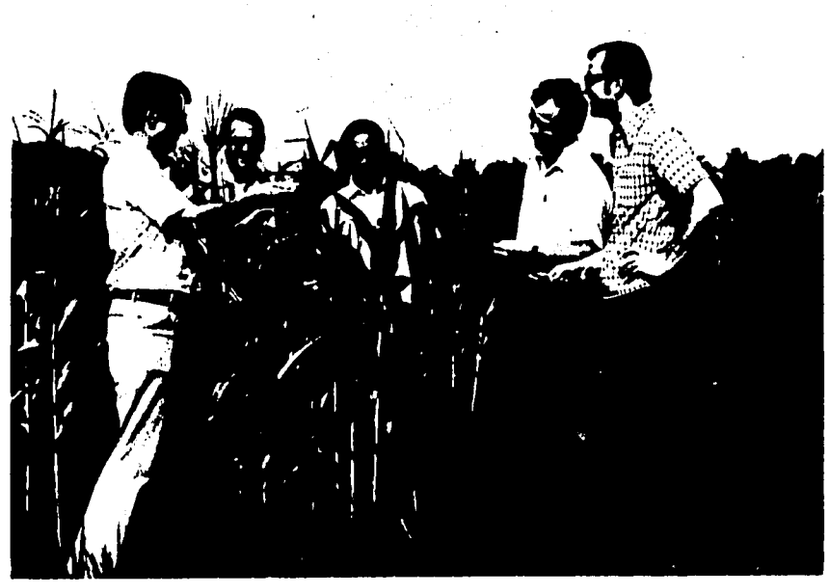
6. Participants at a planning workshop for the International Agro-Economic Network held in Thailand.

- to define and, where practical, test alternative strategies for alleviating constraints and increasing rice production;
- to develop and use procedures to assess the distribution of benefits of the new technology (what impact the technology has on income, income distribution, and employment among various classes of farmers and agricultural laborers);
- to undertake collaborative research in cooperating nations;
- to help train researchers in national programs to identify constraints that hold down rice yields in their own countries; and
- to improve communication among scientists of different disciplines concerned with the application of new rice technology.

By cooperating in the International Agro-Economic Network, scientists hope to gain the knowledge to be able to recommend ways by which national rice improvement programs can increase their impact on small farmers' fields.

International Cropping Systems Network

Although rice is generally the staple crop of small farmers in Asia, it is seldom their only food crop. Farmers can intercrop, or follow,



7. The IRRI cropping systems team collaborates with scientists across the rice-growing world. In an intercropped field of upland rice and corn are (left to right): Dr. James A. Litsinger, associate entomologist; Dr. Dale Haws, crop production specialist; Dr. Virgilio R. Carangal, cropping systems network coordinator; Dr. Richard R. Harwood, agronomist and head of multiple cropping department; Dr. Edwin C. Price, associate economist.

rice with other food crops such as corn, soybean, mung, sweet potato, cassava, or sorghum.

Through the International Cropping Systems Network, scientists are testing different cropping patterns in farmers' fields in Bangladesh, Indonesia, Vietnam, and the Philippines.

Scientists are also evaluating for intensive farming schemes, varieties of crops such as rice, sorghum, soybean, peanut, sweet potato, and cowpea.

The first priority is to develop cropping systems slanted to small farmers in upland and rainfed areas (fig. 7). Most of these farmers are subsistence, but research shows that their potential to produce more food can be substantially raised.

To ensure that the technology developed will be within the management capabilities of small farmers, cropping systems research trials are conducted in farmers' fields, under farmer management.

The experimental sites represent the environmental conditions of specific "agro-climatic zones," or areas of similar soil, climatic, and cultural conditions. Knowledge gained at each experimental site can then be shared and used throughout the agro-climatic zone, speeding the transfer of technology among nations.

The scientists determine the biological parameters – the growth durations, fertility requirements, and food production potentials – of different crops. Then, on the farms, they fit together compatible

combinations of food crops and develop farming schemes to raise the income levels of small farmers.

Because we are studying *rice-based* farming patterns, the Cropping Systems Network must be coordinated with the GEU and with the International Rice Testing programs, and the Agro-Economics and Farm Machinery Development Networks.

Cropping patterns revolve around the best available rice varieties for each agro-climatic zone. As scientists continue to shorten the growth durations of improved rices, the farmers' potential to produce more food increases. For example, modern varieties such as IR28 and IR30 mature in 115 days – from 1 to 2 months earlier than traditional varieties. The short growing seasons leave the farmer adequate time and soil moisture during the late monsoon season to grow other crops.

Work plans for the network are developed jointly with scientists from cooperating national programs (fig. 8). A cropping systems working group has met at IRRI to determine common guidelines for cooperative research.

Farm Machinery Development Network

To intensify food production, farmers in the developing nations need tools and technology to speed certain production practices, such as

8. Scientists from many nations at an international cropping systems conference held at IRRI in early 1975.

9a. The IRRI bellows pump is well suited for pumping water from irrigation ditches, open channels, rivers, and shallow wells. The operator stands on the two foot rests and shifts his weight from one foot to the other, compressing a bellows that forces water from the outlet valve.

9b. The bellows pump being produced in a small machine shop in Gia Dinh, Vietnam. In the background are recently manufactured IRRI power tillers.

land preparation, threshing, and drying. The need will increase as more farmers shift to short-season varieties and multiple cropping.

Much of the machinery developed for large-scale farming in the more developed countries is not suited to the needs of farmers in the rice-producing nations. The machines may be too costly and complex. Or, they may be far too large to meet the needs of farmers with less than 10 ha. Furthermore, they cannot be economically manufactured in low volume in the developing countries because they are designed for capital-intensive mass production. They are hard to service and to maintain because of difficulties in obtaining spare parts.

To help fill this technology gap, IRRI cooperates with a network of national research organizations, manufacturers, and engineers in Asia, Latin America, and Africa.

The philosophy of the network is to develop appropriate mechanization technology for small farms and to encourage local manufacture of suitable farm machines by small metalworking firms (fig. 9).

How the program works. IRRI scientists identify the most pressing production problems in farmers' fields and develop appropriate farm machines to overcome the production constraints.

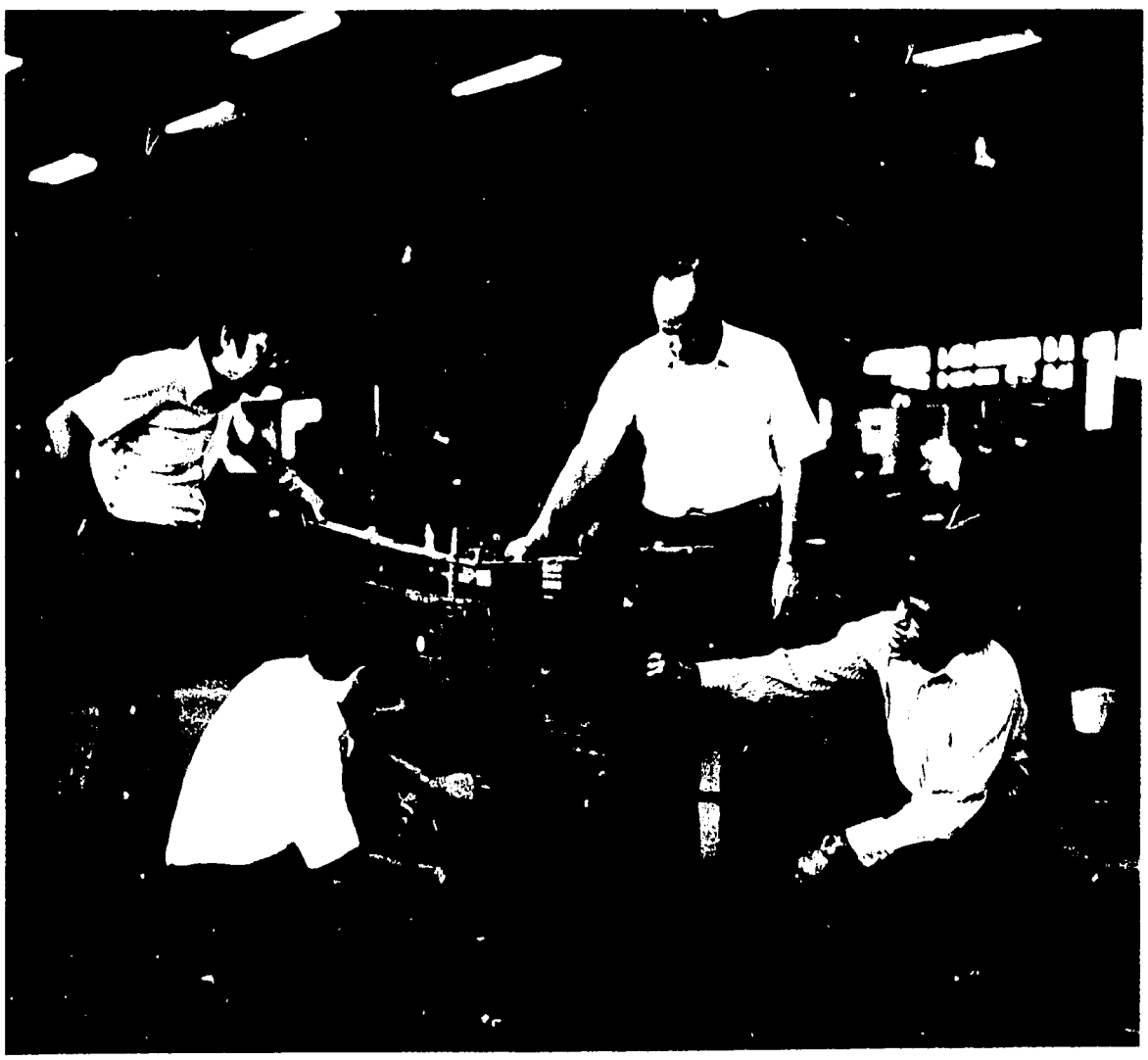
To encourage local production, IRRI releases the designs free to cooperating manufacturers who want to produce and sell the machines.

Local manufacture of farm equipment generates employment. Equally important, indigenous production saves foreign exchange in the developing nations.

IRRI scientists maintain cooperative relationships with local manufacturers. We have found that small metalworking shops often modify the basic IRRI designs to better suit the machines to their specific local conditions.

IRRI provides ongoing technical consultation to ensure machine quality and performance.

Companies that produce IRRI machinery can send prototypes to IRRI for testing and evaluation. Inspecting a prototype power tiller, with tires substituted for the cage wheels for road transport, are (left to right): Dr. Chul Choo Lee, visiting associate engineer; Mr. Donald O. Kuether, associate engineer; Mr. J. Bart Duff, associate agricultural economist; and Dr. Amir U. Khan, agricultural engineer.



Major research results

GENETIC IMPROVEMENT

During 1974, 14 IRRI lines were named as varieties – 11 by cooperating countries, and 3 by IRRI. This brings to at least 45 the number of varieties named from IRRI lines; 36 have been named by cooperators and 9 by IRRI.

All three of the varieties released by IRRI in 1974, IR28, IR29, and IR30, are early maturing, with resistance to major diseases and insects, good grain quality, and high yield potential (fig. 10). Because of their short growth durations, these varieties are especially suited for multiple cropping – the growing of successive crops of rice, or of rice followed by upland cash crops.

IR28, IR29, and IR30 are the first varieties that are highly resistant to grassy stunt virus, a serious disease in many countries. They inherit this resistance from *Oryza nivara*, a wild rice from India.

IR29 is the first IRRI variety with glutinous or waxy endosperm. It cooks soft and sticky, and can be used in special preparations, such as cakes and pastries. Glutinous rice is the staple food in Laos and northeast Thailand.

Farmer acceptance of IR26

Philippine farmers generally seem satisfied with the yielding ability and pest resistance of IR26 under field conditions. About 250,000 ha were planted in the Philippines during the 1974 wet season. As resistant material is widely planted, both brown planthopper populations and insecticide use for their control are declining.

At the time of its approval for cultivation in Vietnam, in late 1974, about 30,000 ha of IR26 had already been planted (fig. 11). IR26 is being multiplied in Indonesia, Sri Lanka, and Kerala state, India, and is being extensively tested in Burma, Bangladesh, India, Sri Lanka, and Indonesia.

IRRI lines named in other countries

Selected IRRI lines were found suited to a variety of ecological conditions and named as varieties in 1974. IR5-198-1-1 was named as ROK-6 in Sierra Leone, where it is adapted to growing under swampy lowland conditions. IR665-4-5-5 and IR841-63-5, which have long and slender grains of excellent quality, were released for cultiva-

opposite page

IRRI research shows that placing small amounts of fertilizers and insecticides below the soil surface increases the efficiency of chemical use. A low-cost deep placement applicator is being developed and tested to speed the process and help farmers maximize returns on expensive farm chemicals.

10. IRRI's more recent varieties, IR26, IR28, IR29, and IR30, have broad resistance to major diseases and insects and to several soil problems.

Resistance ratings of IRRI varieties

Variety	Diseases				Insects			Soil problems			
	Blast	Bacterial blight	Grassy stunt	Tungro	Green leaf-hopper	Brown plant-hopper	Stem borer	Alkali injury	Salt injury	Zinc defi-ciency	Phos-phorus defi-ciency
IR8	MR	S	S	S	R	S	MS	S	MR	S	MR
IR5	S	S	S	S	R	S	S	S	MR	R	MR
IR20	MR	R	S	R	R	S	MR	S	MR	R	R
IR22	S	R	S	S	S	S	S	S	S	S	MR
IR24	S	S	S	MR	R	S	S	MR	MR	S	MR
IR26	MR	R	MS	R	R	R	MR	MR	MR	S	R
IR28	R	R	R	R	R	R	MR	MR	MR	R	R
IR29	R	R	R	R	R	R	MR	S	MS	R	R
IR30	MS	R	R	R	R	R	MR	MR	MR	R	MR

R = resistant MR = moderately resistant MS = moderately susceptible S = susceptible

tion in Brazil. IR747B2-6-3 and IR1614-138-3-1 were named as GPL 1 and GPL 2 in the British Solomon Islands. These two lines are resistant to brown planthoppers, a serious pest in that country. IR837-20-3-6 and IR837-46-2, two lines with excellent long and slender grains and high yield potential, were named as Redras Negras A74 and Bomoa A74 in Mexico. IR841-36-2, an early maturing line, was named Abbasi 72 in Pakistan. IR822-81-2 was released as CR 1113 in Costa Rica, where it is highly resistant to blast. IR532E-208 was released for cultivation as N.G. 6637 in Papua, New Guinea. Malaysia approved for general cultivation IR5-250, a sister line of IR5 and Bahagia as SM1.

Breeding program

The crossing program was further expanded during 1974. Of the 2,849 crosses made, 1,762 were single crosses, 741 were topcrosses, and 346 were doublecrosses. We used several new sources of resistance to diseases and insects in 1974. Similarly, we crossed improved disease- and insect-resistant breeding lines with several tall varieties that have high protein content or tolerance to drought, adverse soils, cold temperatures, or floods.

We grew F_2 populations from 316 cross combinations and grew 45,302 pedigree rows, most without chemical protection.

We evaluated the yield and protein content of 414 dry-season and

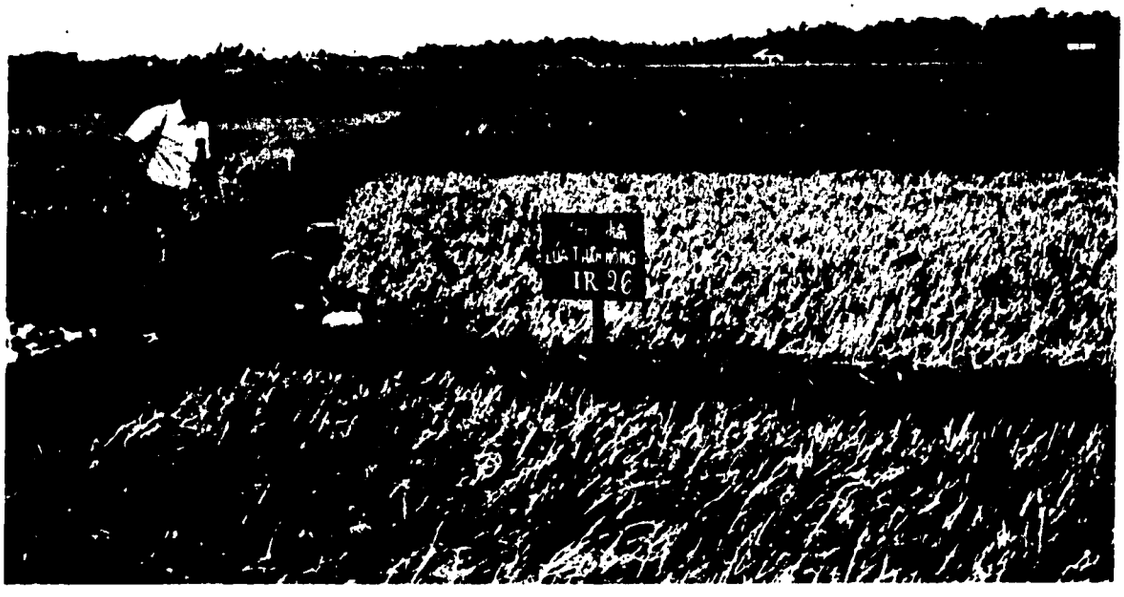
368 wet-season entries in the replicated yield trials, and of more than 1,000 breeding lines in the wet- and dry-season observational nurseries.

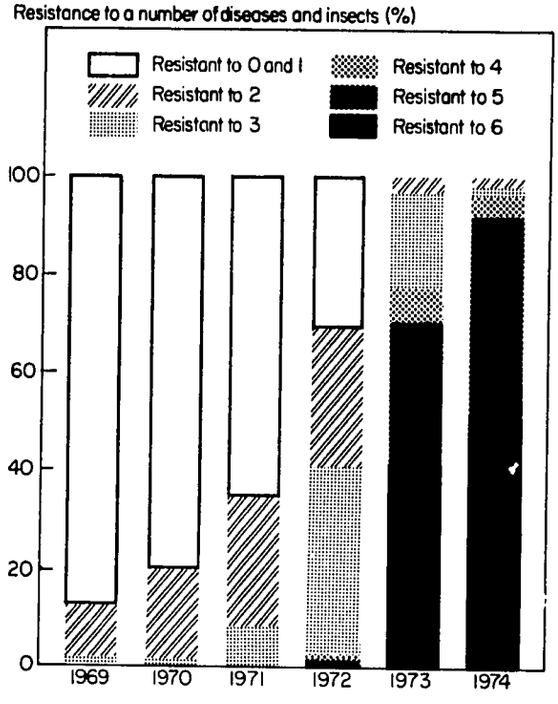
Progress on multiple insect and disease resistance

More than 90 percent of the lines in the 1974 replicated yield trials had at least moderate resistance to five or more of the major insects and diseases (fig. 12).

Outstanding selections with multiple resistance are being tested in various coordinated trials in the Philippines; many are also being tested in other countries through the International Rice Yield Nursery. Many sister selections of these lines have similar levels of disease and insect resistance. At least four of these lines are resistant to gall midge. Two of them, IR2153-26-3-5 and IR2153-43-2-5, are tolerant of salinity and another two, IR1702-74-3-2 and IR2070-747-6, are tolerant of iron toxicity. They vary in growth duration from 105 to

11. IR26 is widely grown in the Mekong Delta of Vietnam. Left to right: Dr. Gurdev S. Khush, IRRI plant breeder, and Dr. Dwight Kanter, rice breeder, IRRI-Vietnam Cooperative Project.





12. The proportion of entries in the annual replicated yield trials with multiple resistance to insects and diseases is steadily increasing. More than 90 percent of the 1974 entries had at least moderate resistance to 5 or more major pests.

growth duration from 105 to 160 days. Plant statures also differ; some lines are taller than others. IR2061-213-2-17, like IR5, is of intermediate height and should be particularly adaptable to areas where farmers prefer intermediate-statured varieties.

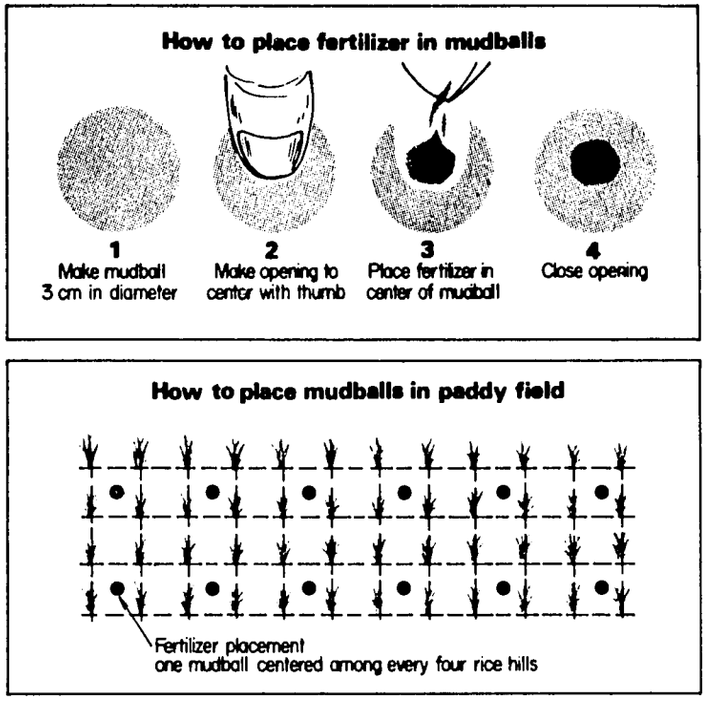
Many of these lines are now serving as parents in the crossing programs.

Exchange of breeding lines

We continued to supply improved advanced breeding lines to scientists across the rice-growing world. We sent 11,492 packages of breeding lines to 57 countries in 1974.

EFFICIENCY OF CHEMICAL INPUTS

High prices of both fertilizers and pesticides add to the problems of all rice farmers, particularly those of low income. As a result, fertilizer use has leveled off or actually decreased. We expanded our research in 1974 to increase the efficiency of both fertilizers and insecticides so that farmers can get higher yields from lower applications.



13. Nitrogen fertilizer placed in a mudball and inserted about 10 cm beneath the soil surface gives significantly higher yields at lower fertilizer rates.

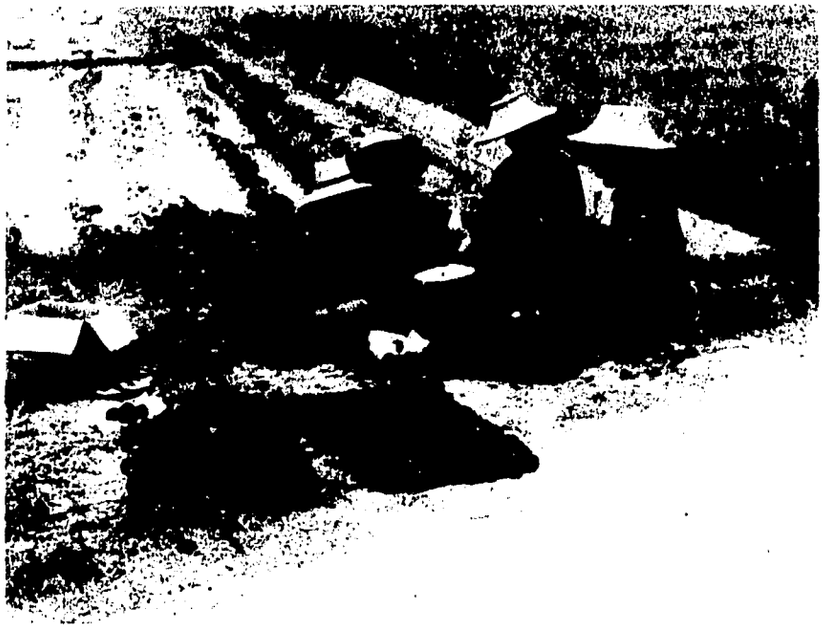
Fertilizers

We concentrated urea in small mudballs and placed them about 10 cm deep in the soil beside newly transplanted seedlings (fig. 13). Using mudballs, we produced 8 t/ha of rice with 60 kg of nitrogen per hectare, compared with 6.6 t/ha using 100 kg N/ha when applied as a topdressing (the system generally used by farmers in the Philippines) (table 3).

Fertilizer efficiency, or kilograms of grain produced per kilogram

Table 3. Higher increases in yield were obtained with 60 kg/ha of nitrogen when concentrated in mudballs and applied to the rice root zone, than with 100 kg/ha applied by the topdressing method used by farmers. IRRI, 1974 dry season.

Fertilizer rate (kg N/ha)	Yield (t/ha) when N applied as		Efficiency of N (kg rice/kg N)	
	Mudball	Topdressing	Mudball	Topdressing
60	**8.0**	5.8	53	23
100	8.4	**6.6**	38	21



14. Fertilizer being inserted into mudballs for experiments by the Thai Rice Division at the Suphanburi Experiment Station, Thailand.

of fertilizer added, was considerably higher using the mudball placement technique than using the traditional topdressing or basal applications (table 3). Concentrating the nitrogen and placing it deep enough in the paddy to prevent oxidation seems to reduce losses of this important nutrient.

The mudball technique has been tested not only at the IRRI farm but also in farmers' fields in the Philippines, and in India, Laos, and Thailand (fig. 14). Further tests are needed to fully exploit its practicality.

Insecticides

We further tested the root zone method of applying systemic insecticides in 1974. We used a modified grease gun to inject three insecticides into the root zone of young seedlings. Urea at the rate of 30 kg N/ha was concurrently injected into the root zone by the same procedure.

Only 1 kg/ha of insecticide applied in the root zone controlled insects as well as 8 kg/ha of carbofuran applied conventionally to the paddy water (table 4).

Carbofuran residues were low in the paddy water following root zone application. The concentration of the insecticide in the roots and shoots reached a peak at about 20 days after treatment, but declined

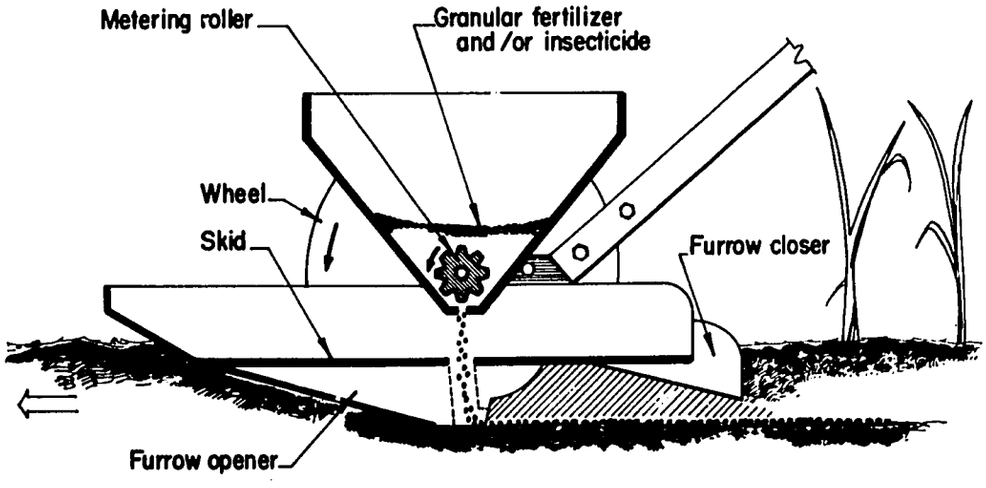
Table 4. The effect of three insecticides injected into the root zone along with a urea slurry (30 kg N/ha) on the yield of IR26. IRRI, 1974 wet season.

Chemical	Placement	Rate (kg a.i./ha)	Yield (t/ha)
Chlordimeform	root zone	1	4.5
Cartap	root zone	1	3.9
Carbofuran	root zone	1	4.2
Carbofuran	paddy water	8	4.3
Control	–	-	3.0

to a low level by 100 days. The efficiency of control was high during early growth and residual hazards were low in the harvested crop.

Application equipment

Despite the advantages of concentrating both nitrogen and systemic insecticides in the root zone, the labor required to produce the



15. The granular chemical applicator opens a furrow, deposits the fertilizer or insecticide below the soil surface, and closes the furrow.

Table 5. The relative yields of IR20 and Peta when lodging is permitted (as under field conditions) and when lodging is prevented under greenhouse conditions. IRRI, 1974.

Variety	Relative yields when			
	Lodging permitted (field)		Lodging prevented (greenhouse)	
	No N	High N	No N	High N
IR20	100	100	100	100
Peta	95	43	151	132

mudballs and to manually place the insecticides discourages their practical use.

We are developing inexpensive, manually operated machines to apply both fertilizer and insecticide (fig. 15). The chemicals are applied in a band below the soil surface between the new seedlings. Preliminary results are encouraging; we are now improving the machine and the placement technique.

We have had large pellets of combined urea and insecticide prepared that can easily be placed in the rice root zone. We will continue our experiments to fully exploit the potential of deep placement of agricultural chemicals.

Varietal yield potential at low fertility levels

We are reassessing the yield potential of different varieties at low fertility levels. We have found yield potential to be related to field resistance to lodging (the breaking of the stem or falling over as the plant approaches maturity). Because the traditional variety Peta lodges even at modest fertility levels, it yields poorly in the field. But when the plants are supported in the greenhouse to prevent lodging, Peta yields higher than widely grown IR20, especially at low fertility levels (table 5).

We are seeking means to incorporate the higher yield potential at low fertility levels of Peta and other traditional varieties into lodging-resistant modern varieties.

Research programs

GENETIC EVALUATION AND UTILIZATION (GEU) PROGRAM

Germ plasm conservation

Rice grows in remarkably diverse ecological and climatic conditions on every continent except Antarctica. One can find rice growing at altitudes of 2,400 meters (8,000 feet) in the Kashmir Valley; as a slash-and-burn hillside crop in Sarawak; in water 6 meters (20 feet) deep in the "floating rice" areas of Bangladesh; at least as far as north As Central Czechoslovakia (50°N) and as far south as New South Wales in Australia (35°S) and Uruguay.

16. Seeds are preserved in cold storage rooms of IRRI's germ plasm bank. Left to right are Dr. Te-Tzu Chang, geneticist, and Mr. Reynaldo Villareal, research assistant.

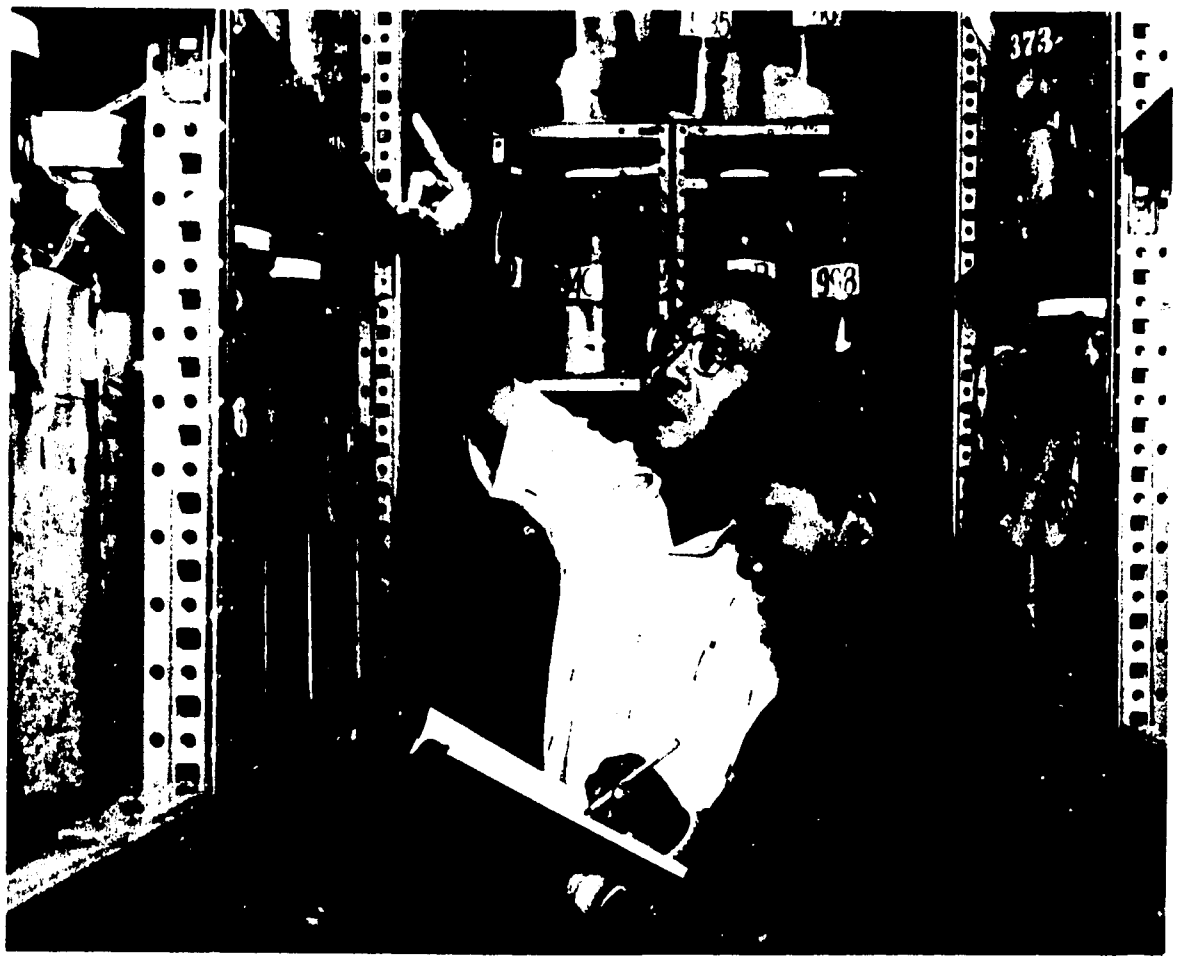


Table 6. More than 4,000 special types of rice varieties and wild taxa have been preserved in the IRRI germ plasm bank between July, 1972, and December, 1974.

Reported feature	Samples (no.)
Tolerance to salinity	124
Tolerance to acid soils (flooded)	150
Tolerance to alkaline soils	11
Upland types	2425
Floating types	518
High-elevation types	600
Resistance to nematodes	5
Escape from rodent damage	9
Aromatic types	89
Wild taxa	82
Total	4013

Scientists take advantage of this wide adaptation to combine, through plant breeding, desirable characters of rices from one area with those of other rices from half way around the world. But first, we must collect the seeds of diverse rices and conserve them so that their genes will be available for the testing and breeding programs. The collected seeds are catalogued and included in our germ plasm bank (fig. 16). Scientists in breeding programs in any nation can deposit and withdraw seeds of rices with outstanding genetic characteristics.

In 1974, almost 6,000 rices were added to the IRRI germ plasm bank. After duplicates and replacements were eliminated, 1,300 new accessions were actually entered. This brings the total number of accessions to about 35,000. The germ plasm bank also contains about 3,000 African entries, genetic testers, and wild taxa.

More than 3,000 varieties and lines were furnished by experiment stations from national rice collections in Asia, Africa, and Latin America. Major contributors were Japan and Bangladesh, but experiment stations in 10 other countries also entered rice varieties.

The IRRI field advisor on rice collection participated in field collection operations in Bangladesh, Burma, Indonesia, and Vietnam during 1974 and early 1975. About 1,400 samples were collected with IRRI's direct participation. Another 1,800 samples were gathered by national centers in five collaborating countries.

The IRRI director brought 38 cultivars on his return from a visit

to China as a member of a U.S. plant science exchange group.

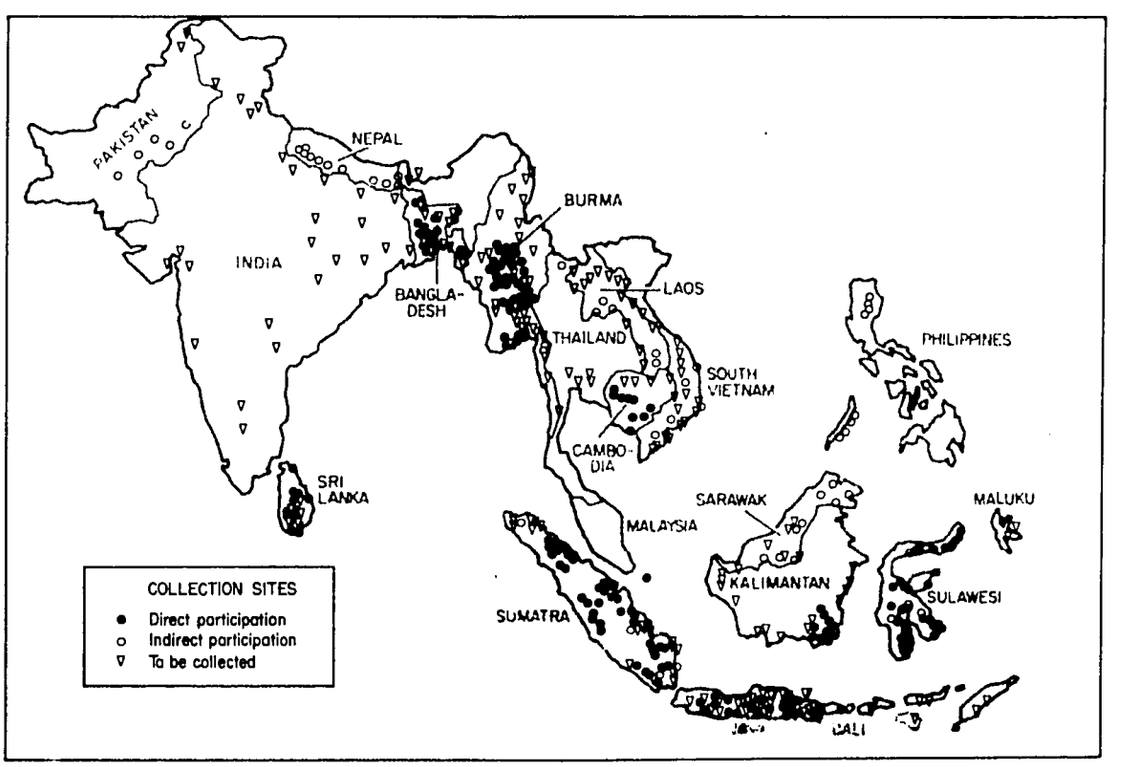
About 840 of the new samples are special types, bringing to almost 4,000 the rices collected in regions of particular environmental stress or with special characteristics that breeding programs need: cold-tolerant rices from the mountains, drought-tolerant rices from rainfed and upland areas, salt-tolerant rices from coastal regions; floating rices; and aromatic types (table 6).

As a service to national rice breeding programs, we sent 2,600 seed samples to 43 countries in response to 142 requests. We furnished 167 seed packets of wild taxa.

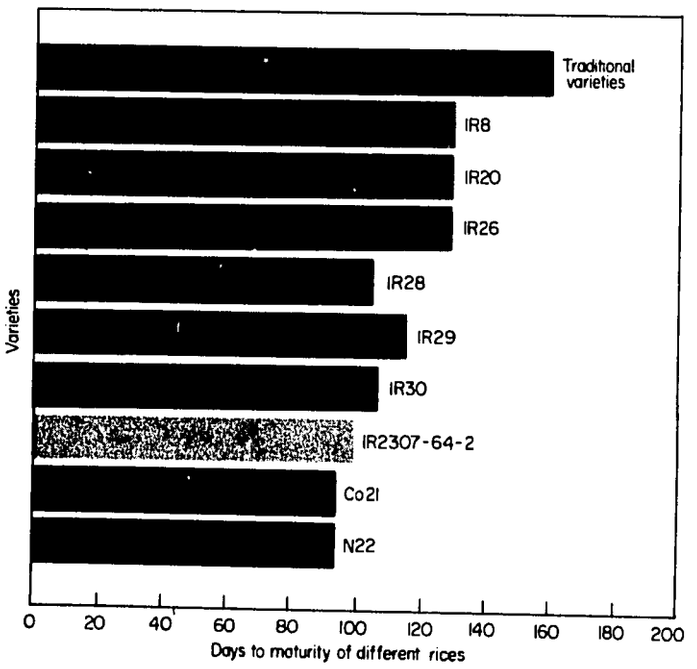
The number of seed samples supplied internally to IRRI scientists tripled in 1974, reflecting the increased emphasis on problem-oriented breeding through the GEU program.

Since IRRI began field collection in 1971, 12 Asian nations have collaborated on the genetic conservation program (fig. 17). Hundreds of African rices *(O. glaberrima)* were collected and supplied by collaborating institutions in West Africa.

17. Sites of past and future germ plasm collection.



Further collection and conservation of rice genetic resources carries a high priority. Seeds of the traditional rices are disappearing as they are replaced by improved varieties and by changing cropping patterns. While these traditional varieties generally are agronomically inferior to their replacements, any one of them may have one or more remarkable genetic characteristics – particularly genes that enable them to resist or tolerate local environmental stresses (such as drought or injurious soils). These genetic sources must be conserved. Our objective is to collect as many as possible of the 100,000 to 150,000 rices in the world before they are lost to future generations.



18. Most traditional rice varieties mature in 160 days or longer. IR8, IR20, and IR26 mature in 130 days; IR28 and IR30 mature in about 105 days. Some experimental lines such as IR2307-64-2 mature in about 100 days. Varieties with even shorter growth durations are being used in IRRI's breeding program.

Agronomic characteristics

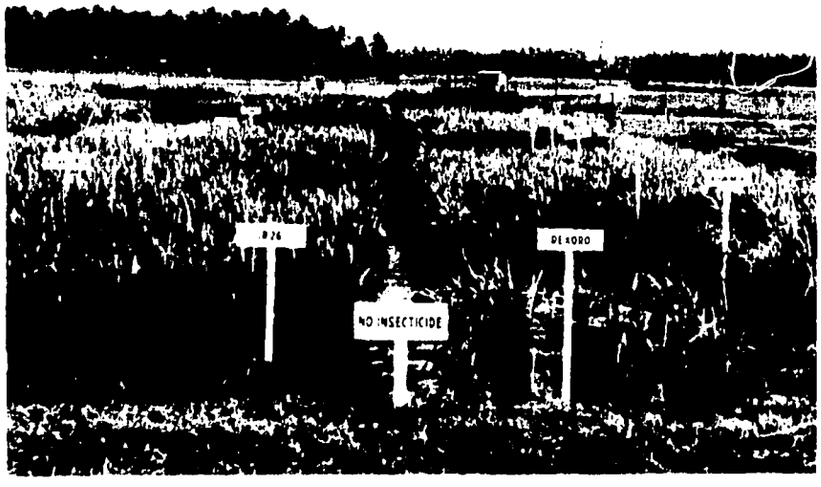
The potential to increase food production by double or triple cropping places increased emphasis on high-yielding rice varieties that mature early. Two of our recent varieties, IR28 and IR30, mature from 15 to 30 days earlier than other IRRI varieties, and about 2 months earlier than most traditional varieties (fig. 18).

But still earlier varieties are being sought; we are evaluating a few lines that mature from 4 to 5 days earlier than IR28 and IR30.

To reach the goal of 95- or 100-day varieties, we have crossed our early maturing lines with several early lines from China, India, and Bangladesh. We are selecting progeny for early vigor and rapid tillering ability.

We have also selected several lines of longer growth duration. We have crossed a photoperiod-sensitive line, IR1060-90-2, with our disease- and insect-resistant lines to develop high-yielding varieties that are sensitive to photoperiod.

Resistance to lodging remains a high priority, especially as we seek medium-statured varieties. Lines with excellent sturdy stems and lodging resistance are being crossed with lines that are resistant to major insects and diseases.



19. IR26 (left) has genetic resistance to a wide range of insects and diseases, so it grows well without pesticide protection. Rexoro and Taichung Native 1 (right) are susceptible and have been destroyed by rice pests. Genetic resistance decreases farmers' dependence on expensive pesticides.

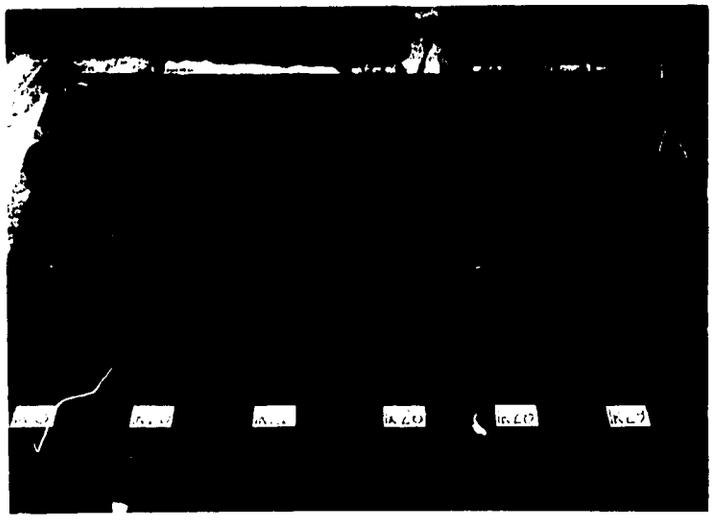
Resistance to insects and diseases

The first significantly improved rice variety that was resistant to insect pests was IR20, released in 1969.

IR20 spread rapidly during the Philippine tungro epidemic of 1971 because of its resistance to both tungro virus disease and its vector, the green leafhopper.

Similarly, IR26 is spreading fast today because of its even wider range of resistance (fig. 19), especially to most biotypes of the brown planthopper, which is becoming one of the most serious insect pests across Asia.

IRRI's newer varieties, IR28, IR29, and IR30, are resistant to brown planthoppers (fig. 20); highly resistant to grassy stunt virus



20a. The brown planthopper is becoming one of the most serious insect pests in Asia.

20b. These seedlings were caged with large numbers of brown planthoppers. IRRI's early varieties are susceptible but IR26, IR28, IR29, and IR30 are resistant.

disease (transmitted by brown planthoppers); and resistant to several other pests. In regions where they are suited, farmers are rapidly shifting to the more resistant varieties as they become available.

As the energy crisis forces up the price of pesticides, IRRI regards resistance to insects and diseases as essential – only pest-resistant experimental lines are considered for release as varieties. Concurrently, many national rice improvement programs are also adopting pest resistance as a breeding goal.

To identify newer and better sources of resistance to major insect and disease pests, IRRI entomologists, plant pathologists, and plant breeders continued to screen promising rice varieties and breeding lines from all over the world in 1974.

Screening for insect resistance. Entomologists and breeders on the GEU insect resistance team screened, crossed, and selected for genetic resistance to the following major insects: the brown planthopper, the green leafhopper, the white-backed planthopper, the striped stem borer, the yellow stem borer, and the whorl maggot (table 7).

We also tested almost 3,000 varieties and lines in field experiments during the dry season *without pesticide protection,* and nearly 2,000 during the wet season. Natural infestations of the following major pests were highest during these experiments: rice whorl maggots, stem borers, brown planthoppers, and accompanying virus diseases.

The most resistant rices identified in the field screening were retested for consistency of resistance in greenhouse and screenhouse trials.

Table 7. Rices identified by screening trials as resistant to various insect pests of rice.[a] IRRI, 1974.

Insect	Varieties or lines (no.)	
	Tested	Selected as resistant or moderately resistant
Brown planthopper (*Nilaparvata lugens*)	5499	202[b]
Green leafhopper (*Nephotettix virescens*)	2876	306[b]
White-backed planthopper (*Sogatella furcifera*)	2259	164
Striped borer (*Chilo suppressalis*)	664	10
Yellow borer (*Tryporyza incertulas*)	2504	56
Whorl maggot (*Hydrellia philippina*)	4898	155

[a]Excludes screening of early generation breeding lines: 32,075 tested against brown planthoppers and 14,848 against green leafhoppers. [b]On further retesting, 17 varieties were highly resistant to brown planthoppers and highly resistant to green leafhoppers.

The best rices were entered in the international screening nurseries for worldwide evaluation through the International Rice Testing Network.

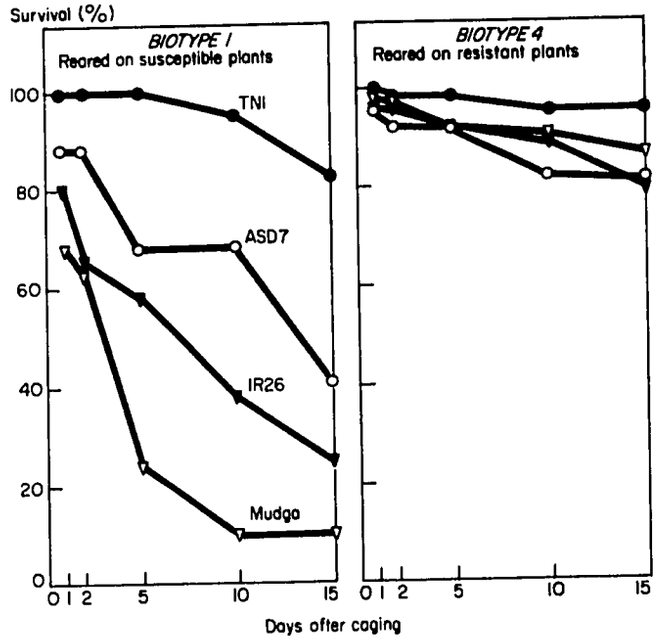
By intercrossing varieties that are moderately resistant to the striped borer, we have produced progeny that are more resistant than any of the parents.

We made similar crosses to build resistance against the rice whorl maggot, for which we have found no distinct varietal resistance, even after evaluating more than 10,000 varieties over the past 4 years.

Intensive experiments have revealed that IR1820-52-2 is moderately resistant to the yellow borer. Moths laid fewer eggs on it than on other test varieties; of the larvae that hatched, fewer survived. Yellow borer incidence on this line was lowest in both screenhouse and field experiments.

During 1974, we identified many additional varieties that are resistant to brown planthoppers. The resistance of some, such as Kentjana from Indonesia and Bathurst from Sierra Leone, appears to be of a different nature than that of earlier-identified resistant varieties. Although both Kentjana and Bathurst are only moderately resistant, they may provide alternative sources of resistance to Mudgo and ASD 7.

We are investigating the genetics of varietal resistance to insect



21. The natural brown planthopper population at IRRI (Biotype 1) suffers high mortality when caged on resistant varieties ASD 7, IR26, and Mudgo, but thrives on the susceptible variety Taichung Native 1. Biotype 4 has high rates of survival, however, when caged on resistant varieties. Biotype 4 evolved when insects were collected from areas intensively planted with resistant varieties and then reared for several generations on resistant varieties.

pests and whether the resistance is due to biophysical or biochemical factors, or to both.

Brown planthopper biotypes. When selected varieties that are resistant to brown planthoppers were evaluated in the International Rice Testing Program, we found that brown planthopper populations in Kerala state, southern India, and Sri Lanka appeared to be of different biotypes than those in the Philippines and many other countries. Varieties that possess monogenic dominant resistance (for example, Mudgo) or monogenic recessive resistance (for example, ASD 7) to the brown planthopper reacted as susceptible in Kerala and in Sri Lanka. Most of the varieties identified so far as resistant to the brown planthopper are indigenous to Sri Lanka and southern India.

We proved that different biotypes can develop by collecting brown planthoppers from fields planted with resistant varieties and then rearing them for several generations on resistant plants in a greenhouse. This led to the development of three new biotypes, including one that can survive on both ASD 7 and Mudgo (fig. 21). We are now using these biotypes to identify newer sources of resistance.

From these and other experiments, scientists hypothesize that if only a few pest-resistant varieties are planted intensively over wide areas, insect biotypes may develop through natural selection that can attack and feed on the formerly resistant varieties.

If the crop resistance is governed by a single pair of genes (monogenic or single gene resistance), the possibility increases that insect biotypes will develop that can survive – and even thrive – on formerly resistant plants. When the resistance is governed by two or more pairs of genes (multigenic or multiple-gene resistance), the possibility lessens. We plan to stress the combining of several sources of resistance to each insect or disease, whenever possible, into single varieties.

Screening for disease resistance. We have screened 10,000 accessions of the germ plasm bank for resistance to blast fungus disease. Many were evaluated not only in the Philippines but also in 29 countries through the International Blast Nursery. About 1 percent were found to have a broad spectrum of blast resistance and 0.1 percent had a *very* broad spectrum of resistance.

We tested 3,705 varieties from the germ plasm bank in 1974 to identify new sources of resistance. Almost 20 percent – 717 varieties – reacted as resistant in the first test. The more resistant will be tested internationally through the blast nursery.

Several varieties that have consistently shown very broad spectrums of resistance over 11 years of testing in 30 countries are Tetep, Nang Chet Chuc, Tadukan, Mamoriaka, Carreon, Ram Tulasi (Sel), C46-15, and Dissi Hatif.

We continued to evaluate a standard scale that scientists in different countries can use to uniformly assess and rate resistance to sheath blight disease in field trials. This will become increasingly important as more scientists join international testing programs.

We screened more than 5,000 varieties and breeding lines for sheath blight resistance in both dry and wet seasons. Although many varieties were moderately resistant, we found no variety that was highly resistant or immune.

Sixty varieties were screened in the second International Sheath Blight Nursery in eight Asian countries: Korea, Indonesia, Taiwan, Malaysia, Philippines, Thailand, India, and Sri Lanka. We received 14 sets of test results.

A few varieties reacted differently in different test locations. These are being re-evaluated to determine if different races of the pathogen may exist.

Some tall varieties that were broadly resistant in many countries are Laka, Ta-poo-cho-z, Kam Bau Ngan, 46 Palman, and Dular. Semidwarf lines with moderately broad spectrums of resistance are IR1542-30-2-4, IR1544-340-6-1, IR883-12-1-3, IR1529-680-3-2, and IR3273-67 P.

We screened about 10,000 new cultivars from the germ plasm bank over two seasons for resistance to bacterial blight. One hundred sixty-three new cultivars were considered strongly resistant.

The inheritance of resistance to bacterial blight in several varieties and breeding lines was investigated, confirming that a single dominant gene governs resistance in some varieties (such as TKM6, Sigadis, and W1263) and a single recessive gene in others (BJ1, DZ192).

We identified for the first time a single recessive gene that controls resistance in IR1698, a progeny of Zenith.

Results from 20 of the 22 cooperating scientists conducting the Third International Bacterial Blight Nursery showed that the Indian lines from RP633 had the broadest spectrums of resistance. Varieties such as IR20 and IR26 were moderately resistant in most countries.

Using the improved mass screening method in greenhouses, we tested about 380,000 seedlings of 15,460 entries for tungro virus resistance in 1974. A total of 278 IR selections were classified as resistant. We are developing a field cage method of tungro screening.

We tested 156,000 seedlings, representing 8,029 entries, for resistance to grassy stunt in 1974. Some IR selections showed resistant reactions even when tested 18 times: IR1704-3-2-3, IR1737-19-7-8-3, and IR2035-708-3.

Drought resistance

The development of drought-resistant or drought-tolerant varieties continues to receive high priority, not only for upland rice, but also for rainfed, non-irrigated rice. Our aim is to combine the drought tolerance of traditional varieties adapted to rainfed cultures with the high-yielding potential and pest resistance of modern rices.

We have found remarkable differences in the response of traditional varieties to drought, using both greenhouse and field techniques (table 8). Since 1971, more than a thousand crosses of drought-tolerant rices and improved breeding materials have been made; 800 in 1974.

Mass field screening. During the 1974 dry season, we screened more than 2,000 varieties and breeding lines from Asia, Africa, and Latin America in IRRI fields for resistance to drought.

Field resistance ratings were based on plasticity of leaf rolling and unfolding, death of leaves, degree of stunted growth, and effects on reproductive processes.

The largest proportion of drought-resistant varieties was found among the traditional upland rices from Africa, followed by those

Table 8. Variation in drought ratings of varieties and lines using three screening techniques. IRRI, 1974.

Variety/line	Stress in		
	Water table box[a] (comparative yield)	Field	
		Relative plant ht[b]	Visual rating[c]
M1-48	100	(71)	R
E 425	47	(78)	MR
OS4	29	(68)	R
Miltex	78	(73)	I
Palawan	2	(68)	MR
IR5	33	(63)	MR
Azucena	30	(64)	MR
IR442-2-58	0	(59)	I
IR1529-680-3	0	(54)	I
IR20	0	(51)	S

[a]Constant water table maintained in water table box at 45 cm below surface.
[b]Plant height under water stress relative to that under well-watered conditions.
[c]Rated by Plant Breeding Department: R-Resistant; MR-moderately resistant; I-intermediate; MS-moderately susceptible; S-susceptible.

from South America, and by hill rices from Laos. A good proportion of the early maturing varieties of Bangladesh were found resistant. The floating varieties of Southeast Asia were rated from moderately resistant to moderately susceptible.

Some early maturing and drought-resistant varieties that produced well-filled grains were N 22, Seratus Malam, Cartuna, Kap Nhay, Padi Tatakin, Rikuto Norin 21, Susono-mochi, Maligaya 5, Kinandang Patong, and Ba Djang Nhu.

Only a small percentage of the upland breeding lines that came from crosses of upland and lowland parents were found to be as drought resistant as the African upland parents (such as OS4).

Among the 567 breeding lines from upland nurseries, the largest number of resistant varieties came from crosses made in 1970 of African upland x semidwarf lowland rices.

Recovery from drought was recorded after watering the stressed plants. Most of the lowland varieties and lines recovered faster and to greater degrees than did the upland varieties and lines. We hope to combine drought resistance with the ability to recover from drought by further crossing and selection.

Performance in upland farmers' fields. During the 1974 wet season, we evaluated the performance of 81 experimental lines in upland

farmers' fields in Batangas province, Philippines, and in several other countries in Asia and Africa. We also evaluated them for field resistance to diseases and insects, agronomic characteristics, and yield potential.

The high-yielding experimental lines were selected from earlier yield and observation trials and installed in six sites across the Philippines. Included were three maturity groups: early, intermediate, and late. An unusually long dry spell during the growing season provided an excellent opportunity to evaluate the experimental lines for drought reaction.

The three early maturing lines that were exposed to drought and that produced the highest average yields in farmers' fields were IR661-1-170 (2.9 t/ha), followed by IR2031-729-3 (2.8 t/ha), and IR2035-227-1 (2.7 t/ha). IR1529-430-3, which produced the highest average yields (3.6 t/ha), had yielded highest among the 1973

Upland rice is seeded directly in rows and grown in non-bunded fields. Few significantly improved upland varieties are available for farmers.

entries, when the rainfall distribution was normal. Other high-yielding lines, which averaged about 3 t/ha, were IR1529-680-3, IR1529-677-2, IR1577-24-1, and IR2035-242-1.

Drought affected the late-maturing group most markedly. No line yielded better than the check, IR5.

At one of the Batangas test sites, two IR1750 lines (from African upland x IR20 crosses) produced 3.6 and 3.1 t/ha while the best local upland variety produced 1.9 t/ha.

Screening for drought tolerance. We developed a greenhouse technique to determine how different varieties respond to soil moisture stress at the early (vegetative) growth stage and at the later (reproductive) stage.

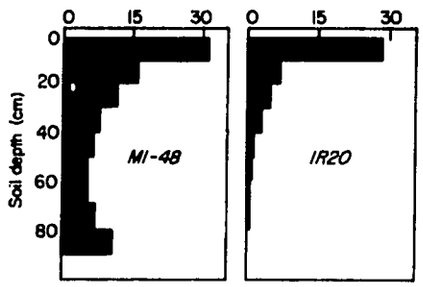
Under moisture stress during vegetative growth, the varieties matured a month later than the checks (which were not subjected to moisture stress). Plant height was reduced, but when relieved of moisture stress, the plants produced additional tillers and panicles that contributed to final yield. Early stress affected the percentage of unfilled grains in only a few varieties.

Moisture stress during the reproductive growth stage did not generally lengthen the maturity dates, but it did reduce yields of several lines by more than half. The promising lines are being further evaluated under field conditions.

Root studies. We compared the root systems of 25 rice varieties with those of sorghum and corn, two crops that are more drought resistant than rice. The root-to-shoot ratio of corn and sorghum was much higher than for the rices although the rices varied considerably in this trait (table 9). IR20, a drought-susceptible variety, had a very

Table 9. The root-to-shoot ratios of 25 rice varieties, one sorghum variety, and one corn variety. IRRI, 1974.

Root-shoot ratio (mg/g)	Designation
209	Sorghum (Cosor)
146	Corn (Early Thai Composite)
101–120	Rikuto Norin 21, Azucena, OS4, E425, Palawan, Dular, Azmil, M1-48
81–100	C22-51, IR442-2-58, 81B25, Miltex, IR5, IR8, Jappeni Tungkungo, PI 215936
60–80	TN1, NARB, Bluebonnet, Peta, IR841-67-2, IR127-80-1, IR1529-680-3, H4
49	IR20



22. The drought-resistant variety M1-48 has a higher root to shoot ratio and a higher proportion of deep roots than a more drought-susceptible variety, IR20.

low root-to-shoot ratio while a number of drought-resistant upland varieties had ratios approaching that of corn.

Drought-resistant varieties also had more deep roots and their roots tended to be thicker than the susceptible ones (fig. 22). The root distribution technique has been standardized and will be used to screen several hundred rices annually.

In general, tall rices tend to have larger and more extensive root systems but some short-statured rices also have extensive systems. This suggests that it should be possible to breed relatively short-statured rices with good root systems and with high drought resistance.

Tolerance to adverse soils

Adverse soils prevent the new varieties from delivering their full potential yields on about 40 million ha of rice land in the tropics.

Another 40 million ha, climatically and physiographically suited to rice, lie uncultivated largely because of soil problems, including salinity, salinity-alkalinity, alkalinity, iron toxicity, toxicity of acid-sulfate soils, zinc deficiency, phosphorus deficiency, and the low productivity of peat soils.

With increasing population pressures, the rice-growing nations cannot afford to let these lands remain low in productivity or idle.

Because improving these lands by chemical amendments or by water management is too expensive for most developing countries, we are selecting and breeding for tolerance to the adverse soil conditions as a component of the GEU program.

During 1974, soil chemists and breeders refined a technique for screening large numbers of plants for salt tolerance. We screened 343 varieties and selections for tolerance to salinity, alkalinity, iron toxicity, zinc deficiency, and phosphorus deficiency (table 10).

The complexity of the evaluation and breeding for problem soils

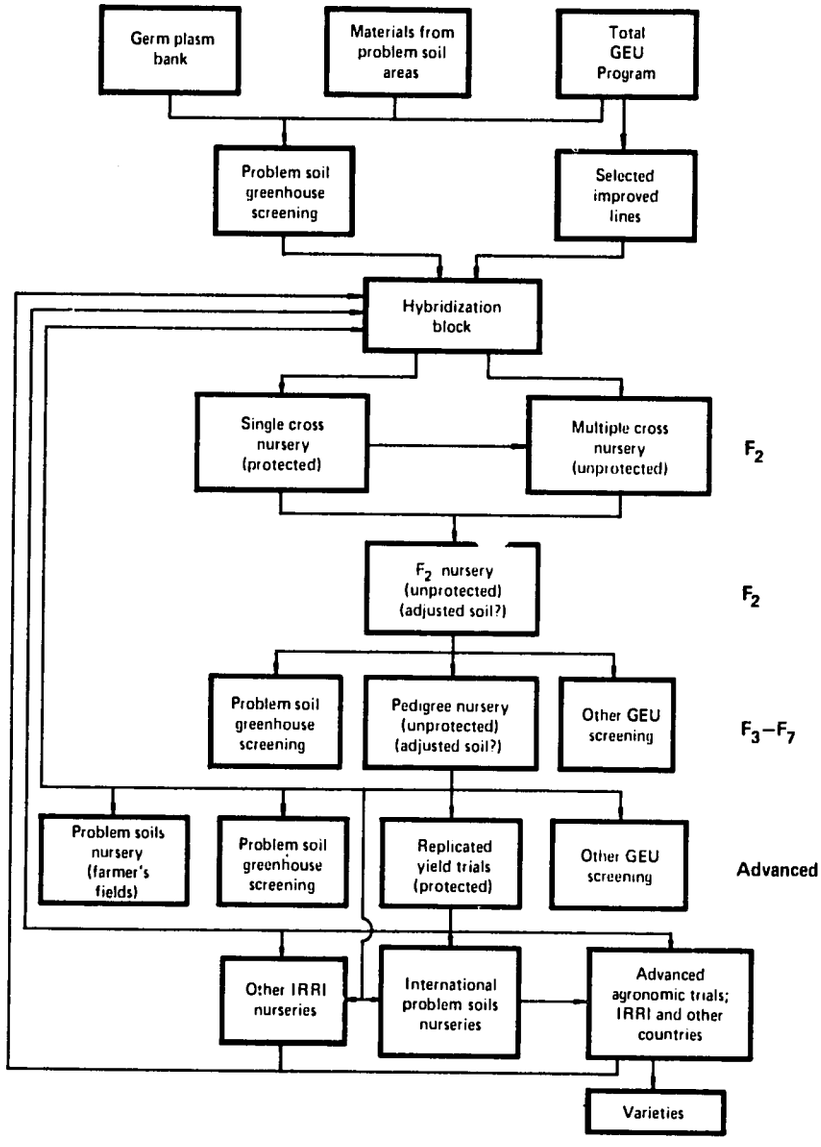
Table 10. Sources of tolerance to soil problems. IRRI, 1974.

Soil problem	Sources of tolerance
Salinity:	BR4-10, Gottelu, Kalarata 1-24 (Karjat Research Station), Muskkan 7, Nona Bokra, SR 26 B (Acc. 5908), Pokkali (Acc. 26869).
Alkalinity:	Pokkali (Acc. 26869), Benzer
Zinc deficiency:	IR30, IR2153-14-1, IR2153-15-1, Pokkali.
Phosphorus deficiency:	IR20, IR26, IR28, RD1, IR2061-214-2.

is illustrated by figure 23, which shows the flow of genetic materials through the steps needed to produce a new variety.

Salt tolerance. We emphasized salt tolerance in the GEU program because salinity is the most extensive soil problem. During 1973, we made numerous crosses with Pokkali, a low-yielding variety that farmers plant in coastal regions of India and Sri Lanka because it

Dr. W. Ronnie Coffman (left), associate plant breeder, and Dr. Felix N. Ponnamperuma, soil chemist, screen rices for tolerance to adverse soils in the IRRI greenhouses, in plots of injurious soils on the IRRI farm, and in farmers' fields.



23. Flow of genetic materials through IRRI's GEU program to develop varieties adapted to adverse soils.

tolerates salinity and several other injurious soils. Pokkali has been a poor combiner, but we were able to select some salt-tolerant progeny of satisfactory agronomic type.

We refined and simplified the technique for screening varieties for salt tolerance. Of 48 reportedly salt-tolerant varieties screened, only

seven actually tolerated salinity. The lines IR2153-26-3-5, IR2153-43-2-5, and IR2035-290-2 tolerated salinity better than other improved varieties or lines tested.

The salt-tolerant IRRI lines are resistant to most of the major diseases and insects, and thus are potential varieties. But because they are all semidwarfs, they would not be suitable for most coastal saline areas where the water is too deep. We are making crosses with taller varieties for these coastal saline areas.

Alkalinity. Alkaline soils limit yields or prevent rice from being grown in many arid regions recently brought into production by irrigation in India, Pakistan, Iran, and other countries.

Twenty-four selections or varieties were tested for alkali tolerance in the greenhouse. Pokkali and Benzer were tolerant; IR2151-918-2, IR2153-96-1, IR30, IR2153-247-1, IR2153-276-1, and Kangni Torh were moderately tolerant.

In an outdoor replicated test in concrete tanks, Pokkali, IR2031-114-2, and M1 273 were least injured.

In a replicated field test in alkalized Maahas clay (pH 8.7) Pokkali and IR26 performed best.

Iron toxicity. Excess water-soluble iron limits rice yields on millions of hectares of strongly acid oxisols and acid-sulfate soils. Built-in tolerance to iron toxicity would be a boon to the poor people who grow rice on these soils.

We planted 2-week-old seedlings of 22 varieties or selections on a strongly acid oxisol that builds up more than 400 ppm iron in the soil solution a few weeks after submergence. Four weeks later, we scored the plants according to the severity of symptoms and found the following to be tolerant – Pokkali, IR30, IR2151-190-3, and IR2153-96-1.

Zinc deficiency. Zinc deficiency occurs on alkali and calcareous soils and on continuously wet soils. In the Philippines alone, about 500,000 ha of soils have this nutritional disorder. About a third of the rice area of India and Pakistan is believed to exhibit some zinc deficiency. Varietal tolerance may be a simpler remedy than applying zinc to the soils or plants.

Using plant symptoms and yields relative to those of zinc-treated plants as our basis for comparison, we screened 100 varieties and selections in pots in screenhouse. IR28, IR29, and IR30 were as tolerant as were 10 experimental lines.

In an outdoor replicated test of 16 varieties on a zinc-deficient soil in concrete tanks, only IR1514A-E666 was tolerant.

Field tests of 20 entries at three locations in Laguna province, Philippines, indicated that IR20, IR1514A-E666, and IR2031-238-4 were tolerant.

Phosphorus deficiency. Phosphorus deficiency limits rice yields on millions of hectares of ultisols, oxisols, and vertisols. Because most of these soils are found in poor countries where farmers cannot afford to use large amounts of fertilizers, we are searching for varieties that can exploit and utilize soil phosphorus more efficiently than others.

We grew 15 varieties or lines in a phosphorus-deficient ultisol (pH: 4.9; Olsen P: 1.2 ppm) in an outdoor trial. IR20, IR26, IR28, IR1514A-E666, IR1529-680-3, and IR2061-464-2 were tolerant.

In a replicated yield trial, we grew 30 varieties and experimental lines with and without 25 kg P/ha, over a basal dressing of N and K, on a phosphorus-deficient soil at Pangil, Laguna province, Philippines. Some varieties yielded more than 4 t/ha with no phosphate fertilizer, and yielded from 33 to 50 percent more when phosphate was applied.

IR26, IR2061-214-2, IR1529-680-3, IR944-102-2, and RD2 were classified as tolerant.

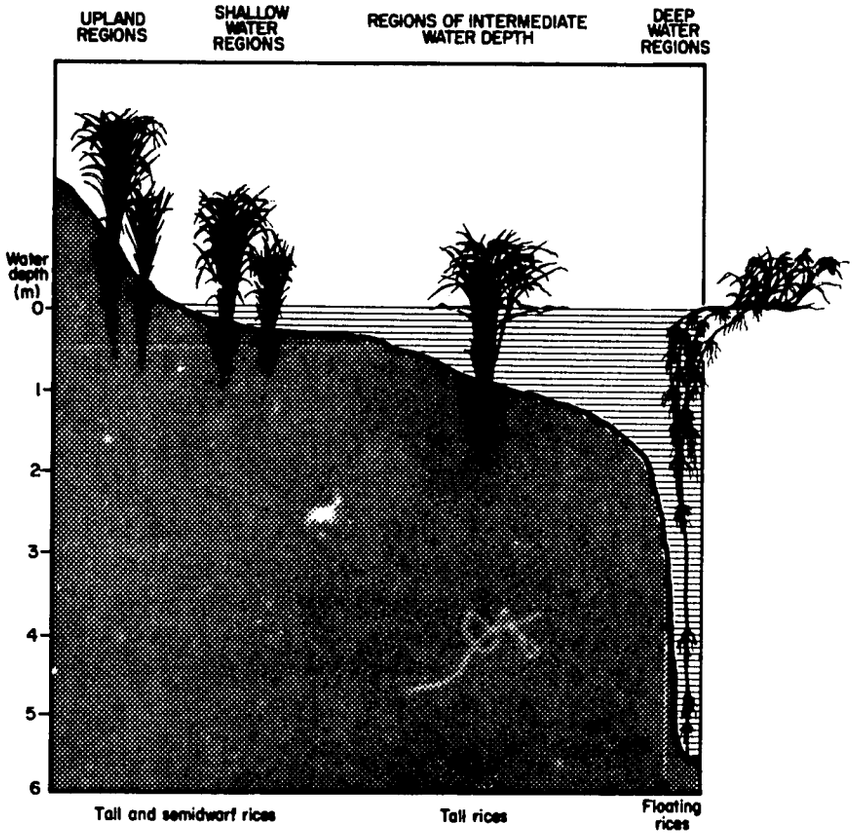
Deep water and flood tolerance

The new rice technology has bypassed the vast regions where farmers cannot control the water, and where water becomes too deep during the monsoon season for the semidwarf varieties. Estimates of such areas range from 25 to more than 40 percent of the world's rice land (fig. 24). Included in the deep water regions are the densely populated valleys and deltas of the mighty rivers of Asia – the Ganges, the Brahmaputra, the Godavari, the Irrawaddy, the Chao Phraya, and the Mekong. Only low-yielding indica varieties, tall enough to grow in deep water and to survive most floods, are available to farmers in these areas.

In the deepest areas, where water normally reaches from 1 to 6 meters, farmers grow special "floating" rice varieties. Over centuries, these varieties have developed genetic mechanisms that enable them to grow normally in deep water and to escape flood submergence – thier stems elongate as waters rise. But their yields are low.

About 10 percent of the rice land in Asia and Africa is planted in floating rices; another 20 or 30 percent is in tall non-floating varieties adapted to medium-deep water.

So far, the improved rice technology has not generally helped farmers in these areas; their yields have remained stagnant for decades or longer at 1 or 2 t/ha.



24. The world's rice land classified by water regimes and predominant rice types.

International cooperation. Improvement of the deep water and floating rices in the past was generally limited to identification of the better local strains. But today IRRI is working with scientists in India, Bangladesh, Thailand, Vietnam, and Indonesia to cooperatively develop improved varieties and cultural practices for the areas of deep water.

In 1974, we joined with the Ministry of Agriculture in Thailand in an expanded program of deep water rice research. Headquarters for the joint research effort is at the Huntra Deep Water Rice Research Center, 100 km north of Bangkok. Research is being done at the station and in cooperation with nearby farmers. Promising genetic materials developed at Huntra, at IRRI headquarters in Los Baños, and through national breeding programs will be shared with other rice improvement programs around the world.

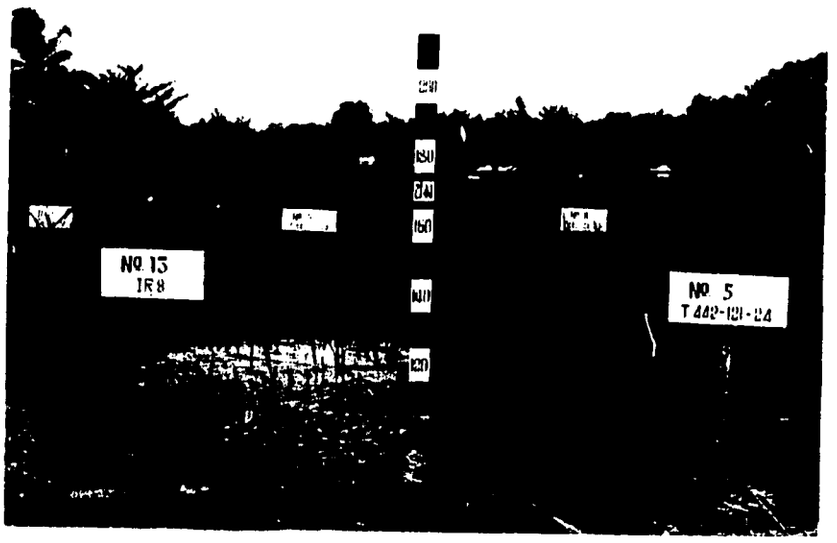
We co-sponsored an International Seminar on Deep Water Rice at the Bangladesh Rice Research Institute (BRRI) in August, 1974 (fig.

25a. The first International Seminar on Deep Water Rice was held at the Bangladesh Rice Research Institute. Bangladesh Minister of Agriculture Dr. Abdus Samad Azad (right) predicted that high-yielding varieties suited for regions of deep water would contribute to a higher standard of living for millions. Left to right are: Dr. David Catling, team leader, cooperative IRRI-Bangladesh project; Dr. Antonio T. Perez, IRRI field advisor for germ plasm collection; and Dr. Benito S. Vergara, IRRI plant physiologist.

25b. Flood waters covered two-thirds of Bangladesh, destroying much of the rice crop during the weeks prior to the deep water rice seminar. During helicopter and boat field trips, the scientists observed fields where semidwarf and even tall indica rices were submerged and killed, while floating rice in adjacent fields survived because it elongated to escape flood submergence.

25). Groundwork for future cooperation among researchers working on deep water rice was set at this seminar.

Screening for deep water tolerance. Rices suitable for deep water and flood tolerance must elongate rapidly as the water rises (fig. 26) and must tolerate submergence in water for at least short periods of time. By December, 1974, we had screened 1,126 varieties to obtain information on these two characteristics.



26. The experimental line T442-121-24, a progeny of a cross of floating and semidwarf rice parents, elongates with rising water. It grows well in water more than 110 cm deep, while IR8 is completely submerged and killed, at the Huntra Deep Water Rice Research Center, Thailand.

We measured the rate of elongation of 20 varieties by completely submerging 40-day-old seedlings for 5 days. We recorded as much as 31 cm internode elongation during the first day (table 11).

In other experiments, 144 varieties were screened for survival when submerged in deep water for 7 days. The internode length of 24 of these varieties increased by more than 40 cm. One variety, Habiganj Deep Water 1 from Bangladesh, elongated 70 cm during the 1-week period.

We compared the submergence survival of 479 varieties with that of a standard check, Nam Sagui 19 from Thailand. Eight of them

Table 11. Varieties with rapid rates of internode elongation (selected from 20 varieties tested). IRRI, 1974.

Variety	Increase in internode length (cm)			
	24 h[a]	48 h	72 h	120 h
Boon Nahk	13	27	34	43
DW 6255	17	40	35	45
HBJ DW 8	27	35	46	44
Leb Mue Nahng 111	23	32	38	51
Nang Dum To	20	34	32	47
Khao Hawn	31	36	40	48
Nak Neva	24	39	36	46

[a]After submergence.

Table 12. Tolerance to submergence. Of 479 varieties submerged in water for 7 days at the seedling stage, eight had survival rates as high as the submergence-tolerant check variety, Nam Sagui 19, used as the basis for comparison. IRRI, 1974.

Comparative survival[a] (%)	Varieties (no.)
0–25	414
26–50	39
51–100	18
100 +	8

[a]Comparative survival (%) =

$$\frac{\text{Survival (\%) of a variety}}{\text{Survival (\%) of Nam Sagui 19}} \times 100.$$

survived fully as well as the check variety (table 12). These will be used in our crossing program to incorporate tolerance to periods of total submergence into higher yielding varieties with resistance to insects and diseases.

Tolerance to extreme temperature

Both cold and hot climates limit the adoption of improved varieties across the rice-growing world. Low temperatures are probably the

Rice terraces at high altitudes in the Himalaya mountains, Nepal.

greater limiting factor. We are just beginning to study the effects of heat stress on rice

Cold tolerance. In mountainous regions of the tropics, and in the temperate rice-growing zones of the world, cold weather is a problem. On about 7 million ha in South and Southeast Asia alone, improved varieties cannot be grown because of low temperatures. This includes rice-growing valleys in Kashmir, Nepal, Pakistan, Indonesia, and the northern Philippines.

In 1974, we screened rices for cold tolerance in farmers' fields in the mountains, in special cold water tanks, and in cold growth rooms in the IRRI phytotron. We selected a steep area in Benguet, Mountain Province, Philippines, to study how varieties respond to cold temperatures and to identify plant characteristics to determine cold tolerance during the vegetative and reproductive stages of growth.

We planted a set of eight varieties at three sites: 1,210 m (3,819 ft), 1,070 m (3,461 ft), and 1,015 m (3,391 ft). This set was also planted at the IRRI farm and in phytotron cold rooms.

We measured the following physiological reactions: tiller number, plant height, panicle exsertion, sterility, grain yield, and growth duration.

We found that plant height seems to be the easiest and most consistent character to determine cold tolerance.

At 36 days after transplanting, China 1039, from Kashmir, was the tallest variety at the three sites in Benguet; at low temperature regimes in the phytotron; and in Los Baños fields.

The growth durations of the eight varieties were markedly greater at low temperatures than at higher Los Baños temperatures (table 13). We found that the minimum temperature of a locality better indicates the delay in growth duration than does the average daily temperature.

The Kashmir variety China 1039 was most impressive, requiring only 137 days from seeding to harvest at Benguet. It also matured earlier in Los Baños fields and in cold growth rooms of the IRRI phytotron.

Plant breeding for cold tolerance. During the 1974 dry season, we evaluated 826 varieties and breeding lines for maturity, fertility, and agronomic traits, and grew 23 F_2 populations in Benguet province. During the wet season, we evaluated 841 varieties and lines and grew 16 F_2 populations. Temperatures were about the same in wet and dry seasons, averaging 23°C and ranging from 16° to 29°C. Several typhoons severely damaged the nursery, making evaluation and selection difficult.

Table 13. Growth durations of eight test varieties grown under different temperature regimes[a] on farmers' fields at elevations of above 1,000 meters in Benguet, Philippines; in Los Baños fields; and in the IRRI phytotron. Cooperative experiment, Philippine Bureau of Plant Industry and IRRI, 1974.

Designation	Origin	Days from seedling to harvest in				
		Benguet (27.5°/15.7°C)	Los Baños (32°/25.6°C)	IRRI phytotron		
				32°/24°C	26°/18°C	20°/20°C
China	Kashmir	137	96	100	118	102
Fujisaka 5	Japan	137	98	97	108	103
Bengawan	Indonesia	181	142	152	156	154
IR8	IRRI	181	126	130	160	141
M1-48	Philippines	158	123	122	143	128
IR24	IRRI	158	119	119	147	130
IR667	Korea	158	107	111	130	124
Kulu	Australia	158	106	120	149	125

[a]Day/night temperature regimes.

The materials were concurrently evaluated at IRRI for resistance to blast and bacterial blight diseases, tolerance of cold water, and various grain quality characters.

We selected 56 of the more promising varieties and lines and, cooperatively with the Philippine Bureau of Plant Industry (BPI), evaluated them during the 1974 wet season in the ancient Ifugao rice terraces of Banaue, Ifugao province, Philippines (fig. 27). Elevation is 1,200 m (3,876 ft).

We identified several cold-tolerant varieties and lines of suitable growth duration – short enough to permit, for the first time, the cultivation of two crops per year (table 14).

These will be further evaluated on farmers' fields in the rice terraces during the 1975 wet season, and in other nations through the International Rice Cold Tolerance Nursery.

We continued to collect the better varieties and breeding lines from areas of cold temperature and to cross them with improved material at IRRI. Seed of 81 F_2 populations was available for distribution to requesting cooperators in national programs at the end of 1974.

Heat tolerance. High sterility has been reported in dry-season lowland crops in Cambodia, Thailand, and India. The same problems may occur in other countries where high temperatures and low relative humidities prevail during the dry season such as Pakistan, Iran, and countries of West Africa.

opposite page

27. Rice varieties being screened for cold tolerance and growth duration on farmers' fields on the ancient Ifugao rice terraces of northern Luzon, Philippines. Left to right are: farmer-cooperator; Mr. Agapito Ronduen, agronomist, Philippine Bureau of Plant Industry; Dr. W. Ronnie Coffman, IRRI associate plant breeder; and Mr. Sirdam, plant breeder, Central Research Institute for Agriculture, Bogor, Indonesia.

Table 14. China 1039, an early maturing, cold-tolerant variety developed in Kashmir, was the most promising selection (from 56 entries) grown on the rice terraces at Banaue, Ifugao province, Philippines. Cooperative experiment, Philippine Bureau of Plant Industry (BPI) and IRRI, 1974 wet season.

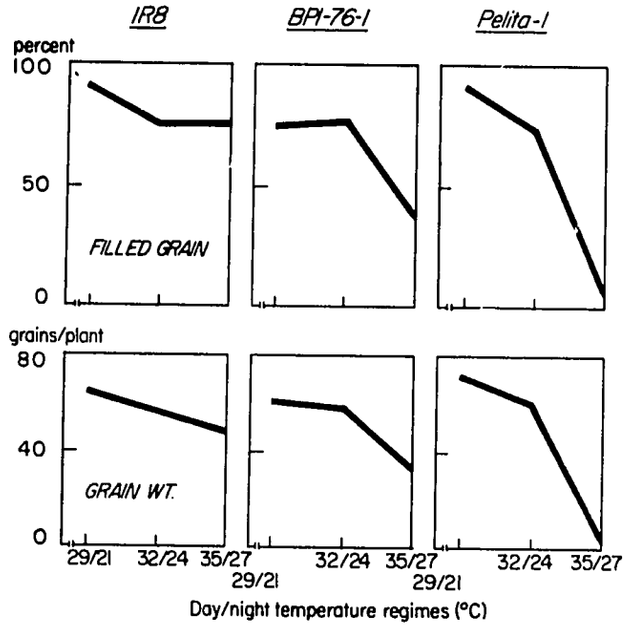
Designation	Origin	Tillers (no.)	Plant (cm)	Days to heading	Panicle exsertion (cm)
China 1039	Kashmir, India	11	85	84	3.0
Claket 520	Indonesia	9	67	87	2.5
JP 5	Pakistan	12	78	76	5.8
Kn-1h-214-1	Indonesia	7	83	90	1.5
Kn-1h-361-1-8	Indonesia	10	87	90	0.6
Sug	Kashmir, India	10	82	56	5.0
Kn-1b-361-1	Indonesia	10	78	87	1.3
Kn-1b-361-18	Indonesia	9	78	87	2.0
Kn-1b-361-B1K-2	Indonesia	8	76	87	2.8
Kn-1b-361-B1K-13	Indonesia	11	84	87	2.0
Kn-1b-361-B1K-22	Indonesia	11	83	92	1.1
Kn-1b-361-B1K-27	Indonesia	9	85	89	2.0
IR1846-300-1	IRRI	13	81	87	1.8
IR1846-314	IRRI	13	86	82	0.6
Fujisaka 5	Japan	12	56	86	3.0

To investigate effects of high temperature on rice, we grew 10 varieties at three temperature regimes in the glasshouse rooms of the phytotron. These varieties cover a wide geographic distribution from 43°N (northern Japan) to the equator (Indonesia). The three day/night temperature regimes used were 29°/21°C, 32°/34°C, and 35°/27°C.

The response of three varieties of these temperature regimes is shown in figure 28. Spikelet numbers were relatively unaffected by temperature differences. But the percentage of filled grain and grain weight per plant were greatly reduced by the higher temperatures. IR8 seemed relatively unaffected by the higher temperatures.

Grain quality

Amylose, a component of starch, partly determines the eating quality of rice. High-amylose rices, such as IR8, cook up light and fluffy, but the grains tend to harden as they cool. Low-amylose rices, such as



28. Higher temperature regimes significantly reduced the percentage of filled grains and the grain weight per plant of the varieties BPI-76-1 and Pelita-1 in the IRRI phytotron. IR8 was affected less.

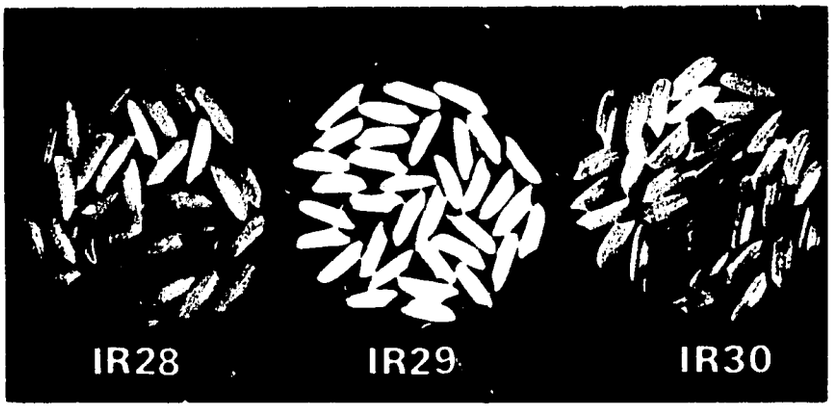
IR24, are sticky and soft when cooked.

IRRI surveyed Asian consumers and found that most prefer rice of intermediate amylose content (20-25%). These rices cook moist, with grains that separate easily, but that do not harden. Because amylose content is under genetic control, the GEU grain quality team (fig. 29), composed of breeders and cereal chemists, uses rices such as the Philippine variety C4-63 and BPI 121-407 in the crossing program, to incorporate superior grain quality and intermediate amylose content into future varieties.

But consumer preferences vary from region to region, so a range of rices with different amylose levels are also being developed.

Several breeding lines from crosses of BPI 121-407 have an improved plant type and intermediate amylose content but lack resistance to one or two of the important rice diseases or insects. These lines were used extensively in the hybridization program during 1973 and 1974. F_3 progenies from several of these crosses were evaluated during 1974 and were found to have intermediate amylose content as well as combined resistance to major diseases and insects. We hope that high-yielding varieties with intermediate amylose content will be available within a few years.

29. Dr. Bienvenido Juliano, cereal chemist (left), and Dr. Gurdev S. Khush, plant breeder (right), of IRRI's grain quality team working in the grain quality laboratory.



30. The grains of IR28 are long, slender, and translucent. IR29 is the first IRRI variety with glutinous or waxy grains. IR30 has medium-long, slender, and translucent grains.

We have also started to screen breeding lines for gel consistency. All the breeding lines with low and intermediate amylose contents screened so far have soft gel consistency.

But high-amylose lines may have either soft, intermediate, or hard gel consistency. Because most of our breeding lines have high amylose content, we have screened them and identified many with soft or intermediate gel consistency. Several advanced lines of the crosses IR2070, IR2071, IR2151, and IR2153 have soft gel consistency.

Eating quality of IR28, IR29, and IR30. The eating quality of IR28 is comparable to that of IR22. IR28 has long, slender, and translucent grains (fig. 30). Its high amylose content and high gel consistency make it cook light and fluffy.

IR30 has soft gel consistency and is likely to gain wide consumer acceptance. It has high amylose content.

IR29 is the first IRRI variety with glutinous or waxy grains. Glutinous rice cooks soft and sticky. It is the staple food in Laos and northeast Thailand, and is used in special preparations, such as cakes and pastries, across Asia.

Increasing protein content

The world's affluent obtain vital protein through foods such as meat, eggs, and dairy products, but millions of the world's poor get most of their protein through rice. Any increases in the protein content of rice could affect millions.

Although the grains of most rices contain 7 percent protein, some are significantly higher. IRRI's chemists, plant breeders, statisticians, geneticists, and agronomists work on the GEU protein team toward a goal of increasing that level by 2 percentage points – from 7 percent up to 9 percent.

In 1974, breeders and agronomists evaluated 437 varieties and lines for protein content during the dry season and 368 during the wet season. Some of these lines with good yielding ability and pest resistance have significantly higher protein contents than existing varieties (table 15).

The elite lines IR2031-724-2 and IR2153-338-3 performed consistently well in both seasons at two levels of added nitrogen fertilizer and two levels of management. They yielded at least as high as IR20, and had about 1 percentage point higher content of grain protein. The only major weakness of IR2031-724-2 is susceptibility to tungro virus disease; IR2153-338-3 is at least moderately resistant to all major pests.

Statisticians and breeders have determined "protein per seed" to be

Table 15. Promising breeding materials with brown rice protein contents at least 15 percent above that of IR20 and with yields at least equal to IR20. Wet and dry season average, IRRI, 1974.

Variety/line	Protein index	Yield index
BRJ1-5-B-7	122	104
IR480-5-7	121	109
IR2003-P3-3	124	100
IR2003-P16-7	119	104
IR2006-P12-12	120	112
IR2016-P-7-4	122	101
IR20 (check)	100	100

a promising criterion for selection in rice pedigree nurseries based on studies of F_3 seeds of the cross IR480-5-9 x IR1514A-E588 and of the 1974 replicated yield trials. Heritabilities associated with "protein per seed" were considerably higher and more stable than those associated with percent of brown rice protein. The studies imply that selection based on "protein per seed" is better than selection based on percent protein.

Agronomists applied defoliants to accelerate leaf senescence to determine if this would stimulate nitrogen transport from the leaves to the developing grains, thereby increasing protein content. The defoliant increased the grain protein content but unfortunately decreased the yield.

We found that the rate, time, and method of applying fertilizer all affect the protein content of rice (table 16). Highest protein levels were obtained when the fertilizer was applied in split doses.

A study of enzymes of nitrogen metabolism in rice seedlings showed that they reached maximum levels per gram of fresh shoot or

Table 16. The effect of method of applying fertilizer on the average contents of brown rice protein of nine varieties. IRRI, 1974.

Nitrogen (kg/ha)	Method of application	Protein content[a] (%)		Yield (t/ha)	
		Dry season	Wet season	Dry season	West season[b]
0	-	7.8	7.0	4.1	3.9
150	Basal	8.7	8.7	7.6	4.9
150	Split[c]	9.4	9.4	7.8	5.2

[a]LSD (5%) = 0.6%. [b]Eight varieties. [c]70 kg/ha basal, 40 kg at 30 days after transplanting, and 40 kg at panicle initiation.

root at 7 to 10 days after germination. Rices that differ in grain protein content were verified to have similar levels of enzymes, indicating that reliable biochemical criteria for selecting grain protein are not applicable at the seedling stage.

High protein content *per se* was found not to be the major cause of the lower eating quality of a high-protein variety from Korea. This finding substantiates previous taste-panel evaluations of cooked rice of high- and low-protein sister lines.

Feeding trials using both raw rice in rats and cooked rice-based diets in preschool children indicated that the nutritional quality of the protein in high-protein rices was as good as that in ordinary rices.

MANAGEMENT OF PESTS

Disease control and management

We identified and classified 26 new pathogenic races of blast fungus disease *(Pyricularia oryzae)* in 1974, bringing the total number of races identified to 255.

We began to study how climatic factors, such as temperature, length and degree of wet period, and relative humidity, affect the disease in the tropics. We found that longer wet periods at lower temperatures favored infection (table 17). Relative humidity did not affect colonization too much, although 85 percent RH was more favorable to the fungus than 50 percent.

We confirmed that rice plants grown in dry soil (50 centibars) and in very dry soil (75 cb) are more susceptible to blast than those grown under flooded conditions. The length of dew period was considerably greater under upland conditions (13 hours) than under lowland conditions (11 hours). The longer dew period may explain why blast is so common in upland rice.

In 1973, we first observed a particularly virulent strain of the bacterial blight pathogen, *Xanthomonas oryzae*, in Isabela province,

Table 17. Effect of temperature[a] and length of wet period on infection rate of blast fungus disease on the variety KTH 17, IRRI, 1974.

Wet period (h)	Blast lesions[b] (no./100 leaves)			
	21°/22°C	26°/28°C	32°/34°C	36°/37°C
4	0	0	0	0
8	49	46	4	3
12	285	116	12	4
24	1133	552	36	10

[a]Day/night temperature regimes in phytotron growth room. [b]Types 3 and 4.

Philippines. It partially breaks down the resistance of IR20 and other varieties that are resistant through dominant genes.

When we studied the more aggressive strain under field conditions in Isabela, however, we found that it did not cause significant loss and does not presently appear to be a threat. Varieties with the recessive gene for resistance to bacterial blight (BJ2 and DZ192) remained resistant to this virulent strain.

We continued to study the epidemiology of tungro disease in 37 farmers' fields in Luzon, Philippines. Conditions tended to favor a tungro outbreak in Central Luzon in 1974 as populations of the insect vector, the green leafhopper *(Nephotettix virescens)*, increased gradually until June. But extensive chemical control and heavy rains in August cut down the hopper population and no outbreak occurred.

We found that the transmission of tungro virus by green leafhoppers decreased when the temperatures were low because the insects' infectivity markedly decreased.

We artificially transferred insects from seedling to seedling under favorable temperature conditions and found that each insect infected only 40 seedlings per day. When the insects were caged with seedlings only, each insect infected 11 per day.

We studied the movement of tungro-viruliferous adults of green leafhoppers when caged with either IR8 (resistant to the insect) or Taichung Native 1 (susceptible). The insects moved more frequently on IR8 and remained on IR8 seedlings for a shorter period of time (table 18). The insect apparently prefers the susceptible variety and feeds on it longer, thereby increasing the chances of viral infection.

Table 18. Comparative movement of the green leafhopper, which transmits tungro virus disease, on a resistant variety, IR8, and a susceptible variety, Taichung Native 1. IRRI, 1974.

Characteristic	Resistant (IR8)	Susceptible (TN1)
Insects that moved in 9 hours (%)	61	14
Movements per insect in 9-hour test (av. no.)	3.03	1.29
Av. duration of insect visit on seedling (h)	2.09	4.82

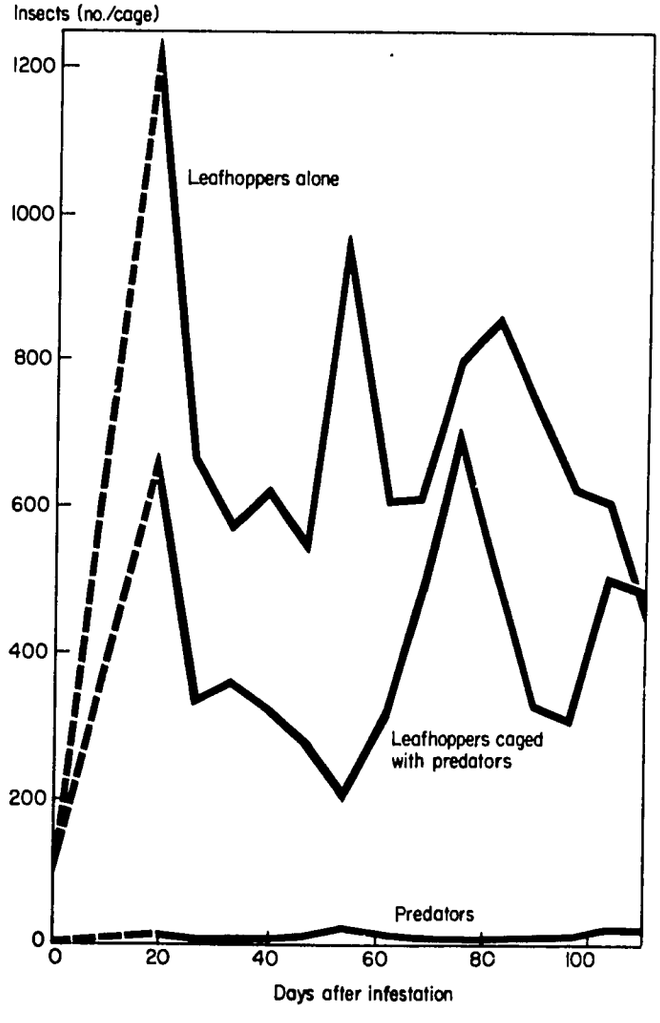
An outbreak of grassy stunt virus disease occurred in Laguna province, Philippines, during 1973, but not in 1974. We compared the numbers of brown planthoppers *(Nilaparvata lugens)*, the vector of grassy stunt, captured in light traps at the IRRI farm during the 2 years.

We found that 8,912 brown planthoppers per day were captured

in 1973 vs. 1,195 in 1974. Further, 3.4 percent were infective in 1973 vs. 2.2 percent in 1974. We concluded that the population of the insect contributed more than the percentage of infective insects to outbreaks of grassy stunt.

Insect control

We continued to seek biological methods of controlling rice insects. We tested two commercial insect pathogen preparations of the bacterium *Bacillus thuringiensis* against larvae of the leaf folder and stem borer. Mortality against leaf folders was high for both preparations but only moderate against stem borer.



31. Caging the predator *Cyrtorhinus lividipennis* with green leafhoppers significantly reduced the population density of the pests.

We found that the predator *Cyrtorhinus lividipennis*, when caged with green leafhoppers, significantly reduced the prey (fig. 31). A second predator, the spider *Lycosa pseudoannulata*, is even more effective against brown planthoppers, killing up to 25 nymphs, or 15 adults, per day.

We recorded that a foliar spray of Perthane was less toxic than other insecticides to predators of rice pests. A combination of plant resistance and predation better controlled brown planthoppers and green leafhoppers than either control method used alone.

Insecticides remain important tools even when new varieties with broad pest resistance are grown. The new varieties are not resistant to the whorl maggot and several minor pests.

In 1974, we screened 65 chemicals for their insecticidal properties against the brown planthopper and the green leafhopper. Carbofuran, MTMC, MIPC, and BPMC were effective against both insects.

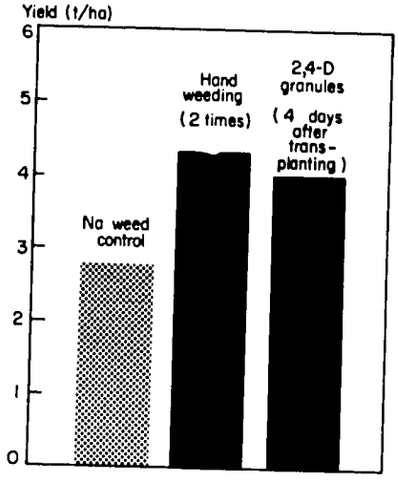
We continued to find that applying insecticides in the root zone of the plants provides highly effective and long-lasting control of common insects such as stem borers, leafhoppers, planthoppers, and whorl maggots. We investigated several approaches to develop practical methods of application.

Weed control

Control of Scirpus maritimus. The perennial sedge *Scirpus maritimus* is becoming one of the most serious weed problems in South and Southeast Asia. Ironically, water management and the control of other weeds have helped spread this fast-growing weed in lowland rice fields. When the farmer applies herbicides that control annual weeds, he creates conditions ideal for *Scirpus* or other perennial weeds to move in. Once established, *Scirpus* multiplies rapidly.

We experimented with the control of *Scirpus* by crop management. We planted alternative crops and tested cultural systems designed to discourage *Scirpus* and shift the weed population to weeds that are more easily controlled. Three cropping patterns were used: continuous rice (lowland culture); corn-peanut intercrop combination followed by lowland rice (upland-lowland culture); and corn followed by two crops of direct-seeded bunded rice (rainfed rice culture).

In the continuous lowland plots, without weed control, the first crop of rice produced 3.2 t/ha and the second crop, which was heavily damaged by *Scirpus*, 1.6 t/ha. In the upland followed by lowland experiment, corn without weed control yielded 9,500 ears



32. Yield response to weed control by hand weeding or by herbicide in IR26 rice in farmers' fields in the Philippines.

per hectare and peanut, 146 kg/ha. The lowland rice sown immediately after corn harvest yielded 2.6 t/ha. Without weed control, yields were higher than in the continuous rice, primarily because the weeds had shifted away from difficult-to-control *Scirpus*.

In the plots where an upland crop, corn, was planted in the dry season, followed by two crops of rainfed bunded rice, without weed control, the rice crops produced nothing, primarily because of heavy competition with upland weeds. With this system of rice culture, however, weed population shifted from *Scirpus maritimus* to annual weeds that are easily controlled by herbicides.

Such integrated weed management systems are possible and practical for small farmers, but they will require rice varieties that can compete with weeds. Such varieties will probably be intermediate in height, high in tillering capacity, high in total leaf area, and able to rapidly establish stands.

Interaction of weed control and fertilizer nitrogen applications. The response of rice to nitrogen fertilizers is markedly influenced by the adequacy of weed control.

In experiments conducted in farmers' fields in the Philippines, without weed control, the applied nitrogen increased grain yield by a maximum of 0.5 t/ha. However, without fertilizer nitrogen and with weed control, the grain yield increase was 1.5 t/ha, indicating the importance of weed control to increase fertilizer efficiency.

Herbicide screening. In 1974, we found that weed control, either by hand or by herbicides, increased yields on farmers' fields by about 1½ t/ha (fig. 32).

Table 19. Cooperative weed control experiments. IRRI herbicide shipment for 1974.

Country	Sets (no.)			
	Transplanted	Broadcast	Upland	Total
Asia				
Bangladesh	1	–	1	2
Fiji	2	–	2	4
India	20	27	8	55
Indonesia	–	–	2	2
Iran	2	2	–	4
Korea	3	1	1	5
Malaysia	3	1	1	5
Nepal	3	2	4	9
Pakistan	1	1	–	2
Sri Lanka	4	4	3	11
Taiwan	1	1	1	3
Vietnam	4	5	1	10
Total	44	44	24	112
Africa				
Egypt	1	2	2	5
Liberia	15	–	15	30
Sudan	–	–	1	1
Tanzania	–	–	1	1
Uganda	–	–	1	1
Total	16	2	20	38
Grand total	60	46	44	150

Agronomists put together herbicide trials and distributed them to cooperating scientists in 24 nations during 1974. The experiments were conducted under transplanted, direct-seeded, flooded, and upland conditions (table 19).

Herbicides for more trials were sent to the West Africa Rice Development Association (WARDA), which used them in their weed programs. Several new herbicides looked promising in 1974.

MON 9358 controlled weeds most effectively in transplanted rainfed IR26 applied 4 days after transplanting (table 20). Each of the new herbicides increased yields by at least 1 t/ha over the untreated control and gave yields similar to those of those of the hand-weeded plots.

Table 20. Several new herbicides almost doubled yields of transplanted rainfed IR26 over the untreated control and gave yields about equal to hand weeding. Herbicides were applied at 4 days after transplanting (before weeds emerge) and at 10 days after transplanting (after weeds emerge). IRRI, 1974 wet season.

Treatment[a]	Rate (kg a.i./ha)	Grain yield (t/ha)
K–223/2, 4-D IPE (G)	1.5/0.75	4.6
Mon 0358 (L)	0.5	4.2
Mon 0358 (L)	1.0	4.4
Mon 0358 (C)	0.5	4.0
Mon 0358 (C)	1.0	4.7
Mon 0358 (G) + 2, 4-D IPE (G)	0.5 + 0.5	4.0
Mon 0358 (G) + 2, 4-D IPE (G)	1.0 + 0.5	4.0
RH 2915 (G)	0.5	4.0
RH 2915/2, 4-D IPE (G)	0.5 + 0.5	4.4
Benthiocarb/2, 4-D IPE (G)	1.0/0.5	3.3
2, 4-D IPE(G)	0.8	3.4
Hand weeding	twice	5.0
Untreated control		2.7

[a]DAT = days after transplanting; G = granulated; WP = wettable powder; L = liquid.

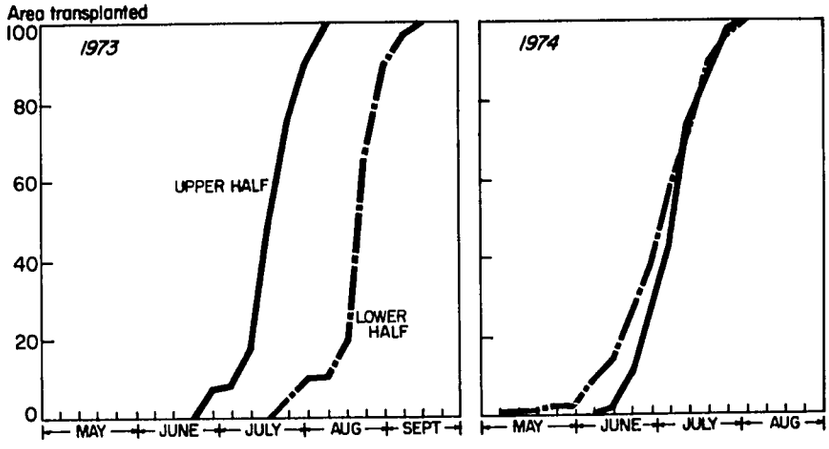
MON 9358 also controlled weeds effectively while causing little crop injury in both direct-seeded flooded rice and in upland rice. The herbicide will be extensively evaluated in rainfed rice during the 1975 wet season.

WATER MANAGEMENT

The water management program focuses on improving the performance of canal irrigation systems. Most systems cannot provide adequate water to all farms within their service areas all of the time.

The most important reason is that most systems divert flowing river water into the canal laterals and onto farmers' fields, with essentially no water storage. But the river flow often drops off during the dry season, or during temporary dry periods in the wet season, and the systems do not receive enough water to supply all farms. Inadequate water results in yield losses. Those farms that are farthest away from the river generally receive the least water during periods of shortage.

In 1973, we undertook a 2-year cooperative project with the



33. During 1974, a water distribution system was tested that allowed farmers in the lower reaches of a Philippine canal system to plant as early as those in the upper regions by delivering water to the lower portion first. This permitted farmers in the lower regions to finish transplanting at about the same time as those in the upper region.

Philippine National Irrigation Administration to attempt to improve water management and distribution in Lateral C of the Peñaranda River Irrigation System, which serves 5,700 ha. During 1973–74, the system was operated in the traditional manner; as a result, farmers in the lower half of the system planted a month later than those closer to the source of water (fig. 33).

During the 1974–75 dry season, we tested a water distribution system to allow farmers in the lower canal reaches of the canal system to plant as early as those in the upper portion. Water was delivered to the lower half of the lateral for the first 2 weeks, followed by alternating 4 days of delivery to the lower half and 3 days to the upper half. This permitted farmers in the lower half of the system to start preparing land and transplanting 2 weeks ahead of farmers in the upper half. This lead was steadily reduced once the farmers in the upper half started transplanting; the two groups finished together (fig. 33).

Because of additional water supplied from new irrigation development, the total area planted increased throughout the system. But the improved distribution of water reduced the difference in yields and total production among the four sections of the canal system.

Rotational vs continuous irrigation

Rotational and continuous irrigation were compared in the Upper Pampanga River Project. The rotational area following the UPRP design is a 50-ha block composed of five rotational units of 10 ha each. We chose three sites and compared yields on two 50-ha blocks at each site, one with and one without rotational irrigation. No

yield benefits were obtained through the rotational scheme at any of the three sites.

Power sources

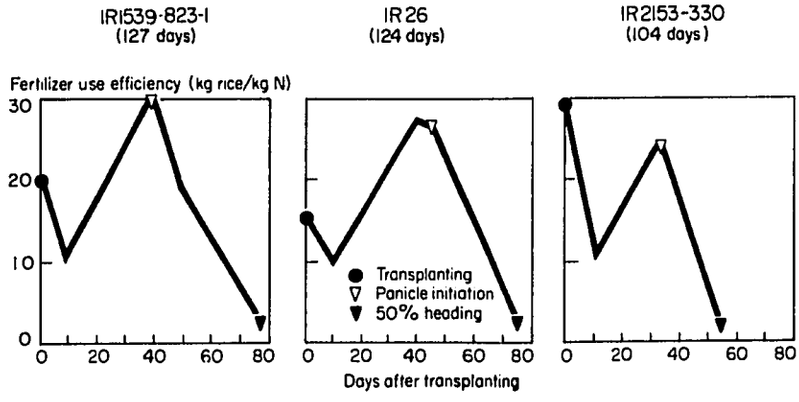
We also examined the effect of different power sources on the speed of land preparation when sufficient water was available. Four-wheel tractors with rotovators, two-wheel hand tillers, and carabaos were the most common power sources. Farmers who hired four-wheel tractors and rotovators averaged several more days to prepare their land than farmers who used carabao or two-wheel tillers, but the difference was not significant. Apparently, the ready availability of a power source under the direct control of the farmer helps speed up land preparation.

SOIL AND CROP MANAGEMENT

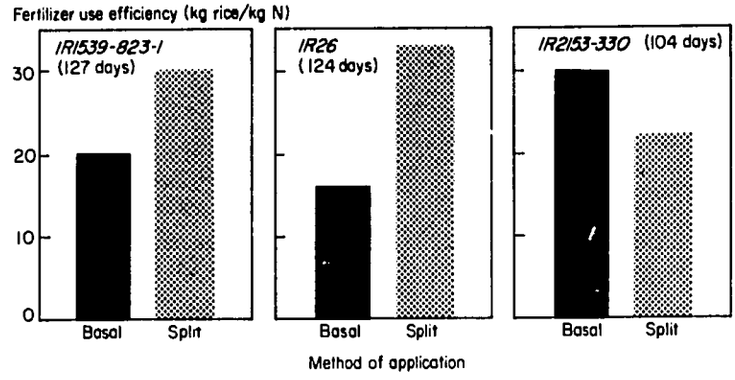
Because of high fertilizer prices, we focused our attention on means of maximizing yields with limited fertilizer. We learned that timing of nitrogen applications greatly influences the efficiency of this element. The yield of rice per kilogram of nitrogen applied was highest when the fertilizer was applied at panicle initiation or at transplanting time (fig. 34). We also found that split applications, part of the nitrogen applied at transplanting and part at panicle initiation, are more effective than single applications (fig. 35).

Nitrogen fixation

We expanded our studies on nitrogen fixation in the rice paddy. We measured the rhizosphere fixation of nitrogen in about 40 varieties



34. Time of N application. The efficiency of nitrogen fertilizer use was highest in terms of kg rice/kg N when 60 kg N/ha was applied at panicle initiation or at transplanting.



35. Method of N application. The efficiency of fertilizer use was higher when 60 kg N/ha (ammonium sulfate) was applied by split application (two doses) than when applied as a single basal application (broadcast and incorporated). Split applications for IR26 and IR1239-823-1 were applied half at 40 days after transplanting and half at panicle initiation; for IR2153-330, half was applied as basal and half at panicle initiation.

and found considerable variation. We are determining the practical significance of rhizosphere fixation.

We used the N^{15} isotope to prove that atmospheric nitrogen moves down the stem of the rice plant to the roots, especially when the plants are at the heading stage (table 21). This suggests the ready availability of nitrogen gas for fixation in the root zone of paddy rice.

We measured nitrogen fixation in a paddy field that had long been known to yield well without fertilizer nitrogen. We found the rate of nitrogen fixation to be about 30 kg/ha per crop. We suspect that most of the fixation was by bluegreen algae.

Water management and nitrogen supply

We learned that drying a paddy field for a few days at mid-season increased rice yields on three different soils. This yield increase is thought to be due to the release of soil nitrogen which, when the soil is rewetted, is quickly absorbed by the plants.

We measured the soil nitrogen content after 16 seasons of differ-

Table 21 Movement of ^{15}N-enriched N_2 through rice plants into the rhizosphere. IRRI, 1974.

Rice plant	^{15}N in atm (%) at		
	0 h	3 h	6 h
		Shoot compartment	
Bonnet-73, tillering stage	21.6	21.7	21.3
Colusa, heading stage	13.2	10.7	
		Root compartment	
Bonnet-73, tillering stage	0.38	0.47	0.53
Colusa, heading stage	0.61	4.78	

Table 22. The nitrogen content of three soils after 16 seasons of dry or flood fallow. IRRI, 1974.

Soil	Soil nitrogen content (%)		Increased N[a] under flood fallow[b] (kg/ha)	Yield increase under flood fallow[b] (%)
	Dry fallow	Flood fallow		
Luisiana clay	0.131	0.199	85	69
Maahas clay	0.127	0.179	65	129
Clay loam	0.118	0.154	45	137

[a]Represents both savings of nitrogen through lower denitrification and increase through nitrogen fixation. [b]Over dry fallow.

ential water management treatment. Where the soil had been kept flooded during the normal fallow period, soil nitrogen content was about 30 percent higher than where dry fallow was practiced (table 22). Long fallow periods probably result in more rapid mineralization and loss of nitrogen.

ENVIRONMENT AND ITS INFLUENCE

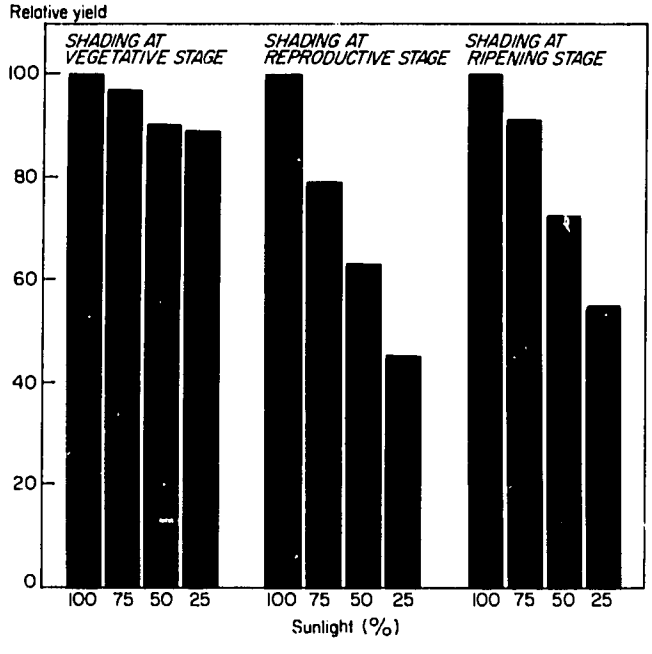
Our environmental studies focus on the responses of the rice plant to temperature, solar radiation, daylength, water supply, and soil density.

Shading experiments at different growth stages demonstrate that the amount of solar radiation is not too important during the vegetative stage (fig. 36). But at the reproductive stage, shading had a pronounced effect on spikelet number and, hence, on yield. Shading during the ripening stage also reduced yields by reducing the percentage of filled grains.

About 5 t/ha yield can be obtained with 300 cal•sq m•day^{-1}, which is about average during the rainy season in many tropical Asian countries. Thus, the amount of solar radiation may not be the first limiting factor in farmers' fields in most tropical countries.

When water is limiting on cloudy days, the stomates (tiny pores on the leaf surface) remain open. On sunny days, however, they remain open only in the morning and close in the afternoon -- perhaps to conserve plant moisture. A simulation model of crop photosynthesis indicates that a large portion of solar energy is wasted when the crop is under water stress on sunny days (fig. 37).

We found that crop photosynthesis on a cloudy day is 70 percent greater than on a sunny day under the same degree of water stress.



36. In shading experiments, scientists found that reducing the amount of solar radiation by shading did not affect yields much at early growth (vegetative) stage. Shading significantly reduced yields, however, at reproductive and ripening stages.

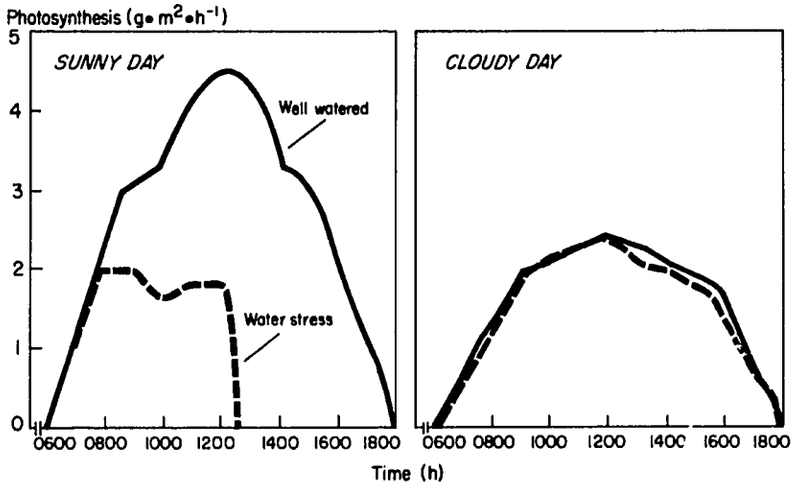
Thus, when water supply is limited, not only is much solar energy wasted, but high solar radiation may also reduce crop growth. This indicates that in areas where drought is common, growing upland rice in a partial shade, such as under coconut trees, may have some advantages.

Temperature affects both growth duration and grain yield. We found that different varieties respond in different ways to temperature. Phytotron experiments indicate that temperature has little effect on growth duration within the day/night range of from 29°/21°C to 35°/27°C.

Temperature markedly affects growth duration, however, between 29°/21°C and 26°/18°C. A difference in temperature of only 3°C extended the growth duration of IR26 from 130 days (at 29°/21°C) to 165 days (at 26°/18°C).

Yield response to temperature varied greatly among varieties. Improved varieties appear to have greater yield stability over a moderately wide range of temperatures than traditional varieties.

Most upland varieties tested were insensitive to daylength; only eight of 30 varieties tested were strongly sensitive. Photoperiod sensitivity may be one way that these upalnd varieties adapt to areas of bimodal rainfall pattern.



37a. Scientists found that a large portion of solar energy is wasted and that crop photosynthesis is lower when a crop is under water stress on sunny days. Under equal water stress on cloudy days, crop photosynthesis continued throughout the day.

37b. This indicates that in areas where drought is common, growing rice under shade such as under coconut trees may have some advantage. Batangas province, Philippines.

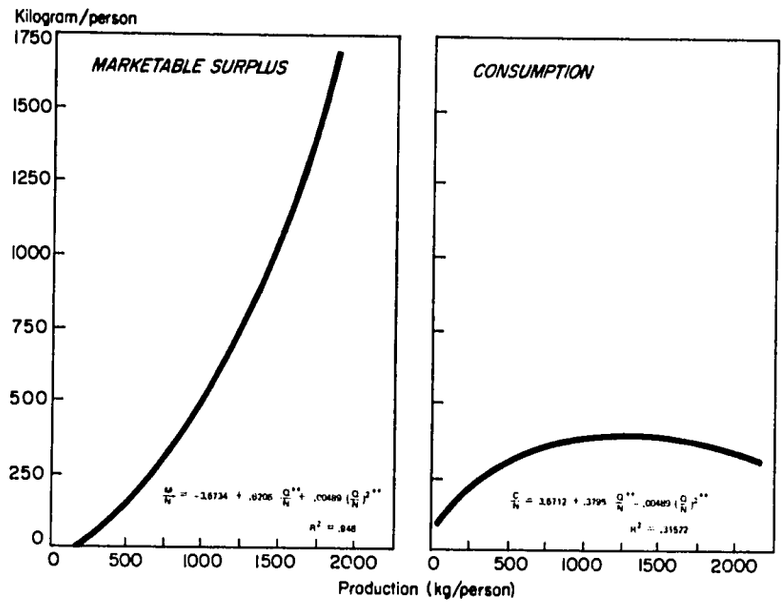
POST-PRODUCTION MANAGEMENT AND TECHNOLOGY FOR RICE

Marketable surplus

During 1973–74, we studied how farmers allocate their paddy after harvest – how much is saved for home consumption and how much is sold in the market. As anticipated, the farmer's first consideration was to save enough good paddy to feed his family through the next

Upper: *Threshing rice with oxen in India.*

Lower: *Milled rice for sale.*



38. Annual per capita consumption of rice in the Philippines was found to rise proportionately with total production up to 264 kilograms of paddy per person (about 150 kg of milled rice/person), after which market sales increased and rice consumption leveled off.

year. In an economy characterized by an underdeveloped rural marketing system, the paddy that enters the market is residual, and sold after household needs have been assured.

We analyzed several factors that affect home consumption and the marketable surplus — family size, quantity produced, price of consumer goods, and price of rice. Not surprisingly, we found consumption needs to be relatively insensitive to changes in the price of rice. The quantity available for the market, however, was affected markedly by the level of production. As output increases, the marketable surplus increases at a rate higher than output (fig. 38).

There is an obvious inverse relationship between family size and the amount sold. We found that most of the rice produced is consumed up to an annual per capita level of about 264 kg of paddy (or, roughly, 150 kg of milled rice), following which it levels off. The amount of rice sold in the market is a relatively low proportion of total output until household consumption requirements are satisfied.

This simple analysis implies that price subsidies to induce movement of more grain into the market may be less successful and more costly than programs designed to increase production, such as improved varieties and cultural practices. This would be particularly true when farm households are large and production is low.

Quality of paddy rice

To determine the quality of paddy rice entering the preprocessing system, we gathered samples from 111 rice mills in three regions of the Philippines. We found significant quantities of immature, fermented, and cracked grains and red kernels in these samples – indications of improper drying and poor post-harvest management. We graded these samples and found that two-thirds were classified as substandard and only one-third were considered of high quality standard.

One conclusion is that Philippine farmers are delivering poor quality paddy to the processors, and saving the better paddy for home consumption.

This has serious implications for both the quantity and quality of milled rice entering the market. Even modern rice processing techniques can do little to alleviate defects resulting from a lack of suitable technology, management, and farm-level incentives.

CONSTRAINTS TO INCREASED RICE PRODUCTION

We expanded our efforts in 1974 to understand why yields are not increasing faster on Asian rice farms. We focused our attention on the "gap" between farmers' actual yield and those that we know are possible with the new technology.

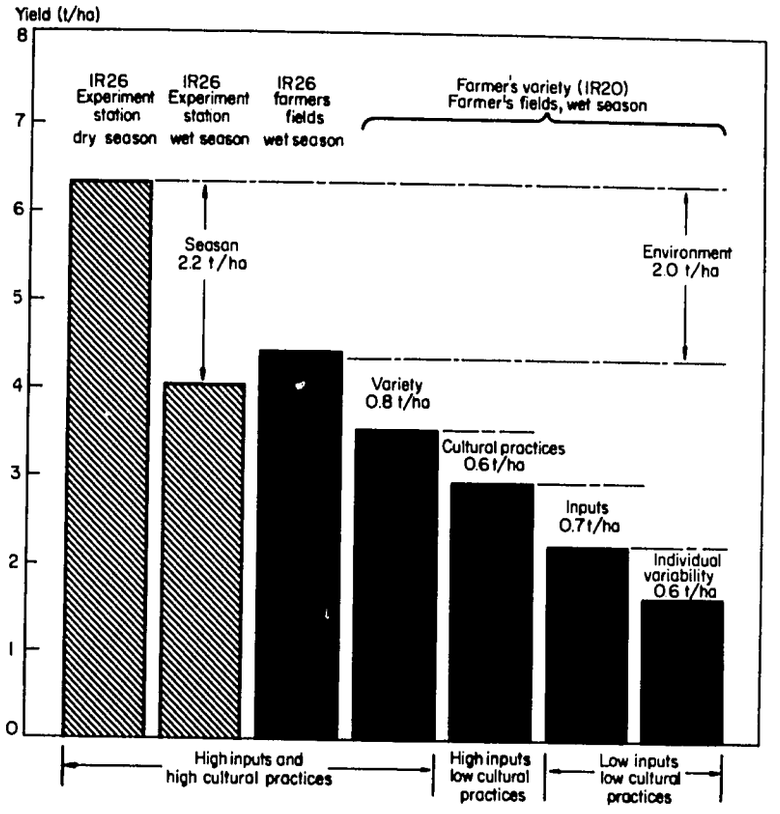
The methodology being developed consists of two parts. Agronomic experiments are conducted in farmers' fields to indicate *what* needed inputs are missing. At the same time and in the same area socioeconomic surveys are being conducted to find out *why* the farmers may not be using the best inputs or cultural practices.

Using this methodology, we were able to identify more clearly the nature of the yield gap in Nueva Ecija and Laguna provinces, Philippines.

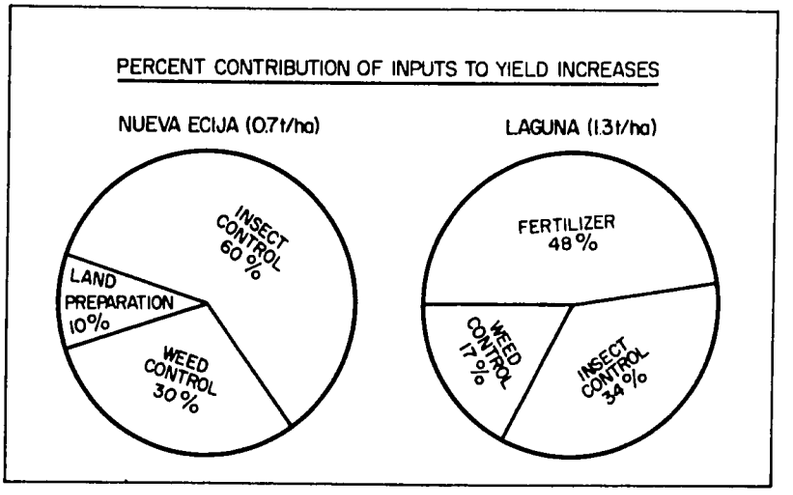
We found that a major constraint on yields in farmers' fields in Nueva Ecija province was the variety used. IR26 produced an average of 1 t/ha more than the IR20 grown by the farmers, probably because of IR26's superior resistance to insects and diseases (fig. 39).

Insects and weeds were major constraints in both provinces. It should be emphasized, however, that the contributions of various inputs to yield gains differ from year to year. For example, fertilizer had no effect on yield in Nueva Ecija, probably because of heavy typhoon damage. Insecticides were quite important in Nueva Ecija and Laguna during the wet season outbreak of brown planthoppers (fig. 40).

Our analysis points out that applying higher levels of inputs such



39. Using IR26 and an optimum level of chemical inputs and improved cultural practices, farmers in Nueva Ecija province, Philippines, produced yields comparable to those on experiment farms. But using IR20 (which has less pest resistance) and the same inputs and cultural practices, yields averaged 0.8 t/ha lower.



40. The contribution of selected inputs to gains in yield above the farmers' level at two locations. Insect control was a major factor in both provinces. Fertilizer did not increase yields in Nueva Ecija because of typhoon damage to the crops. Philippines, 1974 wet season.

Table 23. Percentage of farms of different sizes on which selected practices have been adopted in 32 selected Asian villages during 1971–72.

Farm size (ha)	Farms (%) that reported adoption of				
	Modern varieties	Weeding		Tractors	Threshers
		Hand	Herbicide		
Less than 1	87	82	6	13	36
1 to 3	89	83	20	41	43
More than 3	94	89	29	57	63

as fertilizer, insecticides, and herbicides without giving attention to improved cultural practices and to the right choice of variety increased yields only modestly. In fact, yield increases due to higher levels of chemical inputs alone were generally not adequate to pay for these inputs.

In surveys conducted in 32 Asian villages, we found a close association between the adoption of labor-saving technology and farm size. Hand weeding was commonly practiced on all farms, while herbicides were mostly used on farms larger than 1 ha (table 23). Tractors and threshers were common on larger farms. By contrast, other yield-increasing technologies – fertilizers, insecticides, and modern varieties – were widely used on all farms regardless of size.

We examined the adoption of new technology with respect to *relative* as well as *absolute* farm size, since relative size within the village may reflect the farmers' socioeconomic position and, hence, his access to modern inputs. Except for one village in this study, the rate of adoption of new varieties was not affected much by farm size. Only in a limited number of villages in South Asia did farm size appear to significantly affect the sharing of the benefits of the new technology.

CROPPING SYSTEMS

We worked with cooperators in national programs to identify five macro agroclimatic zones in South and Southeast Asia suitable for multiple cropping. Within these zones, a network of six test sites were selected – three in the Philippines, two in Indonesia, and one in Bangladesh. More test sites will be identified in other nations.

A representative upland rice area with gently sloping, well-drained land represents one zone in Batangas province, Philippines. Research has been underway at this location for several years and was intensified in 1974.

Table 24. The number of farmer participants in cropping systems research in Batangas, Philippines, during 1974.

		Farmer participants (no.)
Cropping pattern studies		40
Daily records of entire farm operations		50
Baseline economic surveys		50(+ above – 90)
Social survey		237
Entomology studies (insect monitoring)		14
Agronomic experiments[a]		18
Intercropping	(9)	
Weed management	(6)	
Insect management	(5)	
Nitrogen response	(5)	
Nitrogen residual on following crop	(8)	
Sorghum patterns	(1)	
Mungbean residual effect	(1)	
Mungbean variety x nitrogen	(2)	
Rice variety trial	(3)	
Totals:		
Daily record keeping		90
Survey		427
Field experiments		76

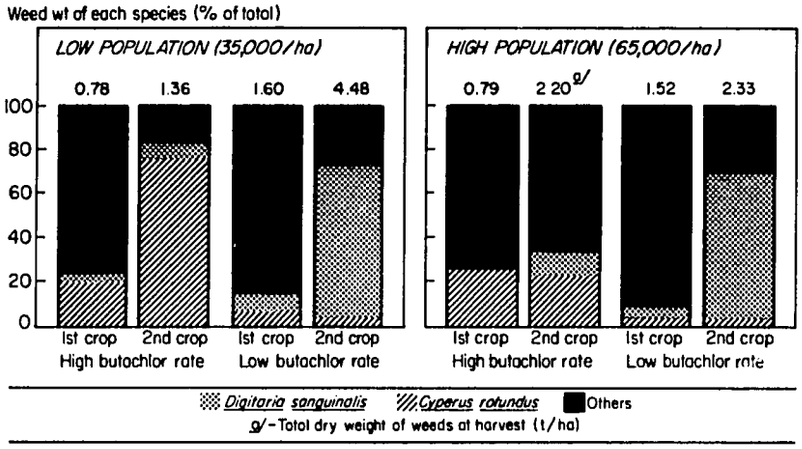
[a] 15 were overlapped with studies of economic record-keeping.

We conducted all of the cropping systems research in Batangas on small rice farmers' fields. Large research plots (1/10 ha each) are superimposed on the farmers' regular management and cultural systems. The farmers helped select the systems to be evaluated. Table 24 shows the number of farmer participants in the various field investigations. The studies included surveys for basic economic as well as social information. We will analyze the data in 1975 and use it to help develop models for improved cropping systems.

Upland rice followed by corn or other field crops is a typical cropping sequence used in this area. Corn and rice intercropped produced a total yield of 5.3 t/ha. Corn alone produce 4.2 t/ha and rice alone, 3.8 t/ha.

Weed management

Supporting research indicates that yields in upland rice areas can be improved considerably through weed management. Combinations of dense stands or leafy varieties, low rates of herbicide, and limited mechanical tillage gave good control from season to season and greatly



41. High density planting and low rates of herbicide application prevented the buildup of the troublesome sedge *Cyperus rotundus* in a corn-rice rotation.

reduced troublesome weeds such as *Cyperus rotundus* (fig. 41).

At low chemical rates, the predominant weed was *Digitaria sanguinalis* in the second crop season. This is an easy-to-control weed that affects crop yield comparatively less than *Cyperus*.

Herbicide screening showed that chemicals such as MON 0358 are promising.

Intercropping

Within the socioeconomic framework of small farms with limited power for tillage and little cash for inputs, we have found that intercropping (growing two or more compatible crops simultaneously in alternate rows) is often profitable.

Corn and upland rice combinations are consistent in their higher yields, giving a 50-percent advantage at optimum row spacings and plant populations. Corn and peanut are similarly productive over a range of planting arrangements on small, labor-intensive farms.

Productivity for corn and soybeans increased at 60 kg N/ha, 120 kg N/ha, and 180 kg N/ha, but not above or below those N levels.

Two-crop rice systems on rainfed land

Millions of hectares in rainfed areas of Asia produce only one crop of rice per year. Farmers transplant their single rice crops in the middle of the monsoon season on most of this land because they must wait until their paddies are waterlogged to plow and puddle the soil. After transplanting, most depend on paddy water to help control weeds.

This delay, coupled with the farmers' use of late-maturing traditional varieties, makes it impossible to grow more than one rice crop during a monsoon season.

42. A direct-seeded rainfed rice crop (right) is almost ready for harvest by the time that surrounding crops (left) have just been transplanted. Bulacan, Central Luzon, Philippines.

We are taking advantage of four developments to try to change this situation and help farmers grow two crops where they have been growing only one: a) direct seeding of rice at the onset of the monsoon rains; b) early maturing improved rices; c) better technology for weed control; and d) timeliness and method of land preparation.

In cooperation with Philippine agencies, we have conducted extensive field trials and a 3-year pilot project to demonstrate the feasibility of two-crop systems in rainfed areas. In early May, we direct seeded short-seasoned varieties, using herbicides to control weeds. The first crop was taken off in mid-August and a second crop planted – either of rice or an upland crop (fig. 42). These second crops were ready for harvest about the same time – of even before – the traditional farmer could harvest his first, and only, crop.

The Philippine government has developed a national program to encourage the two-crop system by direct seeding the first crop. Some 25,000 ha were included in the 1974 phase. The farmers' experiences have helped in our applied research to improve the system.

Direct seeding technology

In 1974, we learned that the success of the direct-seeding technology depends on a number of management factors. Land must be initially prepared after harvesting the wet-season crop so that farmers can mechanically control weeds through the dry season. They can then seed early enough to use the first monsoon rains at the start of the following wet season.

Farmers who sowed their rice before May 20 harvested bumper crops, averaging 3.4 t/ha, compared with 1.9 t/ha for transplanted crops. But farmers that direct seeded after May 20 generally had lower yields than those who transplanted.

We also learned that the herbicides must be applied early to direct-seeded rice. If the early rains are sufficient to germinate the rice seeds, they will also germinate the buried weed seeds; the herbicide must be on the soil to kill emerging weeds.

Butachlor was found to be the most effective herbicide but *only if applied at the time of seeding, with the early monsoon rains.*

Butachlor controlled weeds effectively on the land that was properly prepared and direct seeded in wet soil before weed emergence.

Direct seeding has great potential in irrigated areas, even where irrigation water is only available to supplement rainfall. The new technology also has potential for other Asian countries, Africa, and South America. We hope to cooperate with scientists in national programs to further evaluate that potential through applied research.

MACHINERY DEVELOPMENT AND ECONOMICS

Production of the 5- to 7-hp power tiller continued to steadily increase in the Philippines; six companies produced 5,000 tillers during 1974. Prototype power tillers have been fabricated by companies in Vietnam, Thailand, and Sri Lanka, and have been evaluated through IRRI's cooperative machinery testing programs. Manufacturers in Vietnam, Sri Lanka, and Thailand (fig. 43) have begun regular commercial production of IRRI tillers.

A larger power tiller with a 8.5-hp diesel engine has been developed and released for test production to five companies in the Philippines. This machine was designed for farmers who need features not found on the smaller 5- to 7-hp tiller. It has steering clutches and three forward gears and one reverse.

The axial flow thresher, which was introduced in 1973, has rapidly gone into commercial production. Ten Philippine companies now manufacture the machine; most are selling as many machines as they can produce (fig. 44). It has been well received for custom threshing operations across the Philippines. Prototype axial flow threshers have been fabricated by companies in Vietnam, Thailand, Sri Lanka, Indonesia, India, Pakistan, Ghana, and Ecuador; the machines are being evaluated by cooperating engineers and commercial production has started in some of these countries. An Indian company is testing 15 axial flow threshers before starting regular production. This company

43a. Sign at a machine shop in Ayutthaya, Thailand, where the IRRI power tiller is being manufactured.

43b. A Thai farmer plowing with an IRRI tiller.

is also modifying the machine for wheat threshing, because demand is high for wheat threshers.

IRRI agronomy and entomology experiments indicate that the efficiency of fertilizer and insecticide use can be substantially improved by placing the chemicals below the surface of the puddled soil.* We evaluated several concepts for deep-placement applicators and developed a liquid applicator that injects the chemical into the

*See page 25.

44. The axial flow thresher is one of the more popular of the IRRI farm machines. Threshers being manufactured at Durasteel Manufacturing Company, Cainta, Rizal, Philippines.

mud and an inexpensive push-type granular applicator that places fertilizer at 10-12 cm depth in wet fields.

The power weeder continues to sell strongly in Japan. The manufacturer has developed 14 attachments that equip this machine to prepare both paddy and upland fields. Two more Japanese companies will soon begin production.

About 7,000 IRRI-designed machines were produced in 1974 by Philippine firms. The companies report that 700 additional workers have been employed to manufacture IRRI-designed farm equipment, with an additional average capital investment of US$200 per job.

Since the first IRRI machine was released in 1970, more than 22,000 IRRI-designed machines have been produced by cooperating machinery manufacturers in Asia.

Markets are increasing across Asia, and opening in Latin America and Africa, for the 5- to 7-hp tiller, axial flow thresher, batch dryer, power weeder, and paddy seeder.

INTERNATIONAL PROGRAMS

The ultimate measure of IRRI's contribution to increased worldwide rice production and quality is the extent that we are able to influence and assist national rice research and production programs to attain their goals. Through our cooperative and collaborative programs with rice-growing countries, IRRI is helping to strengthen national rice improvement capabilities.

IRRI continues to coordinate several international testing programs, such as the International Rice Observational Nursery; the International Rice Yield Nursery; and the International Bacterial Blight Nursery. These are being expanded and intensified with an anticipated grant from the United Nations Development Programme for the International Rice Testing Program.

Eleven countries cooperated in evaluating IRRI-designed machinery in 1974. They are India, Indonesia, Vietnam, Korea, Pakistan, Malaysia, Philippines, Ecuador, Guatemala, Ghana, and Thailand.

The groundwork was laid in 1974 for a regional cooperative program on deep water rice research. Plans are for the project to be based in Thailand, and for scientists to cooperate in Bangladesh, Vietnam, India, Burma, and Indonesia.

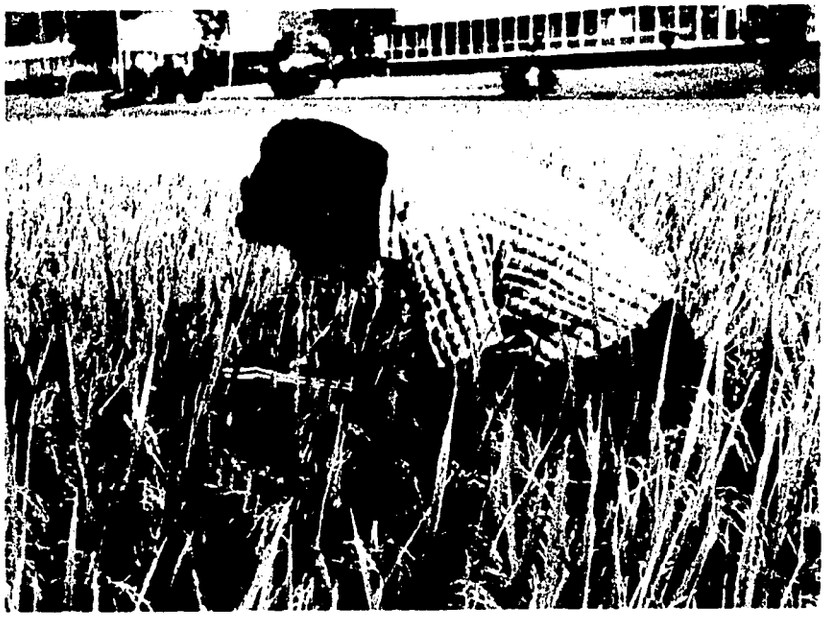
During 1974, IRRI scientists participated as members of collaborative research teams in Bangladesh, India, Sri Lanka, Indonesia, Thailand, Egypt, Vietnam, and the Philippines.

At the International Rice Conference, held annually at IRRI, scientists observe a demonstration of the vacuum emasculator. Left to right: Dr. N. K. Chakrabarti, head, Department of Plant Pathology, Central Rice Research Institute, Cuttack, India; Dr. Mohammed Amirul Islam, Director, Bangladesh Rice Research Institute; Mr. Rizal Herrera, IRRI senior research assistant; and Dr. D. Mukherjee, Economic Botanist, West Bengal Rice Research Station, India.

ASSOCIATED FORMAL TRAINING

IRRI's training programs provide trained people for all four categories of our international cooperative activities: 1) collaborative research; 2) international research networks; 3) strengthening of national capabilities; and 4) coupling of research and action programs. Opportunities are available for degree and non-degree research and production programs.

During 1974, 157 research scholars and fellows and production trainees (fig. 45) from 24 countries studied at IRRI. The participants were staff members of government agencies and institutions concerned with rice research and extension, particularly in countries where IRRI has cooperative or collaborative projects. The institute provided 80 man-years of training during the year.



45. The training of young scientists, extension agents, and educators is an integral part of IRRI's activities. Research scholars, such as Mervyn Sikurajapathy from Sri Lanka (upper photo), conduct research projects from the planning stage through final analysis at IRRI. Rice production trainees, such as Oloche Edache from Nigeria (lower), receive training not only in crop production, but also in how to run similar courses when they return home.

INFORMATION DISSEMINATION

During 1974, the IRRI Office of Information Services (OIS) published the following: *An Agro-Climatic Classification for Evaluating Cropping Systems Potentials in Southeast Asian Rice-Growing Regions; Planting Rice; Research Highlights for 1973; the 1973 Annual Report;* and four issues of the *IRRI Reporter.*

We reprinted five publications, including 40,000 additional copies of *Field Problems of Tropical Rice.*

All back issues of the *IRRI Annual Report* were duplicated on microfiche and made available.

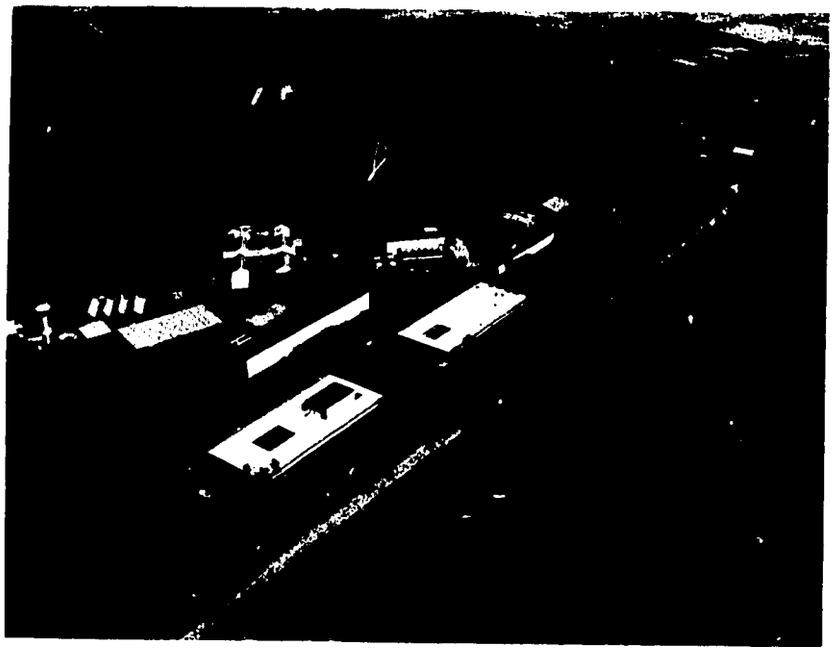
To familiarize our thousands of visitors with IRRI's purpose and programs, we prepared and taped a short audio-visual presentation with synchronized slides.

EXPERIMENTAL FARM

The current experimental area of about 65 ha was increased about three times with the addition of 192 ha made available by the Philippine government through the University of the Philippines at Los Baños (fig. 46). The new area is composed of 114 ha of upland fields and 78 ha of lowland rice paddies.

During the 1974 dry season, we multiplied seed of IR26, the Korean varieties Milyang and Suwon 242, and the experimental line IR1514A-E597. In the wet season, we planted almost 25 ha to IR26, IR28, IR29, IR30, and the lines IR2071-88-3, IR2035-290-2-1-2, IR2061-213-2-17, and IR2061-255-3-6-3.

46. The Philippine government provided an additional 336 hectares of land to the University of the Philippines at Los Baños (UPLB) and IRRI in 1974. IRRI will use 192 hectares of the new land. Inspecting the new area are (left to right): Mr. Federico V. Ramos, farm superintendent; Dr. Nyle C. Brady, IRRI director; Dr. Marcos R. Vega, IRRI assistant director; and Dr. Abelardo G. Samonte, Chancellor, UPLB.



FINANCES

During 1974, the Institute received cash grants amounting to $7,109,248.

The Ford Foundation gave $1,376,040. Of this amount, $750,000 was toward the core operating and capital expenditures of the Institute. The remainder was in support of the rice research and development programs of five countries: Sri Lanka – $162,500 as part of a 2-year grant for the rice production and multiple cropping project and another $185,000 as part of a 2-year grant for the project on modernization of rice processing and distribution; Bangladesh – $85,200 which is part of a 2½ year grant to provide support for the Bangladesh Rice Research Institute; Indonesia – $127,900 which is part of a 2-year grant for an accelerated rice research program; Pakistan – $58,650 which is part of a 2-year grant to assist the Pakistan Agricultural Research Council, through the training of rice scientists and the exchange of breeding materials; and, Egypt – $6,790 which is part of a 2-year grant for the services of a project specialist with the Arid Lands Agricultural Program in the Middle East.

The Rockefeller Foundation contributed $829,990 during 1974. This amount included $700,000 for the core operating and capital expenditure needs of the Institute. The Rockefeller Foundation released: $28,700 as part of a 3-year grant to support the program to develop and introduce improved rice technology to disadvantaged Asian rice farmers in upland and rainfed areas; $3,915 as part of a grant for the collection of the world's rice germ plasm; $90,575 as part of a grant in support of the joint Ph.D. training program with the Indian Agricultural Research Institute; $5,000 as a grant toward the costs of a project to determine constraints to high yields in farmers' fields in the Philippines; and, $1,800 as a grant to study the effects of uncertainty on farmer decision-making in rice production in the Philippines.

From various grants, the U.S. Agency for International Development released a total of $1,787,767. The Institute received $1,000,000 for its core operating and capital expenditures and $230,000 in support of a project entitled "Research on Farm and Equipment Power Requirements for the Production of Rice and Associated Food Crops in the Far East and South Asia." Since 1972, a contract between IRRI and USAID has supported a project for the accelerated development and utilization of improved technology in agriculture in Indonesia with a budget of $640,050, in addition to a budget of Rp. 446,775,159 which is managed by the USAID mission in Djakarta for a period of 3½ years. In 1974, $191,761 was reimbursed to the Institute. Since 1971, a contract with USAID has supported a project to help the government of Vietnam accelerate rice research for a 3½ year period with a budget of $464,000 in addition to a budget of VN$43,070,000. In 1974, $96,349 was reimbursed to the Institute. Since July 1972, a contract between IRRI and USAID supported an intensified crop production and extension program in the Philippines for 2 years and 8 months with a budget of $113,789 in addition to a budget of $92,400 which is managed by the USAID mission in Manila. In 1974, $41,039 was released to the Institute. USAID contributed toward IRRI's training program by supporting scholars from various countries where USAID has active programs. The Institute received $55,720 for this purpose in 1974. The USAID mission in Bangladesh provided $90,500 to finance the training of staff from the Bangladesh Rice Research Institute in the Philippines and in the U.S. During 1974, $72,898 was released to the Institute.

The Overseas Development Administration of the United Kingdom gave $467,833 toward the support of IRRI's varietal improvement, cropping systems, and genetic resources programs.

The International Development Research Centre of Canada gave $626,330. As part of a 2-year grant to the Institute for cropping systems research in the Philippines in cooperation with the University of the Philippines at Los Baños, IDRC released $414,830. The centre also made the following grants in 1974: $10,000 for research on changes in rice farming in Asia; $125,488 as part of a grant to enable IRRI to finance and give technical guidance and support to a cropping systems research project at the Bangladesh Rice Research Institute; and $76,012 as part of a grant to enable the UPLB to conduct, in support of IRRI's cropping systems program, a varietal screening program for maize, sorghum, mungbean, soybean, eggplant, tomato, and sweet potato.

The Japanese government gave $263,500 in 1974 toward the training program of the Institute, to purchase equipment required for research activities and support the institute's plant physiology department.

The International Development Association gave $1,155,000 in 1974 toward the core operating and capital expenditures of the Institute.

The West German government gave $252,221 toward the Institute's capital expenditures.

The Australian government gave $13,093 toward a short-term training program of the Institute.

The government of Indonesia, using a World Bank loan, released $141,481 to IRRI as part of a 5-year contract toward the development of research facilities at the Sukamandi Branch of the Central Research Institute for Agriculture (CRIA) and toward scientific and technical assistance to rice research in this branch of CRIA.

In 1967, IRRI entered into a cost-reimbursement contract with the U.S. National Institutes of Health to study ways to increase the protein and essential amino acids of the rice grain through plant breeding. During 1974, $55,041 was reimbursed to the Institute.

In 1974, the Netherlands government gave $78,752 as part of a 5-year grant for a project for regional station development in Indonesia.

The United Nations Development Programme gave $50,000 as a grant for the training of rice scientists and technicians.

The names of other donors along with the areas supported and the amounts received during 1974 are given below:

Imperial Chemical Industries, weed control, $5,000.

Potash Institute of North America and International Potash Institute, long-term fertility experiments, $3,200.

Stauffer Chemical Co., rice pest control, $3,000

Minnesota Mining and Manufacturing Co., weed control, $1,000.

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